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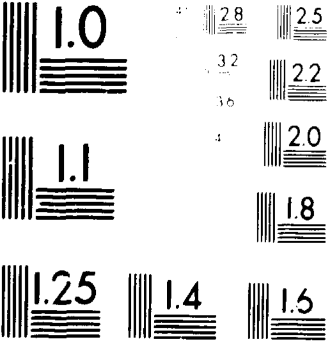

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PROVISION OF EXPERT SERVICES
TO S.I.E.I, IRAQ
THROUGH UNIDO

CONTRACT No. T 81 80 HR

14102

(1 of 4)

FINAL REPORT

OF MR. S. Y. DEVANUR

INSTRUCTOR FOREMAN TOOL MANUFACTURING

[redacted]

HMT (INTERNATIONAL) LTD.
17, ALI ASKER ROAD
BANGALORE-560 052, INDIA

SEPTEMBER, 1984

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FINAL REPORT

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INSTRUCTOR FOREMAN, TOOL MANUFACTURING

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1. INTRODUCTION AND ACKNOWLEDGEMENT

2. BACKGROUND OF THE MECHANICAL WORKSHOP AT SIEI

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4. WORK IN PROGRESS

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1. INTRODUCTION AND ACKNOWLEDGEMENT

In response to an enquiry by UNIDO, Vienna, HMT (International) submitted an offer for rendering technical services to the Specialised Institute for Engineering Industries (SIEI), Baghdad, Iraq. HMT (International) was required to depute three experts covering the following disciplines:

i. Press Tools and Mould Design
ii. Heat Treatment and Materials Engineering
iii. Instructor Foreman - Tool Manufacturing

As per the procedures of UNIDO, HMT(International) shortlisted a few experts in each of the areas for final selection by the representative of UNIDO. The Chief Technical Adviser (CTA), UNDP, Baghdad, who is incharge of the UNDP, SIEI Project visited Bangalore, India, during October 1981 and interviewed the short listed experts. I was selected as Instructor Foreman in the area of Tool Manufacturing to render services to SIEI for a period of two years. After signing of the contract between HMT(I) and UNIDO, I reported to UNDP, Baghdad on 12th February, 1982. After briefing, I reported for work at SIEI on 20th February, 1982.

As part of the on-going project in Specialised Institute for Engineering Industries, I worked as an Instructor Foreman from 20th February 1982 to 11th February 1984. During this period the workshop personnel were taught modern manufacturing techniques and processes, during the day to day work through demonstrations. Guidance was given to the skilled and unskilled operators, fitters and workshop foreman for manufacturing jigs, fixtures, tools and various other equipment including assembly of such equipment.

ACKNOWLEDGEMENT

It is my privilege to thank Mr.S. Buranj the Chief Technical Adviser for all the guidance, and advise given in performing the assignment. I also thank Dr. Abid Ali, Director General, Mr. Adnan Al-Khuzee, Director, Miss. Batool and Mr. Hameed for the wonderful co-operation extended, in completing my assignment. I must thank all the workshop personnel, Mr.Faqzi Abbas and Mr. Hammoodi Selman for all the assistance given to me during day to day work. I also thank the Tool Design, Quality Control, Heat Treatment and Prototype Design Departments for the co-operation extended. With pleasure, I thank UNIDO, UNDP, Baghdad, Resident Representative and the Deputy Resident Representative, for the opportunity given, in the service of building modern Iraq.

2. BACKGROUND OF THE MECHANICAL WORKSHOP AT SIEI

The Mechanical workshop in the Production Engineering Department of SIEI is equipped with machines such as centre lathe, copy lathes, vertical and horizontal milling machines, shaping machines, slotting machines, surface and cylindrical grinders, precision milling machine, jig grinder, profile grinder, spark erosion and jig boring machines. A well equipped quality control department carries out stage and final inspection of the items manufactured in the workshop. A heat treatment shop, with muffle furnaces and a salt bath for HSS is attached to the workshop. The workshop is provided with a wide range of HSS and mounted tip cutting tools and a limited selection of raw materials. For trying out the tools manufactured, shearing, forming and an eccentric press have been provided.

The SIEI, through the mechanical workshop, mainly caters the needs of the engineering industries in and around Baghdad. The specific problems, and requirements, of the industries, are referred to the Institute, and are processed through the various departments of the Institute. The tool design department, takes up such problems and designs, jigs, fixtures, press tools and moulds, to suit the requirements. These toolings are manufactured in the workshop. Apart from this, special equipment are also manufactured, as per the drawings supplied by the industries.

Manufacture of prototypes, as designed by the prototype development department, is one of the main activities of the workshop.

3. WORK COMPLETED

The following jigs, fixtures, press tools, die casting dies and various other items were manufactured through various machining operations and assembled.

1. Milling fixture for fork (1st operation)
2. Milling fixture for fork (2nd operation)
3. Turning fixture for fork
4. Drill jig for fork (1st operation)
5. Drill jig for fork (2nd operation)
6. Setting gauge for milling fixtures
7. Tapping fixture for fork
8. Forks - 54 nos.

The jigs and fixtures, mentioned above were manufactured and assembled, to facilitate batch production of forks. The fork is a steel casting, which is fixed as a universal joint, facilitating movement at horizontal axis, and to an angle at vertical axis. The fixtures were set on the milling machines, to carry out the prescribed operations for a batch. To facilitate easy setting, fixtures, feeler strips were used. After the milling operations, the forks were fixed on the drill jigs, for drilling the necessary holes, for location and tapping. Since the fork was to be in the tolerances specified, it was completely checked, and further it was assembled and tried at the customers end. A batch of 54 nos. forks were manufactured.

9. Piercing tool for corrugated sheets
10. Duplicate piercing tool (alternative design)
11. Feeding arrangement for corrugated sheets to space the corrugation was manufactured and fixed to the forming press.
12. A checking gauge to check the semi-circular forming of corrugated sheets.
13. Accessories for conveyor system to paint corrugated sheets; 200 nos. at a time and clamps, hooks, pulleys etc.

The tools and accessories mentioned from item 9 to 13, were manufactured and assembled to facilitate large scale manufacture of corrugated sheets. The sheets measuring 2mm x 1.5 metres x 2 mts. were corrugated on the forming press and bent to a semi-circular form, on the sheet roll forming machine. Through the holes, which were punched earlier, the formed sheets were hung on the conveyor with hooks and pulleys, for spray painting. The conveyor could accommodate 200 nos. formed sheets for painting at a time. The painted sheets were allowed to dry and were stacked and despatched. In a day around 200 sheets were formed and painted.

14. Die casting die (gravity) for battery terminal. The die block was changed as per the alternative design.
15. Die casting die (gravity) for terminals:
    i) one tool for positive terminal
    ii) one tool for negative terminal

The tool elements of the die were actuated by pneumatic cylinders. Three cylinders were used for each tool. Two cylinders, fixed on the horizontal plane, were actuating 2 nos. mould blocks, which were being slid, to facilitate easy removal of the moulded component, where as the third cylinder was ejecting the moulded component.

16. Distillation of water by solar energy - a model

The model consisted of a distilled water collecting base, on which frames with glass panels were fixed to prevent moisture leakage. Moisture, coming in contact with panels, use to become water drop, and through water channels, distilled water was collected.

17. Water heating by solar energy

This model comprising of two heating panels, with aluminium pipes laid for water circulation, was welded and fixed with a glass top. The water, being circulated through the pipes, gets heated up and due to change in temperature, cold water siphon in to the heating panels and thus the circulation is continued. Both the panels were connected to a tank having 250 litres capacity. The water temperature attained thus was 60°C.

18. Piercing and blanking tool for plate

19. Piercing and blanking tool (duplicate) as per modified design (as per the change in dimensions on the product). It was a progressive tool with three stations. First station piercing, second station piloting and last station blanking. The die block, was hardened and the piercing, piloting holes, were jig ground. Opening for the blanking operation on the die blocks was finished by sparking on the electro-discharge machine.
20. Die blocks, punches for universal die set for aluminium discs. This design facilitating changeable die blocks and punches could punch out, Aluminium discs sizes from Ø 110 - 290 for further processing. The components were punched out at customers end.
21. Progressive tool for heat reflector

A four station progressive tool consisting of piercing, forming, bending and cut-off operations. The forms on the die block were wire-cut and the punches were assembled as per the openings on the die block.

22. Tool housing for press K-2326
23. Tool housing for press K

The above tool housing, were to accommodate changeable tool elements, to carry out number of operations, by changing punches and dies.

24. Piercing and bending tool

The component resembling a triangle of 3mm thickness was pierced in the middle and were bent to 90° at the edges in one operation and the component ejected by spring pad.

25.	Holders size D30 122mm	60 nos.
26.	Levers	10 nos.
27.	Indexing levers	50 nos.
28.	Hooks	10 nos.
29.	Internal lift size 122mm	10 nos.

The above elements were manufactured in batches. During the manufacture, small jigs, fixtures, work holding devices, were manufactured to facilitate machining of identical pieces. The number of operations were analysed and carried out in sequence.

30. Assembly fixture for pins
31. Wrench
32. Fixture for testing
33. Inspection fixture
34. Fixture for measuring
35. Fixture for pressure testing
36. Special wrench
37. Assembly fixture for plunger valve
38. Fixture for pressure testing
39. Inspection fixture
40. Torque wrench
41. Special box spanner
42. Fixture for support
43. Key 1607
44. Key 1608
45. Key 1609

The above fixtures from items 30 - 45, were a set of tools, for dis-assembly and assembly of an axil, with a hydraulic cylinder. Since the axil has to be assembled, at certain pressure and expected to retain the pressure, all the joints were to be strong enough to withstand the load, hence the pressure testing fixtures were necessary. Item no. 39 inspection fixture 1.3 meter long having setting blocks, to check assembly of the axil was manufactured. The fixture was also used to check, and set with feeler strips the required opening, closing of the hydraulic cylinder housed in the axil.

46. Pneumatic toggle joint stopper for controlling length of the pipes
47. Accessories for the conveyor system of the poles

The above fixture and the accessories were manufactured as an additional attachment for the system already working at the pole factory. The toggle joint stopper could be adjusted to get different lengths of pipes.

48. Device for compact rolling of cables

This equipment, consisting of three sets of hardened and ground rollers, having three different radii, was used to reduce the diameter of the twisted aluminium cable. The cable having ø 25mm was pulled through the rollers and was reduced in diameter.

49. Right angled base plate for vice

This box type base plate was manufactured for the quality control department. A precision vice was fixed on the plate. Thereby, a job could be held in the vice, and checked on all the six sides without removing from the vice, just by tilting the base plate on all the six sides.

50. Turning fixture for bearing body
51. Face plate for bearing body
52. Setting and welding fixture for axil

Item 52 fixture was made to facilitate manufacture of axil, cranked at both ends, weighing approximately 300 kg., item 50 and 51 are the fixtures for turning the accessories of the axil. Item 52, consisted of a head stock, with a spindle and face plate, driven by a worm and worm wheel, attached to a reduction gear motor. An adjustable tail stock and locating stands for positioning the axil before welding, were fixed.

53. Manufactured various test pieces for material testing and other in-house requirements.

PROTOTYPES

1. "MEFLAH", a combined agricultural implement to prepare the soil, seeding, and to bring out the seed and fertilizer. A prototype, the implement, used as an attachment to the tractor was manufactured.

2. Mechanical Ladder (Borma). A prototype, an attachment to the tractor ANTAR-70 (and other types), with hydraulic cylinders for tilting the ladder to an angle of 75° and extend the ladder to a vertical height of 12 meters, was made.

   The tractor could be driven to the date palm trees and with the tilting and extending facility, one can climb on the ladder and easily reach the top of the date palm trees to pollinate or harvest dates.

3. "ASSAMA", Ladder 4.2 meters

4. "ASSAMA", Ladder 1.8 meters

   The above two items were fabricated ladders of different lengths used for harvesting dates.

4. WORK IN PROGRESS

The following jobs were in various stages of manufacture when the assignment was completed.

1. Cutting die - 2 nos.
2. Piercing and bending tool - 1 no.

The above three tools are for punching out components triangular in shape, of different sizes.

3. Fixture for checking the feeding arrangement at a height of 1.2 meters.
4. Turning fixture for bearing body. Another fixture used in manufacture of axil and accessories mentioned in item no. 52.

5. TRAINING OF WORKSHOP PERSONNEL

Apart from the manufacture of tools and dies, the workshop personnel were given on-the-job training during day to day work. The operators and fitters were given training, on correct and proper use of machines and accessories, measuring instruments, selection of cutting tools, grinding wheels, during day to day work, through demonstrations. The technological process required for manufacturing the items, was explained to each operator so that the correct method of manufacture can be followed. Skilled operators from an industrial complex near Baghdad were given training on precision milling machine, jig boring and spark erosion machines.

6. FINDINGS AND RECOMMENDATIONS

The following points were observed during the course of day to day work:

1. The counterpart staff, and the workshop personnel were quite receptive.
2. The equipment in the workshop, and in the quality control department are best suited for the type of work being carried out.
3. A surface grinding machine, which could accommodate precision grinding operation for the smaller sizes of work will be an additional help.
4. A selection of NC and CNC machines will complete the machinery requirement, and precision work can be carried out more effectively.
5. There is only a limited selection of raw materials for the tool elements.
6. An effective maintenance system for the machines is necessary.

Recommendations

1. It would be better, in future that the UN experts activities are defined to suit the specific needs.
2. To build up an effective infrastructure, basic training programmes are necessary. The importance of such activity is to be explained such that the industries can run more effectively.
3. Emphasis should be given to specific programmes of a particular industry.
4. By reorganising working systems such as introduction of time study, estimating and costing, strict quality control can be streamlined.

5. For the type of work being carried out in the workshop, the process sheets can be prepared by the workshop personnel themselves.

6. Qualitative and quantitative analysis of problems of industries can be made to make the activities of the institute more effective.

7. Stage inspection procedures can be introduced more effectively to improve the quality of work turned out.

8. The maintenance system, reconditioning of cutting tools and equipment, which are the basic activities, are to be streamlined.

PROVISION OF EXPERT SERVICES
TO SIEI, IRAQ
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(2 of 4)

FINAL REPORT

OF MR. V. BALAKRISHNAN
EXPERT HEAT TREATMENT & MATERIALS ENGINEERING

HMT (INTERNATIONAL) LTD.
17, ALI ASKER ROAD
BANGALORE-560 052, INDIA

SEPTEMBER, 1984

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1. INTRODUCTION

In response to an enquiry by UNIDO, Vienna, HMT (International) submitted an offer for rendering technical services to the Specialised Institute for Engineering Industries (SIEI), Baghdad, Iraq. HMT (International) was required to depute three experts covering the following disciplines:

i. Press Tools and Mould Design
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As per the procedures of UNIDO, HMT (International) shortlisted a few experts in each of the areas for final selection by the representative of UNIDO. The Chief Technical Adviser (CTA), UNDP, Baghdad, who is incharge of the UNDP-SIEI Project, visited Bangalore, India during October, 1981 and interviewed the short-listed experts. I was selected as an expert in the areas of Heat Treatment and Materials Engineering to render services to SIEI for a period of 2 years. My job description is given in Appendix-1. After signing the contract between HMT(I) and UNIDO, I reported to UNDP, Baghdad on 12th January, 1982, and reported for work at SIEI on 20th February, 1982 after completing the briefing.

I have completed 24 months of service as on 11th February, 1984 and am herewith submitting my final report on the work done during this period.

ACKNOWLEDGEMENT

I express my thanks to Mr. Stevan Buranj, Chief Technical Adviser of UNIDO Project, Dr. Abid Ali Sahab Abbas, Director General, SIEI, Mr. Adnan Al Khozaee, Director, SIEI and HMT(I) Bangalore, for the excellent guidance and support given to me in carrying out my assignment. I also express my deep appreciation and thanks to Mr. Yahya Al Shibli, Miss. May Abid Al Hamid and Mr. Mohammed Jowad for their continued co-operation. I also thank the engineers of the various enterprises where consultancy was undertaken.

2. BACKGROUND INFORMATION ON HEAT TREATMENT SHOP AT SIEI

The Heat Treatment section of the Institute is very small. It contains the following equipments:

- Twin Chamber Furnace for Hardening .. 1 No.

  Chamber I - Size 300 x 400 x 1100 mm
  Max. Temp. 1000°C

  Chamber II - Size 300 x 400 x 1100 mm
  Max. Temp. 1300°C

- Vertical Forced Air Circulation Furnace for Tempering .. 1 No.

  Chamber Size - 600 dia x 1000 mm deep
  Max. Temp. 650°C

- Chamber Furnace for Annealing, Heating for Forging etc. .. 1 No.

  Chamber Size - 600 x 600 x 800 mm
  Max. Temp. 1200°C

- Salt Bath Furnace for Hardening High speed steels

  Pot Size - 300 dia x 500 mm deep
  Max. Temp. 1300°C

- Oil and Water quenching tanks
- Forging Hammer
- Hardness Tester

All the above equipments are supplied by M/s. Technoimpex, Hungary.

The heat treatment shop was meant to cater to the heat treatment needs of the mechanical workshop attached to the Institute. In the normal case when the machine shop works to the full capacity there will be sufficient load for the heat treatment section. But since the machine shop was working very much below its capacity due to shortage of man-power, the heat treatment shop had very less load.

My counterpart in the heat treatment section had been Mr. Yahya Al Shibli, who was incharge of the heat treatment and metallurgy section. He is a graduate in Physics, with about 6 years experience in heat treatment. Mr. Yahya was assisted by Miss. May Abid Al Hamid, Engineer, till she was transferred to another factory in October, 1983. Her position was then filled up by Mr. Mohammed Jowad, Engineer. In addition, to the above persons, there was only one operator for the complete section and he was absent for 7 months, due to military service.

3. SUMMARY

3.1 The heat treatment shop of SIEI is small and the work load is very less. The twin chamber furnace used for hardening is not suitable for good quality heat treatment since,

i) there is no atmosphere control and hence parts heat treated in this furnace are not of good quality due to decarburisation and scalling

ii) the temperature control accuracy of the furnaces is ± 50°C, which makes it extremely unsuitable for good quality heat treatment.

3.2 During this period of 2 years 16 major tasks have been carried out. Since the activity in the Institute was very low, more emphasis was given for external consultancy projects. Out of the 16 tasks, 8 numbers were external consultancy projects, in factories belonging to the State Organisation for Engineering Industries.

3.3 The major achievements among the external consultancy projects were the development of S.G. Iron production at the State Enterprise for Mechanical Industries, Iskandariyah and the preparation of a Hand Book for Heat Treatment (Ferrous Materials). One copy of the report on the S.G. Iron project and the Hand Book are attached separately to this report as annexures.

3.4 Details of my findings and my recommendations for future are given in item 5.

4. WORKS PERFORMED

The following are the works carried out during period of my assignment.

4.1 Recommendation of suitable temperature checking and calibrating equipments for the heat treatment shop of the Institute. These instruments were subsequently imported and my counterpart was trained to operate them.

4.2 Establishments of the pack carburising process at the Institute, including the preparation of the pack carburising compound from basic chemicals. This method is now being used for the carburising of components occasionally when the requirement arises.

4.3 Preparation of guidelines for the selection of steels for fixtures and other components, other than press tools and moulds. These guidelines were copied and circulated to the tool design and production engineering departments for their use.

4.4 Recommendation of safety equipments required for the heat treatment section. Some of these safety equipments were procured and they are being used by the operators.

4.5 Proposal for the modernisation of the heat treatment shop of the Institute. Due to financial difficulties the Institute could not proceed further in this matter.

4.6 Design of new furnace pot for the conversion of HSS salt bath into neutral hardening bath for low and medium alloy steels with hardening temperatures upto 900°C. The manufacturing of the new furnace could not be done due to shortage of capacity in the fabrication shop.

4.7 Investigation of the failure of extrusion punches of Al-Noor Battery Company. The findings given were accepted by the Italian suppliers and free replacement was agreed by them.

4.8 Recommendation of equipments for the subzero treatment of tools for the heat treatment shop of the State Enterprise for Mechanical Industries (SEMI), Iskandariyah. No action was taken due to shortage of funds.

4.9 Preparation of proposals for the equipments and layouts for establishing two new heat treatment shops. These proposals are under study for further action.

4.10 Study and preparation of proposal for the suitable chemical composition and heat treatment process for obtaining high tensile and high impact castings which are to be used as replacement for forging.

4.11 Recommendation for the equipments for the cleaning of heat treated components of the tools department of State Enterprise for Mechanical Industries (SEMI), Iskandariyah.

4.12 Recommendation of new processes/machines for the fettling of castings at the foundry of SEMI, Iskandariyah.

4.13 Development of S.G. Iron castings at SEMI, Iskandariyah. Detailed report on this project is given in Annexure-I.

4.14 Preparation of a hand book in Arabic for the heat treatment of ferrous materials in factories belonging to the State Organisation for Engineering Industries. A copy of the hand book in English is given in Annexure-II.

4.15 Study of the feasibility and economics of converting the conventional cupola into cokeless cupola using natural gas as fuel instead of coke.

4.16 Advice on material selection and heat treatment for the routine works of the Institute.

5. FINDINGS AND RECOMMENDATIONS

5.1 The equipments available in the heat treatment shop of the Institute are outdated models (except for H.S.S. Hardening Furnace) and they are inadequate for good quality heat treatment. The temperature control accuracy of the furnaces is very poor and the error can be as high as ± 50°C. Secondly the chamber furnace is not suitable for good quality heat treatment because of (i) heavy decarburisation and scaling due to lack of atmosphere control and (ii) non-uniformity of temperature within the chamber.

The Institute, being a research and development oriented organisation should have quality equipments. Hence, it is recommended that the following additional equipments are provided in the heat treatment section.

a) Double chamber vacuum furnace, with provision for oil quenching, vacuum carburising and nitriding. Chamber size 500 W x 300 H x 500 mm D.

b) High frequency induction heating unit, frequency 350 KHz, with output power 50 KW.

5.2 The work on S.G. Iron project should be continued in the following lines:

5.2.1 The stock of special grade pig iron (sorelmetal) required for the production of S.G. Iron was limited and hence it was sufficient only for a few trials. Further, quantity of this material has been ordered. This should be followed up and further melts should be produced to stream-line the process and to continue regular production.

5.2.2 One of the major advantage of S.G. Iron castings over steel castings is the higher casting yield obtained for S.G. Iron. At present the same pattern that is meant for steel casting is used for the S.G. Iron casting, resulting in no increase in casting yield. Hence, the patterns should be suitably modified, considering the less shrinkage of S.G. Iron in order to increase the yield.

5.2.3 At present only a few components are selected for production in S.G. Iron, mainly those parts which are now produced in steel casting. But many other parts which are at present made out of steel bars or forgings can be also economically converted to S.G. Iron. Hence, it is necessary that a complete study be made to identify further parts which can be manufactured out of S.G. Iron.

5.3 The 'Handbook for Heat Treatment' prepared now covers the heat treatment of ferrous materials only. A similar handbook should be prepared for the heat treatment of non-ferrous materials also.

5.4 In general, heat treatment is becoming more and more an exact science, but at the Institute, heat treatment is far away from this and the results are not always as required. The main reasons for this are improper selection of material, unsuitable design for heat treatment, and the poor quality of the heat treatment equipments. Hence it is suggested that a comprehensive manual for the selection of materials and guidelines for designing for heat treatment be prepared for the use in the Institute and followed strictly. Regarding the inadequacy of the heat treatment equipments, the recommendation is already given in 5.1.

5.5 At present the Institute takes up only those problems or requests received from other engineering industries. Many a times there may not be a problem, but the practice followed may not be right or the optimum for getting minimum cost and the required quality. In such cases there will not be any request from the unit and hence no action will be taken to rectify the same.

It is therefore proposed that the Institute takes up the work of studying the process sheets of the various heat treated production components in the different factories belonging to the State Organisation for Engineering Industries and recommend suitable materials and heat treatment processes with a view to reduce cost and to improve quality.

5.6 Unfortunately during my term no training course in heat treatment was arranged by the Institute. It is recommended that suitable training programme be arranged for the heat treatment shop personnel with theory and practical exercises. For this purpose, a manual for training in heat treatment along with slides and transparent sheets for overhead projector may be prepared.

APPENDIX-1

JOB DESCRIPTION

Post Title : Expert in Heat Treatment and Materials Engineering.

Duration : Twenty-four months

Date Required : January 1982

Duty Station : Baghdad, with possibility of travel within the country.

Duties : The expert will work in co-operation with the Chief Technical Adviser, the Production Engineering Department and partly with the Quality Control Department's Laboratory Section of the Specialised Institute of Engineering Industries and will specifically be expected to:

1. Assist the Departmental Director, as regards technical matters, in setting up and running the Heat Treatment Materials Engineering Section with its workshops;
2. Direct the work of the Section, from the technical point of view, together with the Leading Metallurgist. The duties of the above Section are the following:
    a) to improve the existing or introduce new heat treatment methods;
    b) to prepare necessary heat treatment technology documentation (process and operation sheets, specification of equipment and relevant instructions);

c) to advise on the use and replacement of materials;

d) to provide internal and external services in heat treatment;

3. Take part in the testing and introduction of new heat treatment technology;

4. Assist the Chief of Laboratories, as regards technical matters, in setting up and running the Material Testing Laboratory (mechanical and metallurgical) and the work of the laboratory, from a technical point of view;

5. Guide, instruct, technically supervise and train personnel in the field of the heat treatment and materials engineering as well as in the material testing professions;

6. Introduce the use of standards and norms for heat treatment and for material testings;

7. Advise product and tool designers in choice of material;

8. Assist in implementing specialised training courses in heat treatment and design;

9. Prepare a detailed work plan and reports according to the instructions of the Chief Technical Adviser.

The expert will also be expected to prepare a final report, setting out the findings of the mission and recommendations to the Government on further action which might be taken.

Qualifications: University Degree in Technology or Metallurgy; extensive experience in up-to-date heat treatment processes for tools, dies and engineering components as well as in their materials; experience in running a Heat Treatment Technology office and in the training of personnel.

Language : English, Arabic and asset.

Background Information : The country has a growing engineering industry and has laid emphasis on the raising of industrial productivity through the use of modern products and up-to-date production methods. Agricultural machinery, trailer, bus, transformer, electric and household equipment industries have already been established. In addition, the National Plan has given high priority to the continued expansion of the mechanical and electrical industries. The existing production is introduced mainly under various types of licence agreements. There are public, mixed and private sectors.

The Government has established the "Specialised Institute for Engineering Industries" with the main objective of assisting the development of engineering industries in the country and to extend this assistance to other Arab States at a later stage.

The Institute, which is an autonomous body, has a Board of Directors, is headed by a Director General and has an initial basic engineering and supporting staff, has been functioning since 1973 but on a very limited scale. It is presently housed in temporary premises but will be relocated in its new head-quarters in Baghdad, where it will have well equipped manufacturing workshops as well as technical offices and other necessary facilities.

The project is designed to develop the Institute along up-to-date scientific lines so that it could effectively render services and training in the following areas:

a) product development and design;
b) production engineering;
c) prototype manufacturing (products, special tools, sophisticated components and parts);
d) quality control and inspection;
e) industrial information and documentation;
f) techno-economic studies.

Bearing in mind the rapid expansion of the engineering industry and urgent needs for its assistance, the Government has agreed with the United Nations Development Programme to include this project in the 1977-1981 Country Programme and partly in the 1982-1986 Country Programme. The executing Agency is the United Nations Industrial Development Organisation (UNIDO);

The objectives of the Production Engineering Department are the following:

a) to establish a Technology Section within the Department which will consequently work on the improvement of the existing and introduction of new production technology in the engineering industry.

b) to strengthen the existing Tool Design Section and improve its capabilities enabling it to design special tools and dies required for the development of the industry;

c) to establish a Heat Treatment and Material Engineering Section within the Department which will render services to the Institute and industry;

d) to establish a Manufacturing Workshop and to manufacture prototypes, special tools and sophisticated components.

ANNEXURE-I

REPORT ON
THE DEVELOPMENT OF S.G.IRON

14102
(3 of 4)

UNIDO-HMT (INTERNATIONAL)
CONTRACT NO.T81/80 HR

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1. INTRODUCTION

Spheroidal Graphite Iron (S.G. Iron), though developed only recently, has proved itself to be one of the major types of casting material in the engineering field. The rate of growth of production of S.G. Iron from the time of its initial production in the fifties, has been very high; much higher than that of any other type of casting produced so far in this world. This is mainly due to its better foundry properties, possibility to get the mechanical properties in the as cast condition without any heat treatment and better machinability at the same time providing strengths equal to that of steel castings. In the engineering industry, especially in the automotive field, more and more parts of steel castings and forgings are now being replaced with S.G. Iron castings.

In line with the above trend, the State Enterprise for Mechanical Industries (SEMI), Iskandariyah planned to replace gradually the steel castings used by them with S.G. Iron castings. The first attempt to produce S.G. Iron at SEMI was carried out in 1975 with the help of experts from Messrs. SAVIEM, France. Unfortunately the trials were unsuccessful due to limitations of the facilities and materials available at that time. Further trials were conducted in 1978, 1981 and 1982 with the help of experts from Messrs. SAVIEM, France, Messrs. QIT Fer-et-Titane, W. Germany and the Specialised Institute for Engineering Industries (SIEI), Iraq respectively. These trials were also unsuccessful.

Hence in 1983, a team consisting of the following members was formed to conduct trials and to establish the melting of S.G. Iron.

Mr. V. Balakrishnan - UNIDO Expert
Mr. Yahya Al Shibli - SIEI, Baghdad
Dr. Abdul Razak - University of Technology, Baghdad.
Mr. Salah Mehdi Witwit - SEMI, Iskandariyah
Miss. May Abid Al Hamid - SIEI, Baghdad.

The task of the team was to conduct trials and to establish the melting process for S.G. Iron at SEMI, Iskandariyah. The team started its work in January 1983 and successfully completed the trials by September 1983. This report covers the details of the works carried out by the team in establishing the melting process and its recommendations for future production.

2. S.G. IRON - ADVANTAGES AND APPLICATIONS

In the grey cast iron the graphite is present as flakes, which makes it brittle whereas in the case of S.G. Iron, the graphite is present in approximately spherical form, making it strong and ductile. The mechanical properties of S.G. Iron are comparable with those of steel castings. S.G. Iron has better foundry properties when compared to steel castings due to its higher fluidity ie., it is easier to cast S.G. Iron than steel. As the shrinkage of S.G. Iron is much less when compared to steel, heavy risering is not necessary, thereby improving the casting yield. Another major advantage of S.G. Iron is that different mechanical properties can be obtained in the as cast condition itself without subjecting to any heat treatment operations. Apart from the above, S.G. Iron has higher damping capacity, reduced notch sensitivity and better machinability over steel.

Due to the above advantages, S.G. Iron is used as substitute for steel castings. S.G. Iron also replaces malleable iron castings in many cases as the mechanical properties are comparable with those of malleable iron. Typical items produced in S.G. Iron are parts for automobile industry, textile machinery, machine tools etc. With the development of alloyed S.G. Irons, parts requiring very high strengths such as Crankshafts, Camshafts etc., are also made out of S.G. Iron. Large pipes account for a major share of production of S.G. Iron.

3. REQUIREMENT OF S.G. IRON AT SEMI, ISKANDARIYAH

The details of the parts selected at SEMI, Iskandariyah for replacement with S.G. Iron are given below:

- Part No. 51113301
  Front Axle Bracket (for tractors)
  Present Material - Steel Casting
  Weight of casting - 54 kgs.
  Weight of metal poured - 74.700 kgs.
  Quantity required - 500 nos./month

- Part No. 40115011
  Bracket (for tractor)
  Weight of casting - 5.250 kgs.
  Quantity required - 1000 nos./month

- Part No. 5000 003 939
  Front drum for Truck
  Weight of machined casting - 40 kgs.
  Quantity required - 600 nos./year

The material specifications for the above parts were studied and found that two grades of castings with mechanical properties as shown in the table given below are required:

Grade of casting	Tensile strenght minimum N/mm^2	0.2% Proof stress minimum N/mm^2	Elongation minimum %	Hardness HBN
42-12	420	280	12	150-200
42-5	420	280	5	150-200

Since the grade 42 - 12 meets the requirements of both the types, the trials were restricted to the production of this one grade only. This grade corresponds to the grade 42 - 12 of ISO - R1083 - 1969 (E) and the equivalents in other standards are given in the table shown below:

ISO R1083 1969-(E)	DIN 1693	B.S. 2789 1973	GOST 7293 -70	AFNOR NFA-32-201
42 - 12	GGG40	420-12	42 - 12	FGS42-12

The chemical composition and microstructure are not binding conditions for the acceptance of the S.G. Iron. In order to achieve the mechanical properties, the matrix structure should be predominently ferrite. Though the ferritic structure can be produced by heat treatment, it was aimed at obtaining the required structure (and mechanical properties) in the as cast condition without resorting to any heat treatment. Based on the above, 'The Technical Conditions for Acceptance of S.G. Iron Casting' (Appendix-I) was prepared as a standard for quality control department and also as a norm for evaluating the results of the trials.

4. TECHNOLOGY OF MELTING S.G. IRON

Basically S.G. Iron is produced by treating the molten iron with magnesium. Though very simple to say, it needs thorough care in all stages of melting to ensure that proper spheroidisation takes place. Deviation in any stage will prevent the formation of graphite spheres. The various stages involved in the melting are briefly explained below:

4.1 Preparation of Base Metal

Unlike grey cast iron, the preparation of the base metal has to be done very carefully. The reason for this is that if the base metal contains certain elements like As, Bi, Sb and S even in small amounts, the nodularisation of graphite will not take place. Hence special care has to be taken in selecting the raw materials for melting. In order to ensure freedom from the above subversive elements, special quality of pig iron (eg. sorel metal) is generally used as raw material. The general composition of base metal used for producing S.G. Iron, is given below:

C %	Si %	Mn %	Cr %	Ni %
3.5-3.8	1.6-1.8	0.04	0.10	0.10
P %	S %	Cu %	C.E.	
0.06	0.02	0.10	4.1-4.4	

Apart from the above, the base metal should be free from traces of subversive elements such as Pb, Sb, Bi, Ti, etc., which will prevent the formation of spherical graphites. The maximum allowable percentage for these elements are as given below:

Pb $\leq$ 0.002%; Sb $\leq$ 0.002%; Bi $\leq$ 0.002%; Ti $\leq$ 0.010%

Therefore, generally for S.G. Iron melting a special quality of pig iron eg. (sorel metal) is used, which ensures freedom from these subversive elements. The typical composition of the special pig iron is as follows:

C - 3.8-4.3%; Si - 0.180%; Mn - 0.010%;
P - 0.025%; S - 0.006%; Ti - 0.020%

The steel scrap to be added should also be of known composition free from the subversive elements and without any contamination.

The melting process should be as fast as possible and the temperature should be determined accurately before tapping.

4.2 Desulphurisation

Magnesium has great affinity towards sulphur. Hence, if the base metal contains large amount of sulphur, the magnesium added will be consumed by the sulphur and the nodularisation will not be complete. The maximum allowable percentage of S in the base metal is 0.02%. Hence, if the sulphur content is higher than 0.02%, desulphurisation has to be done to remove the excess sulphur. The normal procedure for desulphurisation is to add calcium carbide into the molten metal. The addition can be done inside the furnace, in the fore-hearth or in the ladle. But, since the desulphurisation causes drop in temperature it is preferable to do it inside the furnace so that the metal can be reheated after desulphurisation. In the case of basic lined furnace it is easier to effect the desulphurisation by increasing the basicity of the slag. But with acid lined furnaces the desulphurisation has to be done outside the furnace.

Desulphurisation can be avoided if raw materials with very low sulphur content are used. Eg. Sorel metal (special pig iron) contains less than 0.005%. If such raw materials are used, it is possible to obtain a sulphur content of less than 0.02% in the melt without any desulphurisation.

4.3 Magnesium Treatment

This is the most important stage in the production of S.G. Iron. Magnesium is added either in pure form or as alloy into the molten metal to cause the nodularisation of graphite. As magnesium has low melting and boiling points, it reacts violently with the metal causing heavy glare and spurting. Different methods are available for adding magnesium to the molten metal. The common methods adopted are,

(a) open ladle process, (b) sandwich process, (c) plunger process, (d) porous plug process and (e) pressure vessel method. The principle of these methods are shown in Fig. 1 (a) to (e).

In all the above methods, except in the pressure vessel method, magnesium is used as an alloy of silicon or nickel. The pressure method makes use of pure magnesium and hence requires special treatment ladle which can withstand the high vapour pressure of magnesium. In all the other methods the ladle is open and hence there will be heavy glare and loss of magnesium due to burning. But these methods are simple and needs no costly equipment.

Hence, for small foundries, any of the first four methods are used. But in all these methods, the ladle is open and hence it causes heavy glare and magnesium fumes, resulting in environmental pollution. In order to avoid the above, a new modification has been developed recently, which makes use of a tundish cover to contain the fumes and glare. Fig. 2 shows the principle of the tundish cover.

By adopting the tundish cover, the following advantages are obtained:

(a) no fume or glare

(b) better Mg. recovery and the resultant low Mg alloy consumption.

(c) consistant results due to the controlled reaction

and

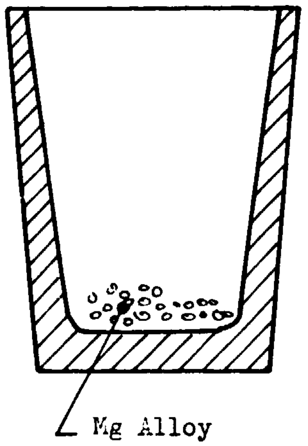


Fig. 1(a) Open Handle

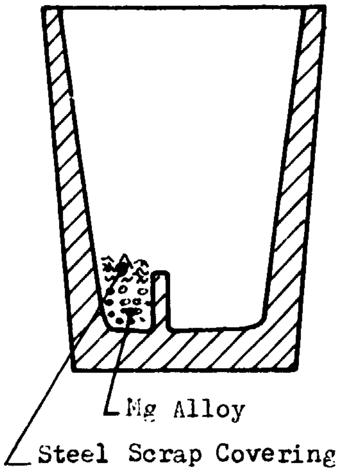


Fig. 1(b) Sandwich Process

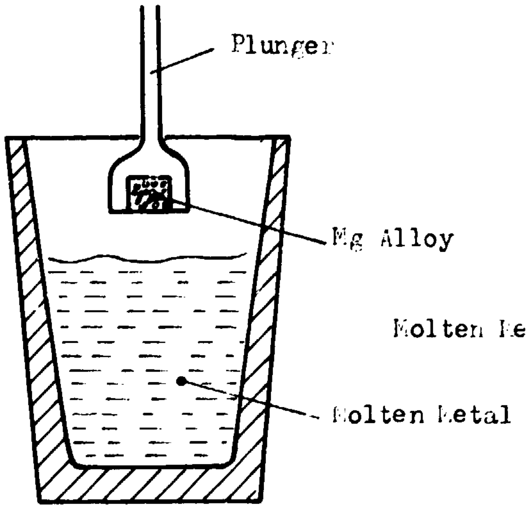


Fig. 1(c) Plunger Process

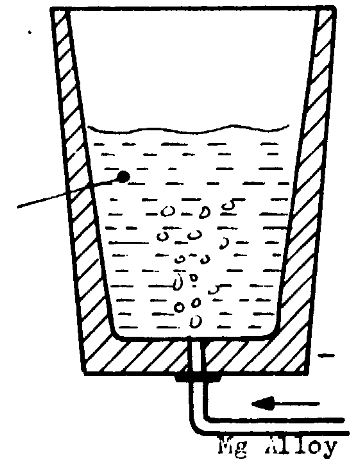
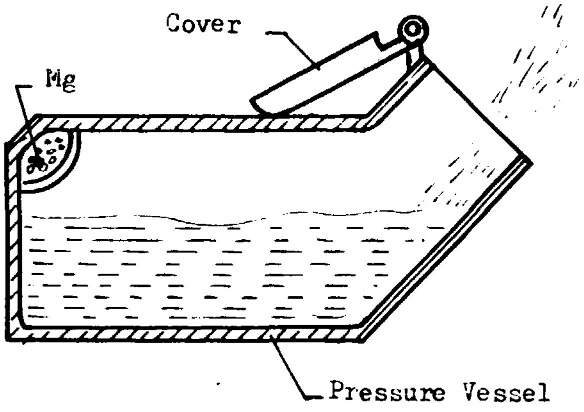
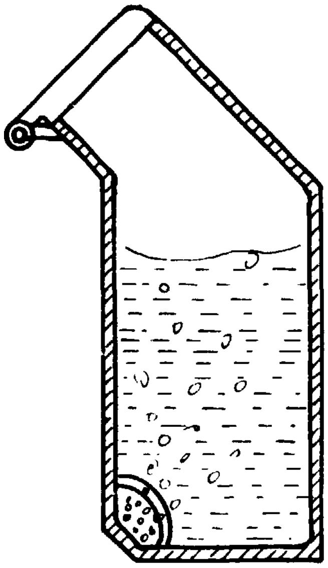


Fig. 1(d) Porous Plug Process

(i) Tapping



(ii) Reaction



(iii) Pouring

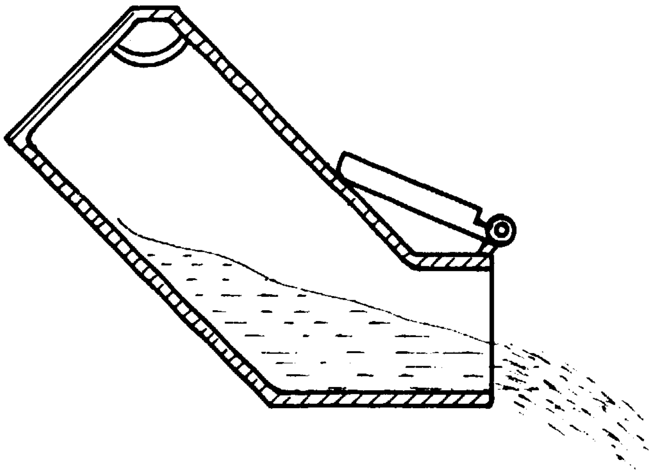


Fig. 1(e) - Pressure Vessel Method

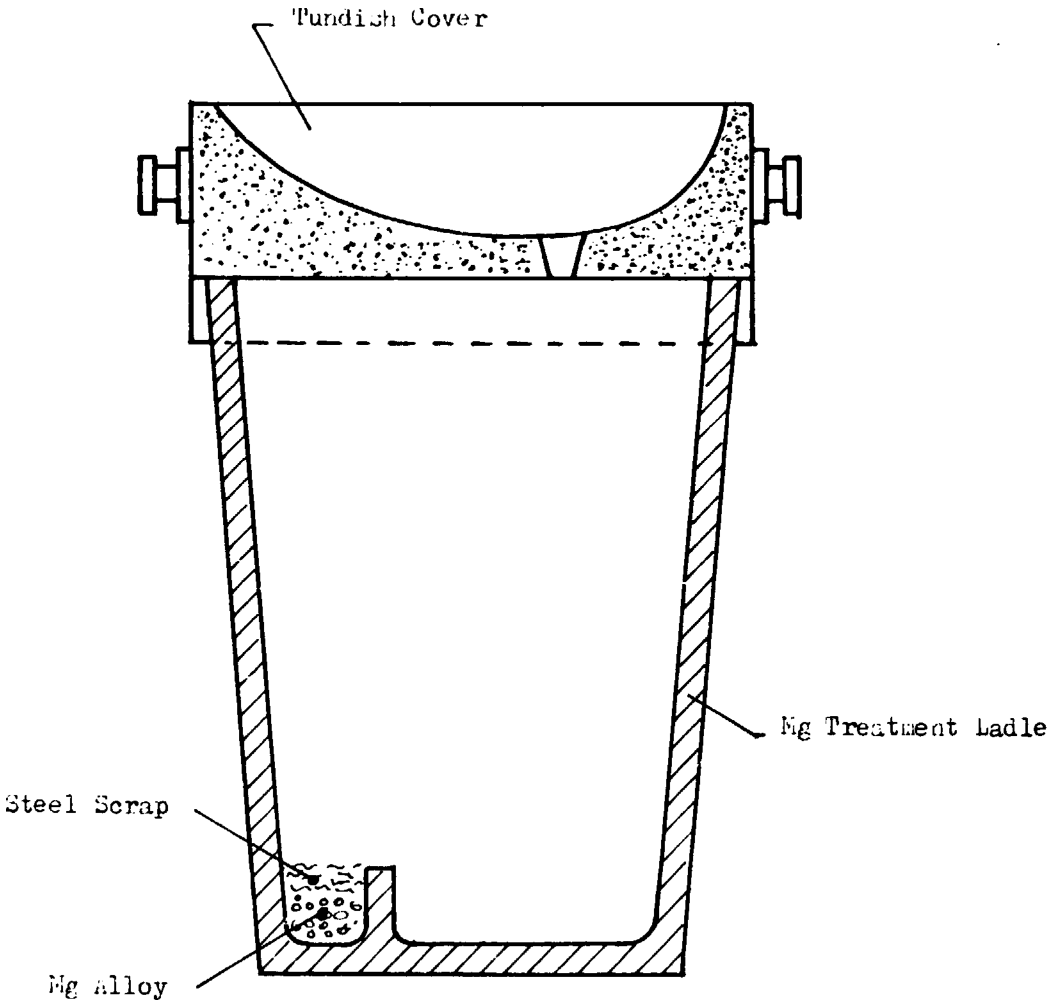


Fig. 2 - Principle of the Tundish Cover Method

(d) safe working condition as there is no chance of the metal spurting violently

In view of the above benefits, many foundries using the sandwich process are adopting fast the tundish cover technology. The cost involved in adopting the new technology is negligible since the tundish cover can be fabricated locally without any large expense.

4.4 Inoculation and pouring

After Magnesium treating the next stage in the production of S.G. Iron is inoculation of the magnesium treated metal with ferrosilicon. The purpose of inoculation is to make the graphite fine (high nodule count) and to avoid chilling of small sections. After inoculation the metal is poured into moulds.

The metal after magnesium treatment should be poured within about 15 minutes as the effect of the treatment fades with time. If the pouring is delayed for a longer period, the effect of magnesium treatment gets lost and the nodularisation will not be proper. Hence the magnesium treatment is done for small quantities of metal (about 500 kg) at a time so that the pouring of the complete metal can be finished in 15 minutes.

5. STUDY OF THE FACILITIES AVAILABLE AT SEMI

A detailed study of the facilities available at SEMI was undertaken to determine the most appropriate method for conducting the trials. The following are the salient points emerged from the study.

5.1 Furnaces for Melting

The foundry is having six numbers of electric arc furnaces of 1.5 tons capacity each for the melting of iron and steel. Out of these two numbers are basic lined and the balance acid lined. Arc furnaces are least suited for the production of S.G. Iron because of its drawbacks viz;

(a) difficulty in controlling the chemical composition of the melt due to the non-homogenity caused by the lack of stirring action.

(b) difficulty to control the temperature of the molten metal due to the localised high temperature around the arc.

Since no alternate facility for melting was available, it was decided to conduct the trials with these furnaces.

Basic lining for the furnace was chosen so that the desulphurisation, if found necessary, is easy. The material used for the basic lining was chrom-magnesite bricks. Since this lining will cause excessive chromium pick up in the metal, it was decided to change the lining material to pure magnesite instead of chrom magnesite.

5.2 Temperature Measurement Equipments

The SEMI had immersion thermocouple for measuring the temperature inside the furnace and infra-red pyrometer for measuring the temperature while pouring. Both these instruments were not working satisfactorily. The immersion pyrometer was rectified but still the temperature readings were not accurate.

5.3 Ladle for Magnesium Treatment

The special ladle used for magnesium treatment during the previous trials was available. But this ladle did not have tilting mechanism for pouring out the metal. The same ladle was used after fixing a gear box for tilting from another old ladle. The pocket for the magnesium alloy was also modified.

5.4 Testing Facilities

The SEMI had facilities for the quick estimation of Carbon, Silicon, Manganese and Chromium. Other elements such as S, P, Cu, Ni etc., were estimated by wet analysis. For the quick determination of silicon, a new rapid silicon determinator was available at SIEI which was shifted to SEMI foundry. The furnaces also had a carbon-equivalent meter for rapid checking of carbon equivalent.

5.5 Pattern and Moulding Facilities

Patterns for all the three components were available but designed for steel castings and not for S.G. Iron. As the shrinkage for S.G. Iron is low, it is necessary to modify the pattern to obtain correct dimensions and increase in casting yield. But for the trials the same patterns were used without any modifications.

6. AVAILABILITY OF RAW MATERIALS AND OTHER CHEMICALS

6.1 Pig Iron

The pig iron used in regular production was not suitable for S.G. Iron production since it contained higher percentages of Mn, P, S and Si. For the previous trials, a special grade of pig iron (sorel metal) with low S, Mn, P and Si was imported and a balance quantity of about 20 tons was available. The composition of this pig iron is:

C%	Si%	Mn%	P%	S%	Ti%
3.8-4.3	0.180	0.010	0.025	0.006	0.020

This pig iron was used for all the trials for producing S.G. Iron.

6.2 Steel scrap

The steel scrap available in the foundry was a mixture of different kinds of steel and hence not suitable for S.G. Iron production. Hence, alternate sources for steel scrap were searched for and it was found that the scrap from the press shop can be used. This scrap was of known composition and there was no chance for any mix up. The composition of the steel scrap was as below:

	1 K II
C%	0.1
Si %	≤ 0.03
Mn %	0.25-0.50
P%	0.04
S%	0.04
Cr%	0.10

Arrangements were made to collect this scrap directly from the press shop.

6.3 Mg Treatment alloy and other materials

Magnesium alloy left over from the previous trials was available. The composition of the alloy was -

Mg	Si	Ce	Fe
9%	45%	0.5%	Bal.

This alloy was found suitable for further trials. Other items such as inoculation grade of ferrosilicon, calcium carbide, graphite etc. were available.

7. SELECTING THE APPROPRIATE METHOD FOR TRIALS AND PREPARING DETAILED INSTRUCTIONS FOR THE TRIALS

After studying the facilities available at SEMI, the appropriate method for preparing S.G. Iron was worked out. The sandwich method for magnesium treatment with the addition of the tundish cover was selected as the most suitable method for Mg treatment. As the next step detailed procedure/instructions for conducting the trials was prepared for the convenience of the foundry staff (Appendix II). These instruction were translated into arabic so that they can be followed easily by lower level staff in the foundry.

8. TIME SCHEDULE

After deciding the procedure for the trials, a detailed assessment of the works to be carried out in preparation for the trials was made. Based on this a time schedule for the preparatory works and for the trials was prepared (A ppendix-III) and was used for monitoring the progress.

9. TRIALS

9.1 Trial No.1

The first trial was conducted on 5th May 1983. A basic lined furnace was used. The charge consisted of :

Special Pig Iron (Sorel metal)	1200 Kg	80%
Steel Scrap (IK II)	300 Kg	20%
Graphite (As anthrasite)	24 Kg	-
Ferrosilicon (75% Silicon)	39 Kg	-

The weighed quantity of anthrasite powder was put at the bottom of the furnace and covered with lime stone. The previously weighed pig iron and steel scrap were then charged using the special bottom discharging ladle. After the charging was complete, the cover was put in position and the melting started at 10.20 a.m.

Simultaneously, the special ladle for magnesium treatment was cleaned and put on preheating with gas. The tundish cover was also arranged for preheating. The required quantities of magnesium alloy (7.0 Kg. for each treatment), steel scrap to cover the magnesium alloy (7.5 Kg. for each treatment) and the ferrosilicon for inoculation (1.6 Kg. for each pouring ladle) were weighed and kept ready in separate boxes. Steel scrap from the nut manufacturing section (material S35C-Japanese) was used for covering the magnesium alloy since it was available in small pieces most suited for covering.

As soon as the metal was melted, a sample was poured to check the carbon equivalent and also another specimen taken for the chemical analysis. The analysis obtained was as follows :

C%	Si%	Mn%	S%	Cr%	C.E.
3.93	2.09	0.10	0.005	0.10	4.62

As the analysis showed that the metal was close to the required base metal composition except for silicon no correction of composition was required. The temperature was then raised and a final sample was taken for analysis which showed the following results.

C%	Si%	Mn%	Cr%	C.E.
3.75	2.04	0.42	0.15	4.43

Silicon was again high and in order to limit the final silicon within the range, it was decided to reduce the FeSi inoculation to 1.2 Kg. instead of 1.6 Kg. .

The immersion thermocouple was used to measure the final temperature but the reading was erratic. Hence, the final temperature was decided by the colour of the metal.

After preheating, the reaction ladle was prepared for receiving the metal. First the weighed quantity of magnesium alloy was put at the bottom of the pocket and then covered with the steel scrap. The tundish cover was then placed over the ladle and the ladle taken to the furnace for tapping. A crane hook balance was used to note the weight of metal tapped.

Exactly 500 Kg. of metal was tapped into the ladle. Unlike, with open ladle, there was no glare, fumes or burning away of the magnesium alloy. When used without the tundish cover, the glare and fumes will mask the field of view of observing the balance and it will be very difficult to note the reading. But with the tundish cover, there was no such problem and it was possible to stand near the ladle and note the reading properly.

After the tapping, the ladle was taken to the stand near the pouring station. The tundish cover was then removed and the metal was then poured into the pouring ladle and was inoculated with ferro-silicon during pouring. The capacity of the pouring ladle was 160 Kg. Hence, the metal was poured in three batches, each time inoculating with ferrosilicon.

The temperature of the metal at the time of pouring could not be determined as the radiation pyrometer available was not giving accurate results.

Before and after pouring the metal from each of the pouring ladle, a sample piece was poured, to enable to check the quality of each batch.

The total time taken from the time of tapping till the last batch of metal poured was 10 minutes. This was well within the maximum time 15 minutes allowed to prevent fading effect.

After the pouring was complete, the treatment ladle was tilted completely to pour out all the remaining metal and the bottom was cleaned. The ladle was then prepared for the next tapping in the same way as for the first time. Again 500 Kg. of metal was tapped and poured following the same procedure as for the first tapping. The complete molten metal in the furnace was tapped in three batches.

The sample pieces were taken out and analysed for chemical composition, microstructure and mechanical properties. The results obtained are given below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.03-0.05
Actual (average)	3.54	2.54	0.62	0.003	0.05	0.34	0.20	0.03

Microstructure

The microstructure showed completely spherodised graphite. The matrix contained about 50% pearlite and 50% ferrite.

Figs. 1 to 6 show the microstructures obtained.

Microstructures of Trial No.1
Magnification X 100

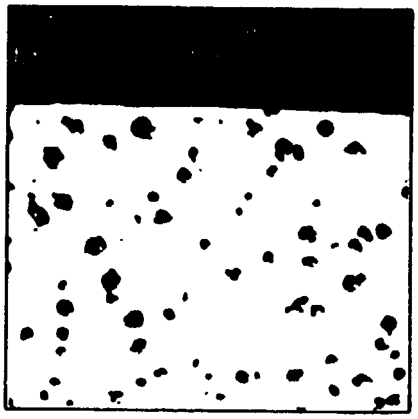


Fig. No. 1
Nodule Count: 297 N/mm^2

Fig. No. 2
Nodule Count: 238 N/mm^2

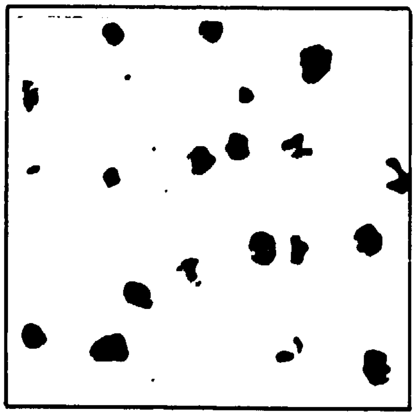


Fig. No. 3
Nodule Count: 105 N/mm^2

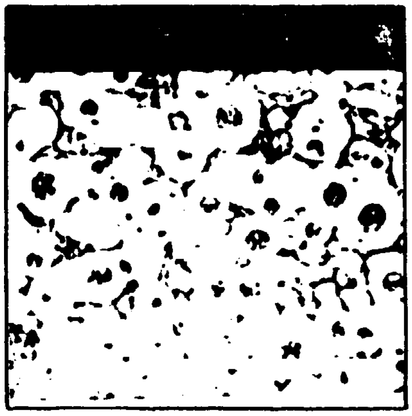


Fig. No. 4
Pearlite 40%

Fig. No. 5
Pearlite 50%

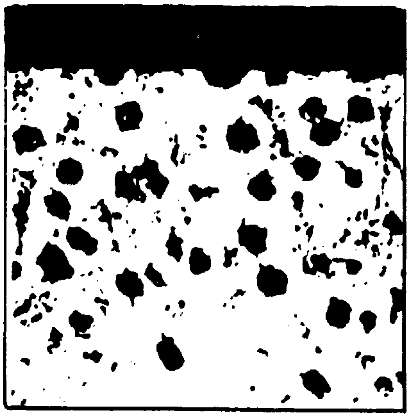


Fig. No. 6
Pearlite 50%

Mechanical Properties

	Tensile Strength Kg/mm	Elongation %	Hardness HBN
Planned	42.0	12 min.	150-200
Actual (average)	66.9	8.6	251

The reason for the low elongation was that the matrix was having more pearlite. The pearlite should be less than 25% whereas the actual percentage was 50%. The high percentage of pearlite was caused by the excessive manganese and chromium contents. It was later investigated and found that the high manganese was caused by the usage of the furnace previously for melting high manganese steel. Also the furnace lining was with chrome magnesite bricks instead of pure magnesite, which accounted for the presence of high chromium.

The complete data on this trial melting are given in Appendix-IV(a).

9.2 Trial No.2

The second trial was conducted on 14.5.83. To avoid the defects observed in the previous trial a newly relined furnace was used for melting. The lining was out of pure magnesite bricks only.

The same charge and other parameters were used as for the first trial. The initial melt showed a lower percentage of carbon (3.21%). Therefore, 125 kg of sorelmetal and about 10kg of graphite were added to increase the carbon percentage. The final base metal composition was :

C%	Si%	Mn%	Cr%
3.66	2.20	0.40	0.10

The temperature was then raised to tapping temperature (decided by observing the colour as the immersion thermo couple was not giving correct readings) and the metal was tapped to the magnesium treatment ladle. The same procedure as practised for the first trial was followed for magnesium treatment, inoculation and pouring. For the inoculation 1.6 Kg. of ferrosilicon was used instead of 1.2 Kg. used in the first trial.

The analysis of the sample pieces showed the following results :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5- 3.8	2.6- 2.8	0.4	0.01	0.06	0.010	0.10	0.03- 0.05
Actual (Average)	3.39	2.97	0.16	0.005	0.04	0.094	0.074	0.04

Microstructure

The microstructure showed completely spherodised graphite with a ferritic matrix (pearlite only 2-15%). The graphite nodules were fine (Nodule Count - 120 - 263 Nodules/mm^2). Typical microstructures obtained are shown in figs. 7 to 12.

Mechanical Properties

	Tensile Strength kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min	150 - 200
Actual (average)	51	19.75	175

All the data on trial No.2 are given in Appendix-IV(b).

9.3 Trial No. 3

The third trial was conducted in the presence of Mr. John Berry Wheeldon, expert from M/s. QIT Feret-Titane, West Germany. As per his suggestion the percentage of sorelmetal in the charge was reduced from 80% to 60%. The composition of the charge was as follows :

Microstructures of Trial No.2
Magnification X 100

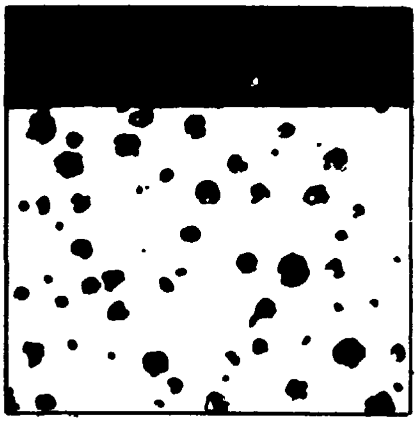


Fig. No. 7
Nodule Count: 255 N/mm^2

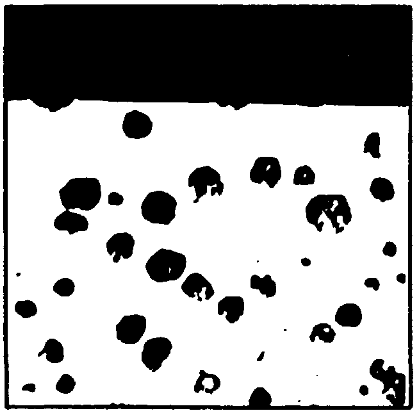


Fig. No. 8
Nodule Count: 153 N/mm^2

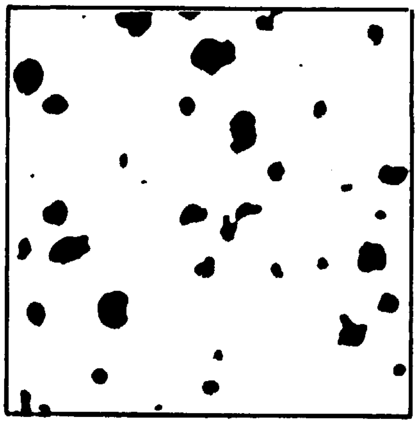


Fig. No. 9
Nodule Count: 120 N/mm^2

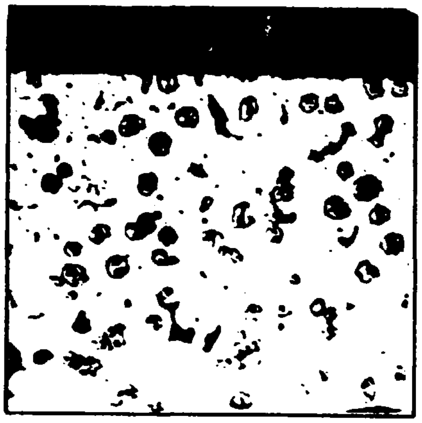


Fig. No. 10
Pearlite 2%

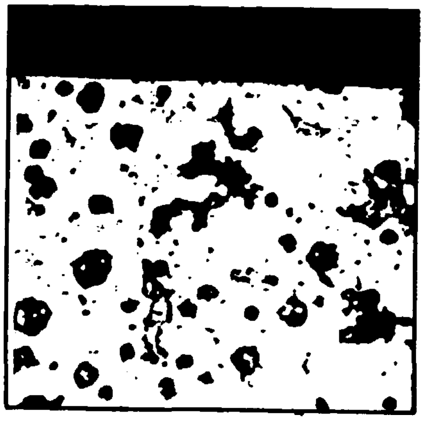


Fig. No. 11
Pearlite 5%

Fig. No. 12
Pearlite 15%

Pig Iron (Sorel metal)	-	900 Kg	-	60%
Steel Scrap (IK II)	-	600 Kg	-	40%
Ferrosilicon (75% Silicon)	-	40 Kg	-	-
Graphite (Anthrasite)	-	43 Kg	-	-

The melting, magnesium treatment inoculation and pouring were done in the same way as in the previous trials.

The results of the trial are as given below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.03-0.05
Actual (Average)	3.23	2.93	0.19	0.004	0.02	0.31	0.02	0.04

Microstructure

The microstructure showed completely spherodised graphite. The matrix was ferritic with only about 5 - 15% pearlite. Photographes of the microstructure are given in Fig. 13 to 18.

Microstructures of Trial No.3
Magnification X 100

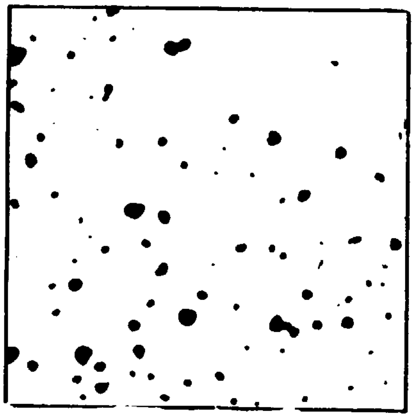


Fig. No. 13
Nodule Count: 351 N/mm^2

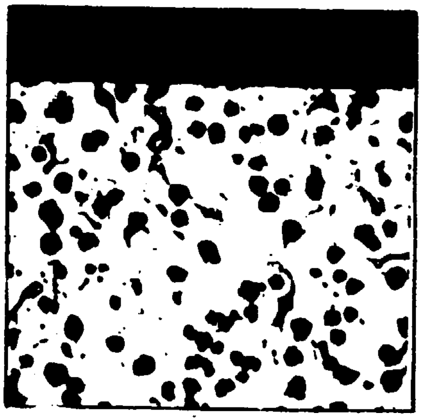


Fig. No. 16
Pearlite 5%

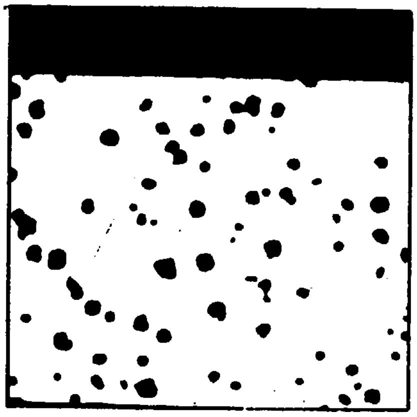


Fig. No. 14
Nodule Count: 238 N/mm^2

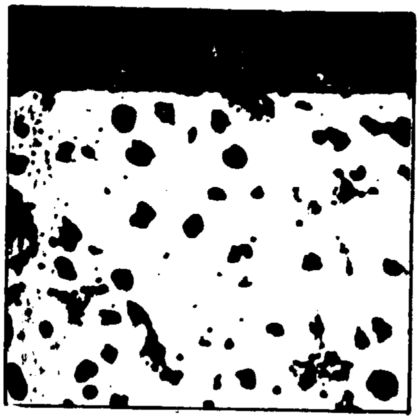


Fig. No. 17
Pearlite 5%

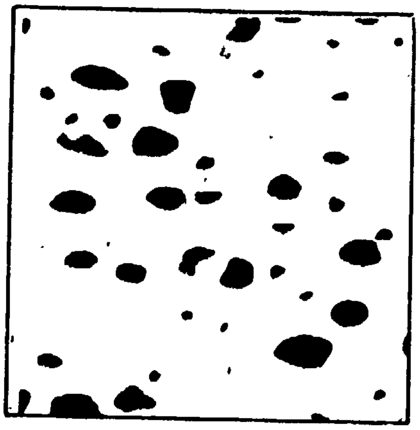


Fig. No. 15
Nodule Count: 154 N/mm^2

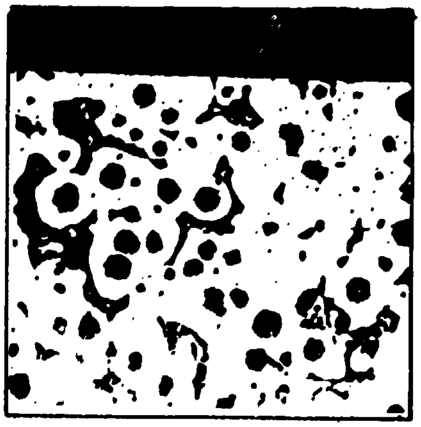


Fig. No. 18
Pearlite 15%

Mechanical properties

	Tensile Strength	Elongation %	Hardness HBN
Planned	42	12 min.	150 - 200
Actual (Average)	59	14.8	196

All the data pertaining to trial No.3 are given in Appendix - IV (c).

9.4 Trial No. 4

The trial No.4 was carried out in the same way as trial No.3. The raw material charge was :

Pig Iron (Sorel metal)	-	900 kg	60%
Steel Scrap (IK II)	-	600 kg	40%
Ferrosilicon (75% silicon)	-	39 kg	-
Graphite (2 mm thick powder)	-	38 kg	-

After preparing the base melt, before tapping 15 kg. of metallurgical grade of calcium carbide was added to desulphurise the melt. Finally 5 kg. of silicon carbide was added to compensate for the bad effects of overheating. Old silicon carbide grinding wheels were used for this purpose.

The results of the testing of the sample are give below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.6-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.03-0.05
Actual (Average)	3.51	3.08	0.16	0.006	0.06	0.25	0.028	0.03

Microstructure

The microstructure showed the shape of graphite as spheroidal. The matrix was highly ferritic, only about 2-5% pearlite. Some of the micro structures obtained are shown in figs. 19-24. The graphite spheriods were fine with a nodule count of about 178-283 N/mm^2.

Mechanical Properties

	Tensile Strength Kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min	150 - 200
Actual (Average)	54.5	17	199

Microstructures of Trial No.4
Magnification X 100

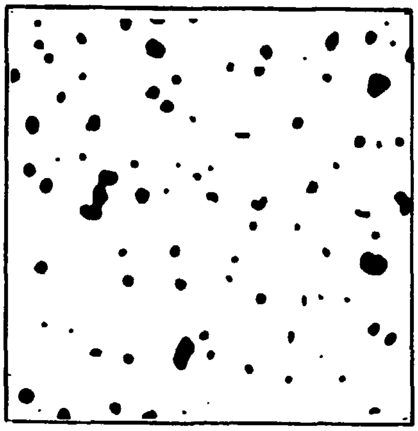


Fig. No. 19
Nodule Count: 283 N/mm^2

Fig. No. 22
Pearlite 2%

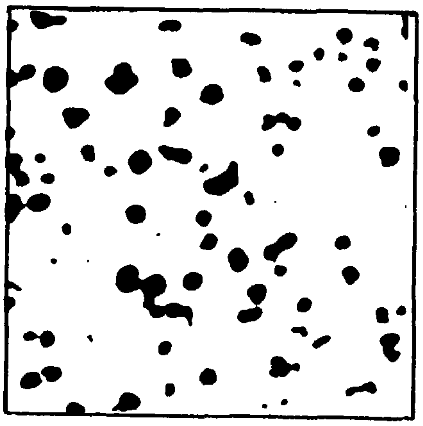


Fig. No. 20
Nodule Count: 248 N/mm^2

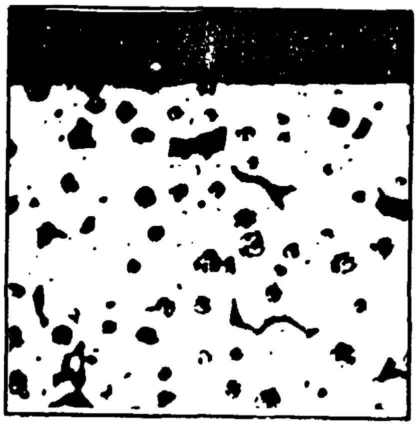


Fig. No. 23
Pearlite 3%

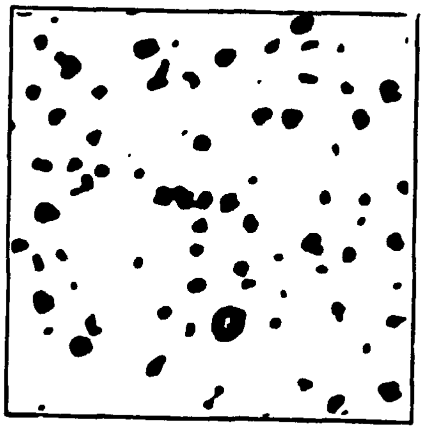


Fig. No. 21
Nodule Count: 178 N/mm^2

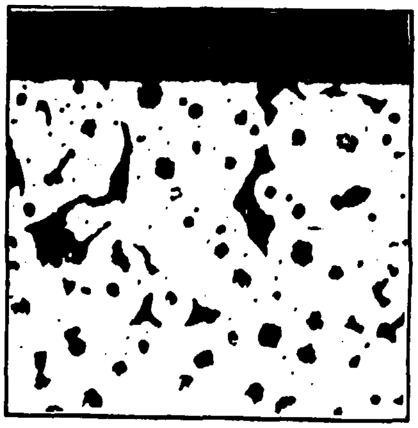


Fig. No. 24
Pearlite 5%

All the data on trial No.4 are tabulated in Appendix - IV (d).

9.5 Trial No. 5

Encouraged by the good results obtained in the previous trials, it was decided to reduce the special pig iron (Sonel metal) content to 50% Accordingly, the raw material charge consisted of :

Pig Iron (Sorel metal)	-	750 kg	50%
Steel Scrap IK-II	-	750 kg	50%
Ferrosilicon (75% Si)	-	35 kg	-
Graphite (as powder)	-	44 kg	-

The melting, magnesium treatment and pouring was carried out in the same way as for the previous trials. 15 kg. of calcium carbide and 5 kg. of silicon carbide were added before tapping.

During the melting two numbers of Chromemagnesite bricks fell down from the roof. This has caused high percentage of chromium in the base metal.

The results obtained from this trial are given below :

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.04	0.01	0.06	0.10	0.10	0.03-0.05
Actual (Average)	3.86	2.59	0.58	0.003	0.028	0.75	0.06	0.033

Microstructure

The microstructure continued predominantly spheroidised graphite. The matrix was ferritic with 80-90% ferrite and 10 - 20% pearlite. The photographs of typical microstructures obtained are given in Figs. 25 to 30.

Mechanical Properties

	Tensile Strength Kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min.	150 - 200
Actual	70	6.6	235

The complete data on trial No.5 are given in Appendix - 4 (e).

9.6 Trial No. 6

The same charge composition as for the previous trial was followed for the 6th trial.

Pig Iron (Sorel metal)	- 750 kg	- 50%
Steel Scrap (IK II)	- 750 kg	- 50%
Ferrosilicon (75% silicon)	- 35 kg	-
Graphite	- 38 kgs	-

Microstructures of Trial No. 5
Magnification X 100

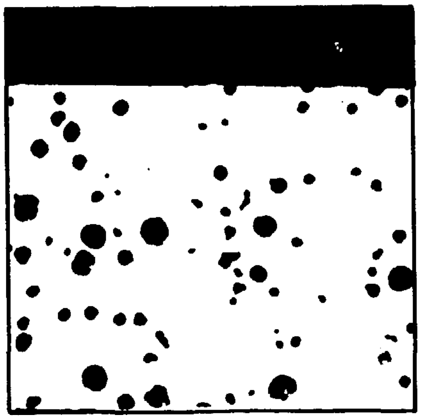


Fig. No. 25
Nodule Count: 259 N/mm^2

Fig. No. 26
Nodule Count: 238 N/mm^2

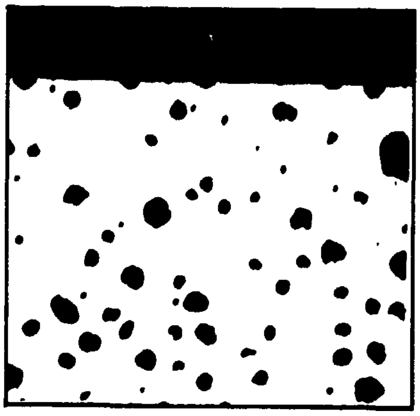


Fig. No. 27
Nodule Count: 209 N/mm^2

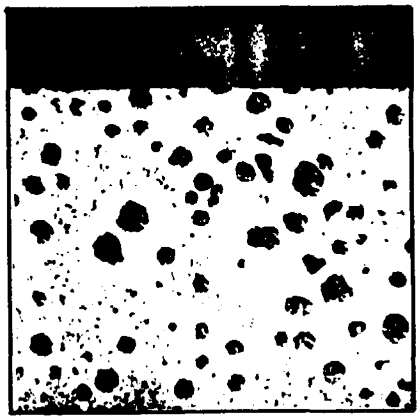


Fig. No. 28
Pearlite 10%

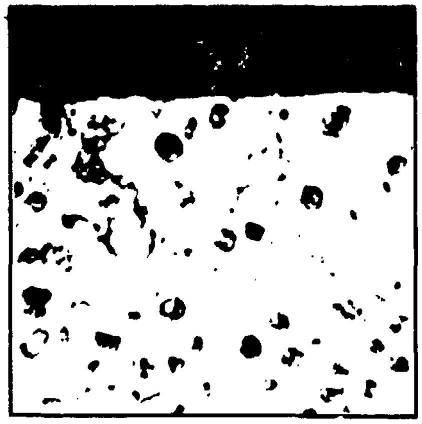


Fig. No. 29
Pearlite 20%

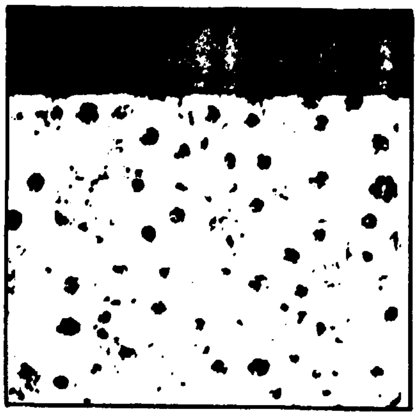


Fig. No. 30
Pearlite 20%

There was heavy slag in the metal. This may be due to insufficient cleaning of the furnace after the previous melting. The first tapping weight was not correct since the pit was not clean and the bottom of the ladle was touching the floor. The cover was damaged due to excessive slag.

The results obtained on the sample prices are given below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.03-0.05
Actual	3.5	2.8	0.23	0.005	0.04	0.5	0.5	-

Microstructure

The microstructure consisted of completely spheroidised graphite. The matrix was predominently ferritic, with 15-30% pearlite. Some of the microstructures obtained are shown in Figs. 31 to 36. The nodule count varied from about 134 to 157 N/mm^2.

Mechanical Properties

	Tensile Strength Kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min.	150 - 200
Actual (Average)	63	10.3	204

Microstructures of Trial No.6

Magnification X100

Fig. No. 31

Nodule Count: 157 N/mm^2

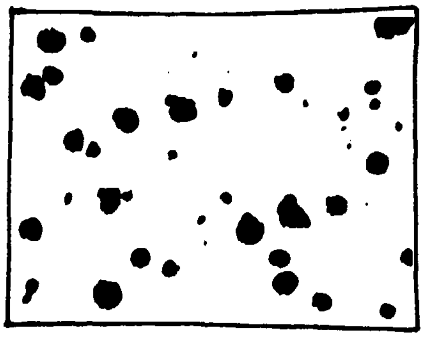


Fig. No. 32

Nodule Count: 145 N/mm^2

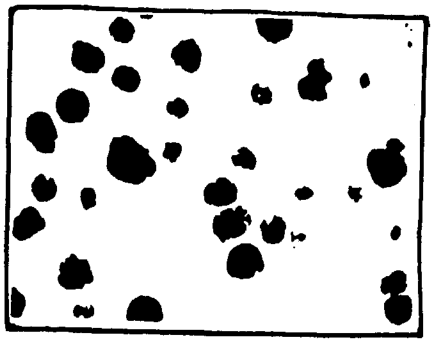


Fig No. 33

Nodule Count: 134 N/mm^2

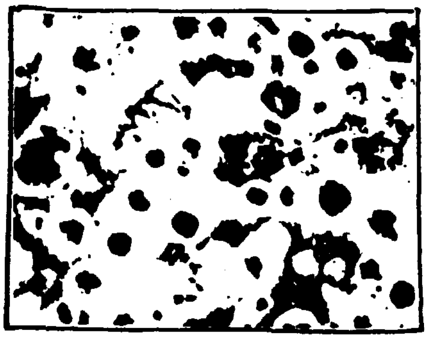


Fig. No. 34

Pearlite 15%

Fig No. 35

Pearlite 20%

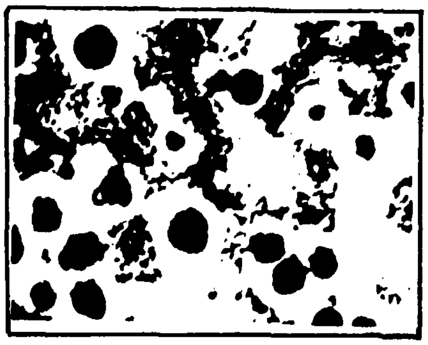


Fig. No. 36

Pearlite 30%

The complete data on the trial are given in Appendix - IV (f).

9.7 Trial No. 7

The same procedure as for the 6th trial was followed. The charge consisted of :

Pig Iron (Sorel metal)	- 750 kg	- 50%
Steel Scrap (IK-II)	- 750 kg	- 50%
Ferrosilicon (75% Si)	- 30 kg	-
Graphite	- 38 kg	-

The moulds for the sample pieces were not prepared properly. Hence, all the moulds collapsed when the metal was poured. So no sample piece was available. However, in order to get some idea about the trials, sample pieces were prepared from the risers. Hence, the values obtained for the mechanical properties are only indicative.

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.03-0.05
Actual (Average)	3.1	2.78	0.26	0.005	0.03	0.16	0.03	-

Microstructure

The microstructure consisted of predominently spherodised graphite. The matrix contained 15 to 30% pearlite and the balance ferrite. Typical photographs of the microstructures are given in Figs. 37 to 42. The graphite was coarse and nodule count varied from 55 to 116N/mm^2.

Mechanical Properties

	Tensile Strength kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min	150 - 200
Actual (Average)	49	6.22	170

All the date on the 7th trial are given in Appendix-IV (g).

9.8 Trial No. 8

Raw material charge

Pig Iron (Sorel Metal)	750 kg	50%
Steel Scrap (IK-II)	750 kg	50%
Ferrosilicon (75% Silicon)	35 kg	-
Graphite	38 kg	-

Microstructures of Trial No.7

Magnification X 100

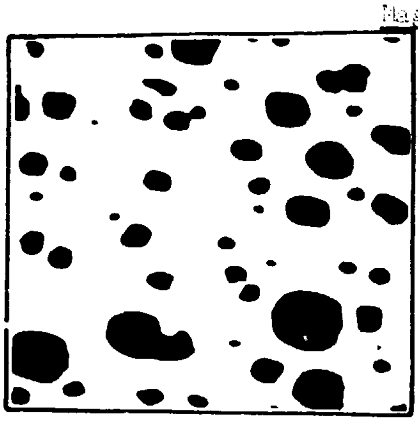


Fig. No. 37

Nodule Count: 116 N/mm^2

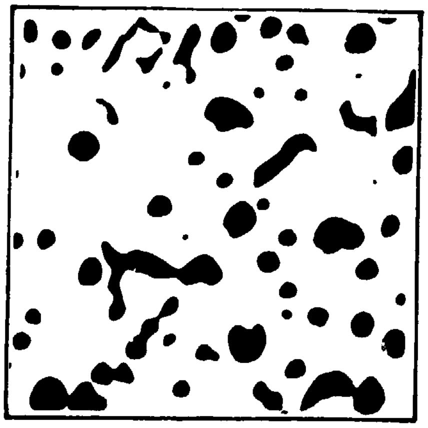


Fig. No. 38

Nodule Count: 90 N/mm^2

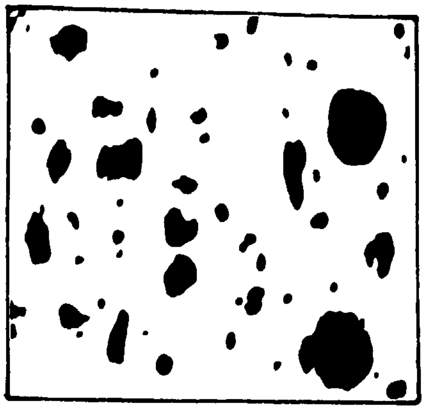


Fig. No. 39

Nodule Count: 55 N/mm^2

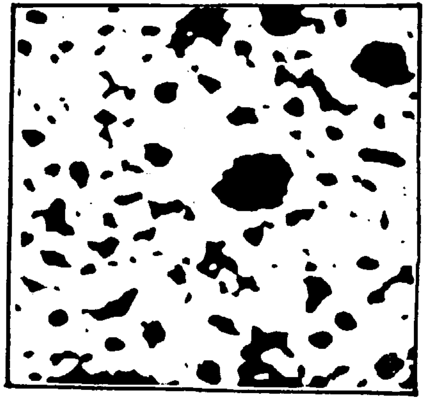


Fig. No. 40

Pearlite 30%

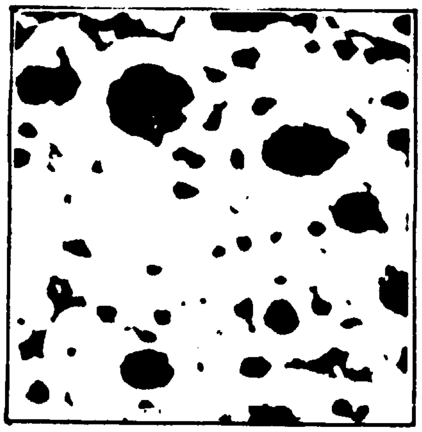


Fig. No. 41

Pearlite 20%

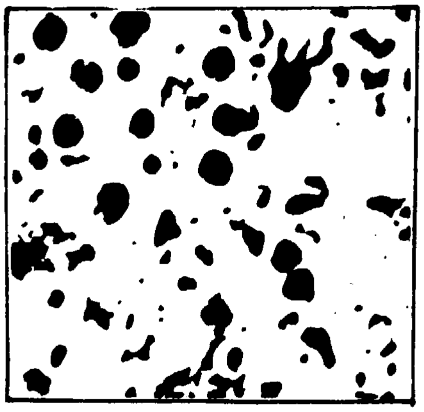


Fig. No. 42

Pearlite 15%

The melting was carried out in the same way as in the previous trials. The results obtained are given below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5- 3.8	2.6- 2.8	0.4	0.01	0.06	0.1	0.1	0.03- 0.05
Actual (average)	3.2	2.85	0.16	0.003	0.035	0.22	0.04	-

Microstructure

The microstructure consisted of completely spherodised graphite in a ferritic matrix. The pearlite was very coarse. The nodule count varying from 34 to 68 N/mm^2. Typical photographs of the microstructures are given in Figs. 43 to 48.

Mechanical Properties

	Tensile Strength Kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 min.	150 - 200
Actual (Average)	50	12.1	201

Microstructures of Trial No.8

Magnification X 100

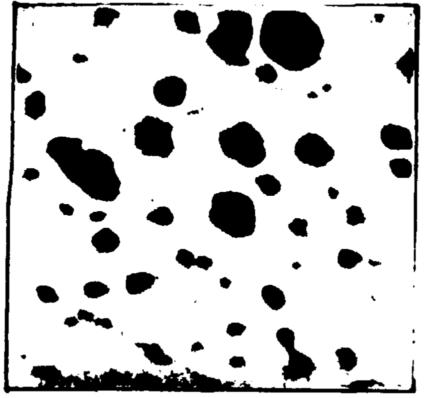


Fig. No. 43

Nodule Count: 68 N/mm^2

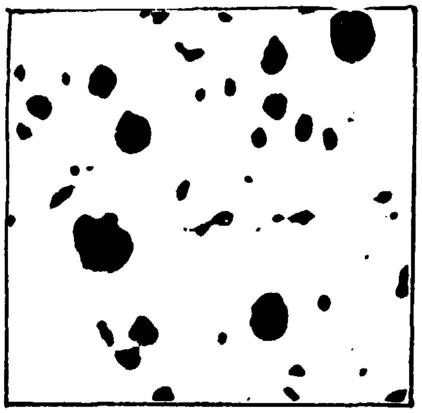


Fig. No. 44

Nodule Count: 50 N/mm^2

Fig. No. 45

Nodule Count: 34 N/mm^2

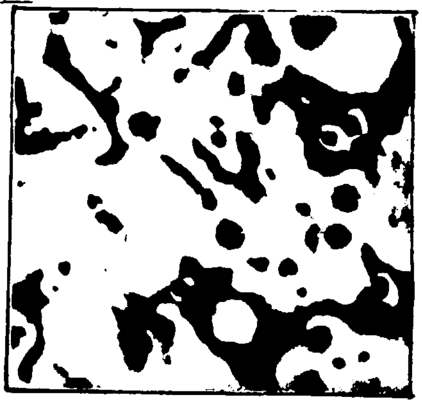


Fig. No. 46

Pearlite 30%

Fig. No. 47

Pearlite 10%

Fig. No. 48

Pearlite 5 %

The details of the trial are given in Appendix-IV(h).

9.9 Trial No. 9

The raw material charge consisted of :

Pig Iron (Sorel metal)	-	750 kg	50%
Steel Scrap (IK-II)	-	750 kg	50%
Ferrosilicon	-	28 kg	-
Graphite	-	38 kg	-

The same procedure was followed for melting. Heavy slag was present in the metal probably due to the fact that the slag has not been removed completely from the previous melt.

The results obtained are given below :

Chemical Composition

	C%	Si%	Mn%	S%	P%	Cr%	Ni%	Mg%
Planned	3.5-3.8	2.6-2.8	0.4	0.01	0.06	0.10	0.10	0.08-0.05
Actual (Average)	3.2	2.7	0.1	0.005	0.025	0.07	0.15	-

Microstructure

The microstructure consisted of completely spheroidised graphite. The matrix was predominently ferritic with only 5 - 15% pearlite. The graphite was coarse, the nodule count being 43 to 113 N/mm^2. Typical photographs of the microstructure are given in Figs. 49 to 54.

Mechanical Properties

	Tensile Strength Kg/mm^2	Elongation %	Hardness HBN
Planned	42	12 Min.	150 - 200
Actual (Average)	52	18.4	168

All the details of the trial are given in Appendix - IV (i).

Microstructures of Trial No.9

Magnification x 100

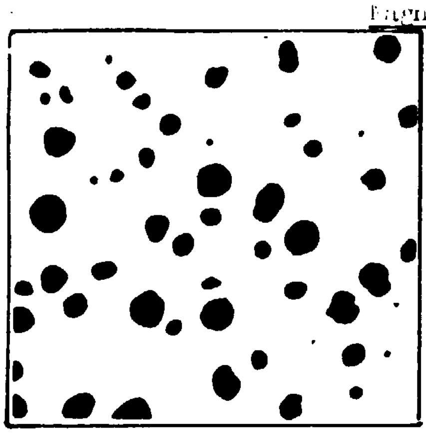


Fig. No. 49

Nodule Count: 113 N/mm^2

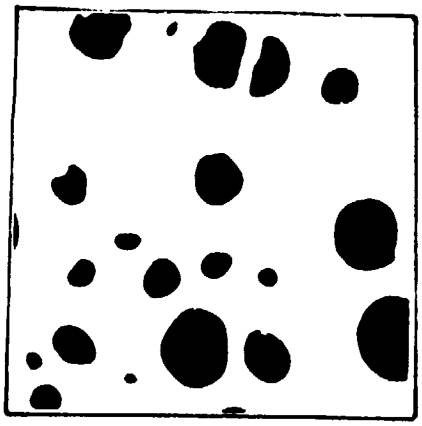


Fig. No. 50

Nodule Count: 52 N/mm^2

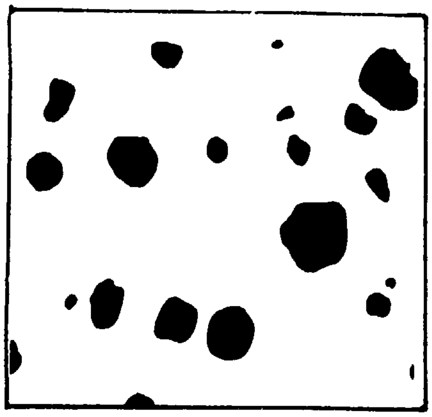


Fig. No. 51

Nodule Count: 43 N/mm^2

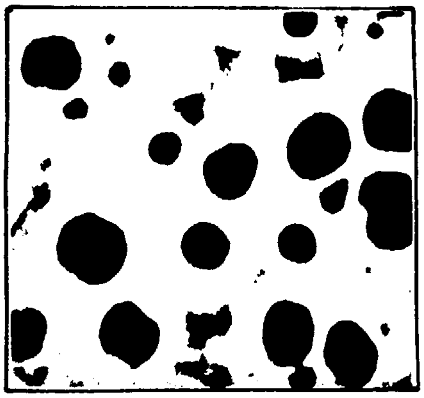


Fig. No. 52

Pearlite 15%

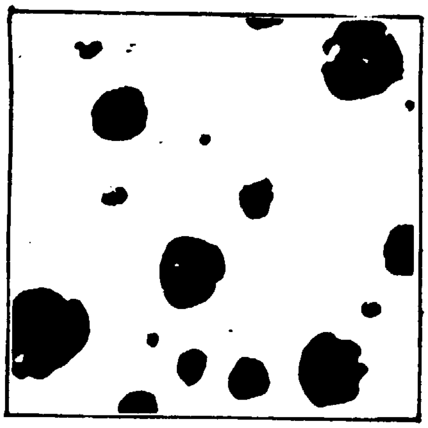


Fig. No. 53

Pearlite 10%

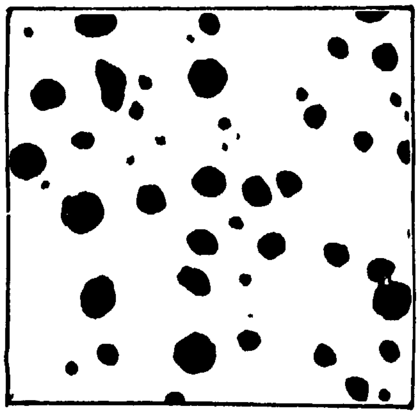


Fig. No. 54

Pearlite 5%

10. DIFFERENT STAGES OF MELTING S.G. IRON - PHOTOGRAPHS

Photographs of the different stages of melting S.G. Iron are given in Figs. 55 to 71

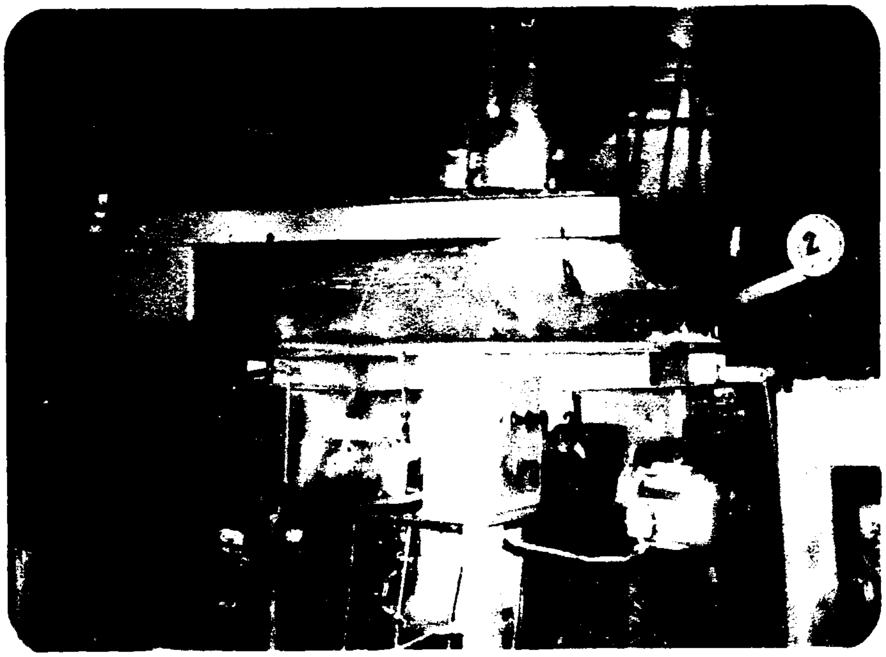


Fig. 55 THE FURNACE USED FOR MELTING S. G. IRON

Fig. 56 PREHEATING OF THE SPECIAL LADLE

Fig. 57 TUNDISH COVER-WITHOUT LINING

Fig. 58 TUNDISH COVER-AFTER LINING

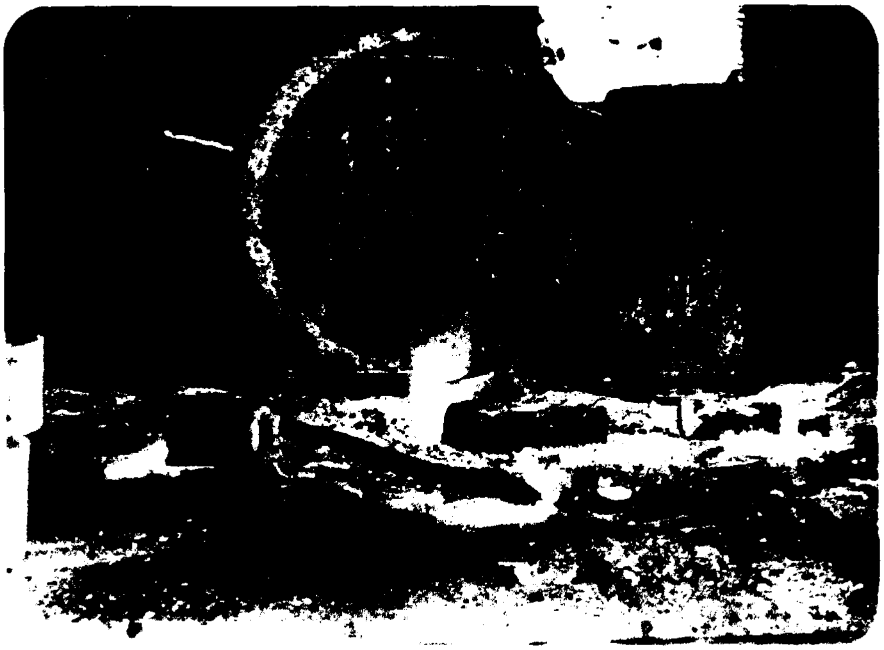


Fig. 59 PREHEATING OF THE TUNDISH COVER & POURING LADLE

Fig. 60 MELTING IN PROGRESS

Fig. 61 TEMPERATURE MEASURING

Fig. 62 KEEPING THE MAGNESIUM ALLOY IN THE POCKET OF THE SPECIAL LADLE

35.01.16

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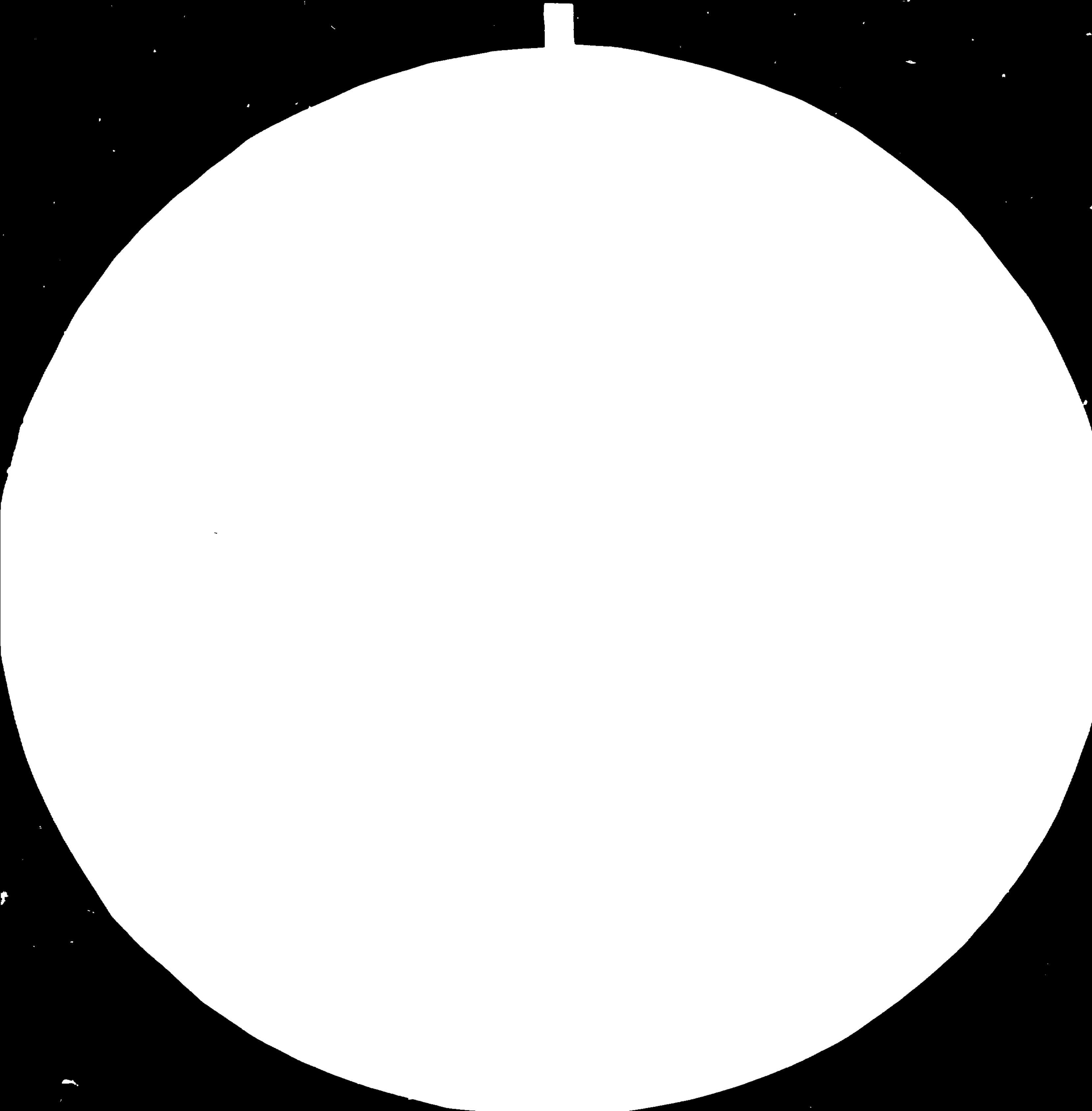
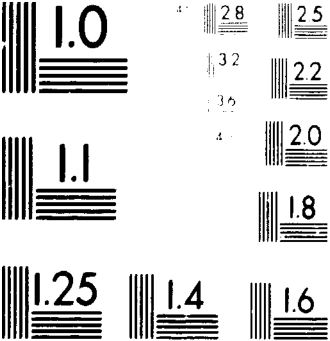




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

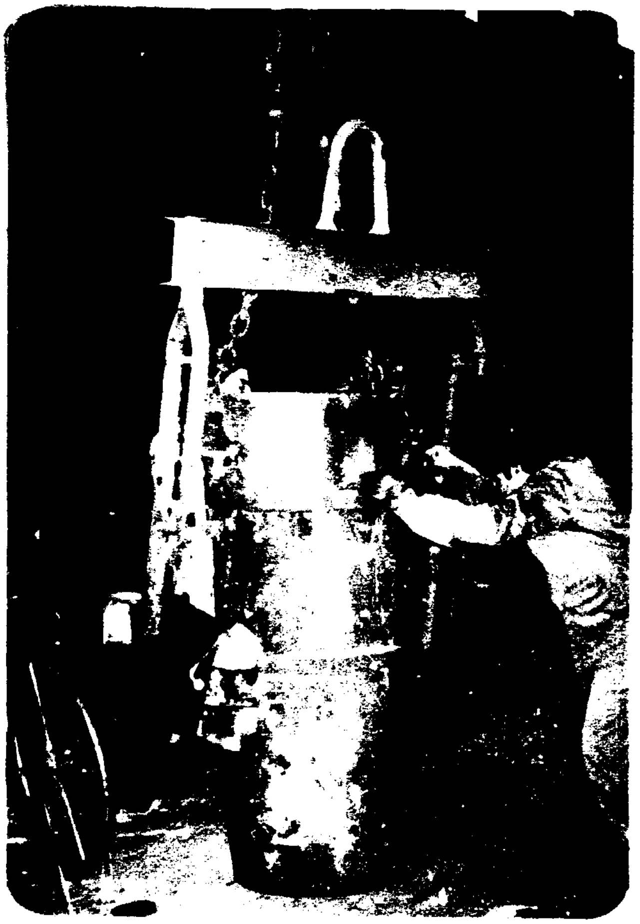


Fig. 63 PLACING THE TUNDISH COVER AFTER CHARGING THE MAGNESIUM ALLOY & STEEL SCRAP

Fig. 64 TAPPING OF METAL INTO THE SPECIAL LADLE

Fig. 65 TRANSPORTING THE LADLE AFTER TAPPING INTO THE POURING STAND

Fig. 66 PLACING THE LADLE ON THE POURING STAND AFTER TAPPING

Fig. 67 BEGINING OF TRANSFERING METAL INTO POURING LADLE

Fig. 68 INOCULATION OF THE METAL DURING TRANSFER TO POURING LADLE

Fig. 69 REMOVING THE SLAG FLOATING ON THE METAL

Fig. 70 POURING INTO MOULDS

Fig. 71 GLARE & FUMES PRESENT WHEN USING LADLE WITHOUT TUNDISH COVER

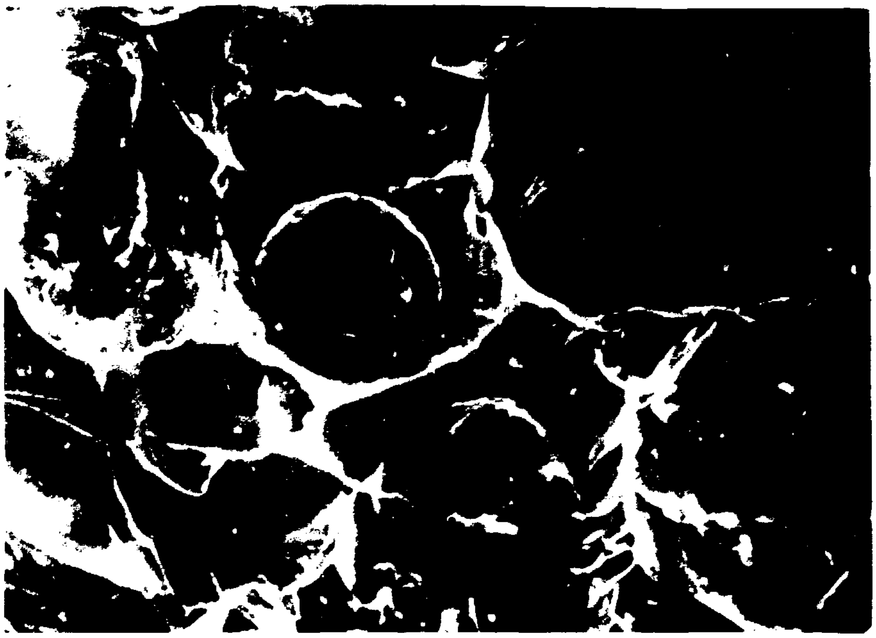


Fig. 72 SCANNING MICROSCOPE PHOTOGRAPH SHOWING THE GRAPHITE GLOBULES AT x 1000 MAGNIFICATION

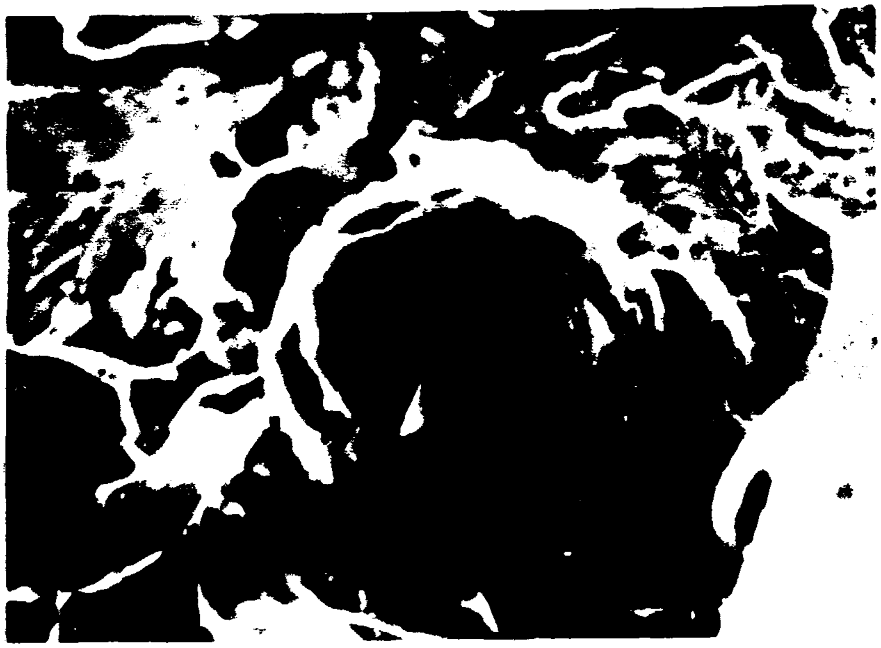


Fig. 73 SCANNING MICROSCOPE PHOTOGRAPH SHOWING THE GRAPHITE GLOBULES AT × 2000 MAGNIFICATION

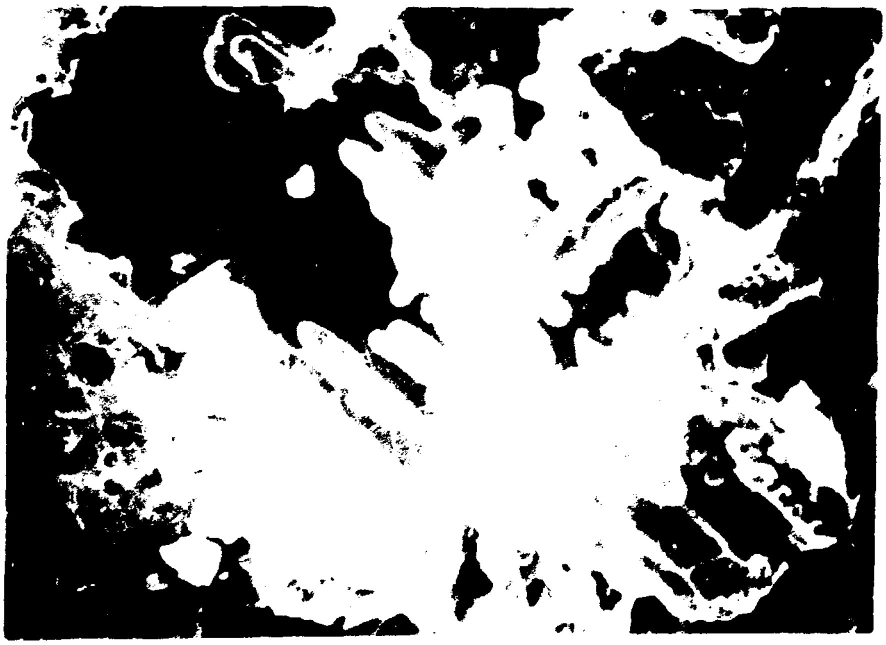


Fig. 74 SCANNING MICROSCOPE PHOTOGRAPH SHOWING THE POROSITY AT × 1000 MAGNIFICATION

11. EVALUATION OF THE RESULTS

11.1 In all the trials the graphite obtained is spheroidal. This shows that the magnesium treatment is proper.

11.2 Except for the first trial the matrix structure is predominantly ferritic, which is necessary to obtain the required percentage of elongation. Hence, no heat treatment for the castings is necessary.

11.3 It is necessary to control the percentages of manganese and chromium and in two trials the elongation values obtained are low due to high percentages of manganese and chromium.

11.4 Sample pieces from the first and second trials were sent to M/s. Sorel metal Research Department and their report confirmed that the S.G. Iron produced is of high quality and that it is suitable for tractor parts. A copy of the report received from them is enclosed as Appendix - V.

11.5 Few sample pieces from the later trials were sent to M/s. Zetor, Czechoslovakia for their expert opinion. They also agreed with the results obtained at SEMI. Copy of their report is enclosed as Appendix - VI.

11.6 The fracture surface of the S.G. Iron sample was inspected using scanning microscope and it was found that the graphite is almost of egg shape. Photographs of the graphite obtained with scanning microscope are given in Figs. 72 to 74.

11.7 In all the trials the tensile strength obtained is above the minimum requirement of 42 kg/mm^2.

11.8 The hardness values obtained in two trials are above 200 HBN. This was due to the pearlitic structure or due to the presence of carbides formed by the high percentage of chromium.

11.9 A few castings were tried in the CNC machining centres and it was found that the machinability of these castings were superior to that of steel castings.

11.10 The values of elongation obtained are within the acceptable minimum for all the trials except for trials nos. 1, 5, 6 & 7. The reason for the low values in these trials is the presence of higher percentage of manganese and/or chromium.

11.11 The size of the graphite particles are coarse to medium. The main reason for the coarse graphite is the prolonged melting time and the eventual overheating of the metal

12. RECOMMENDATIONS

12.1 The stock of special grade pig iron (Sorel metal) required for the production of S.G. Iron was limited and hence it was sufficient only for a few trials. Further quantity of this material has been ordered. This should be followed up and further melts should be produced to stream-line the process and to continue regular production.

12.2 It was observed during the trials that the operators for the melting furnace were changed each time. As the melting of S.G. Iron is a highly specialised process, the operators should not be changed often. The operators should be trained properly and they should be retained for this purpose.

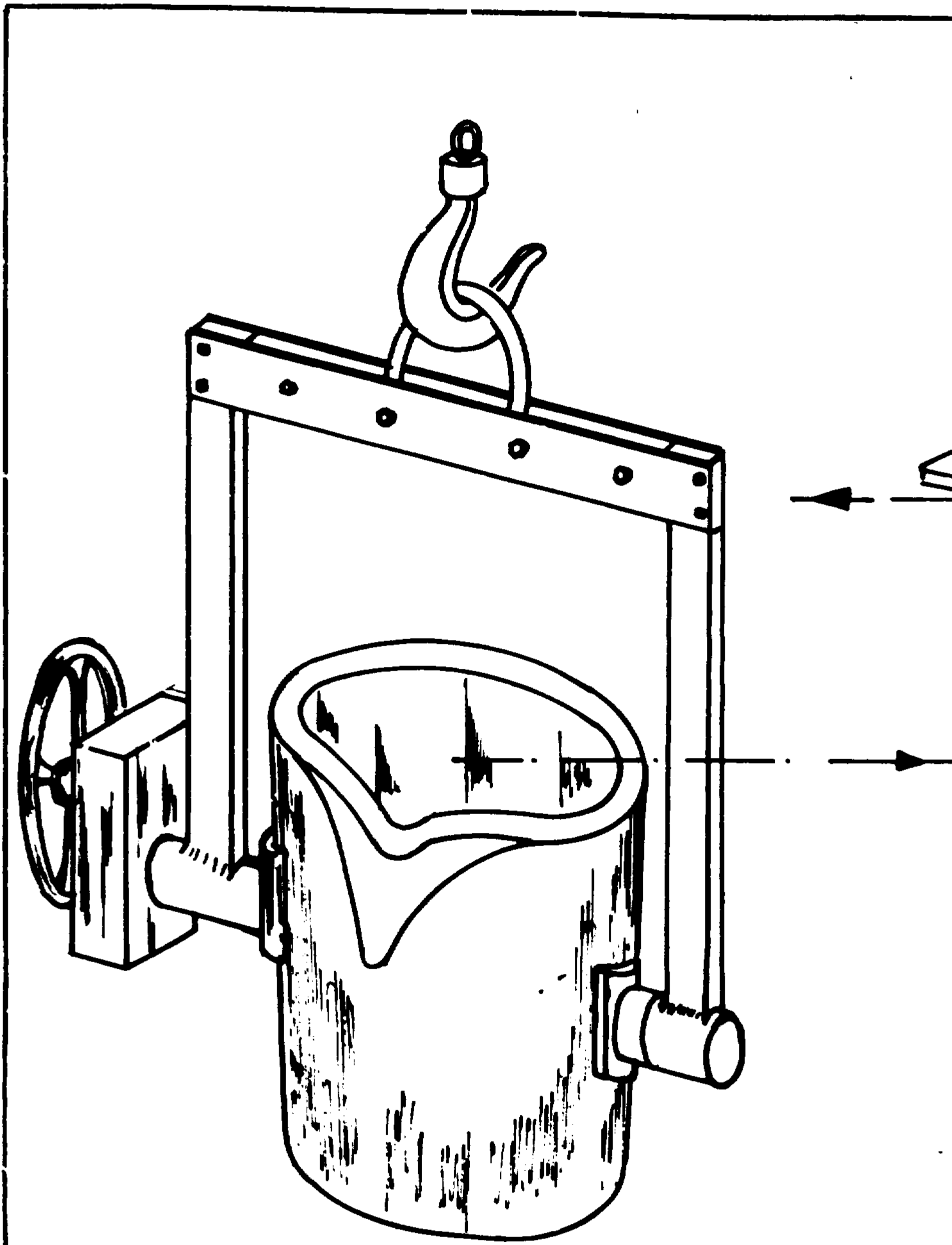
12.3 It is recommended that one arc furnace is kept exclusively for melting S.G. Iron as melting of other metals will cause contamination of S.G. Iron. In case it is not possible to set off one furnace exclusively for S.G. Iron, the melting should be so scheduled that the S.G. Iron melting is carried out continuously to cover two or three months requirements at a time.

12.4 The shrinkage of S.G. Iron is less when compared with that of steel casting. Therefore S.G. Iron requires less risering resulting in higher casting yield. In order to take advantage of this, the patterns of steel _ castings should be suitably modified or new patterns manufactured for S.G. Iron with a view to get higher casting yield.

12.5 The conversion to S.G. Iron should not be limited to the three components selected now. It is possible to convert advantageously to S.G. Iron many other components which are presently produced from steel casting or forgings. Hence a systematic study has to be conducted to identify further components which can be changed over to S.G. Iron.

12.6 During the trials the tundish cover was lifted separately after the magnesium treatment and placed back for the next treatment. This involves additional time lapse as well as lot of inconvenience. In order to avoid this delay and inconvenience, a simple arrangement as shown Fig.75(a) & (b) can be used for removing and replacing the cover.

12.7 The present melting equipment ie., Direct Arc Melting Furnace, is least desirable for the production of good quality S.G. Iron due to its inherent limitations. Hence, when the volume of production increases (say above 250 tons/year) the arc furnace should be replaced with induction melting furnaces.



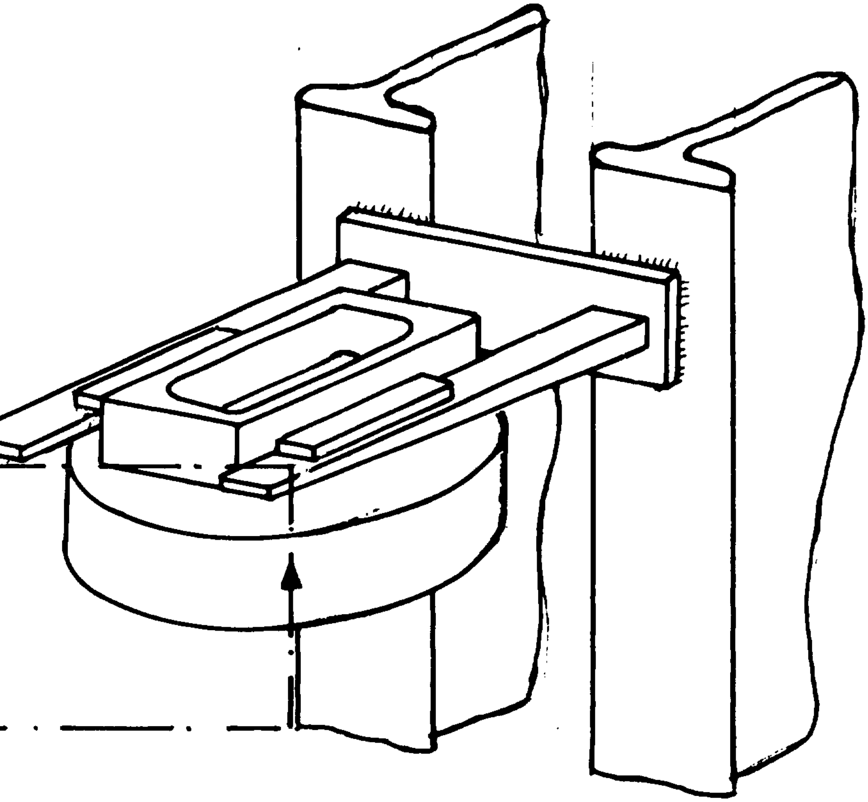
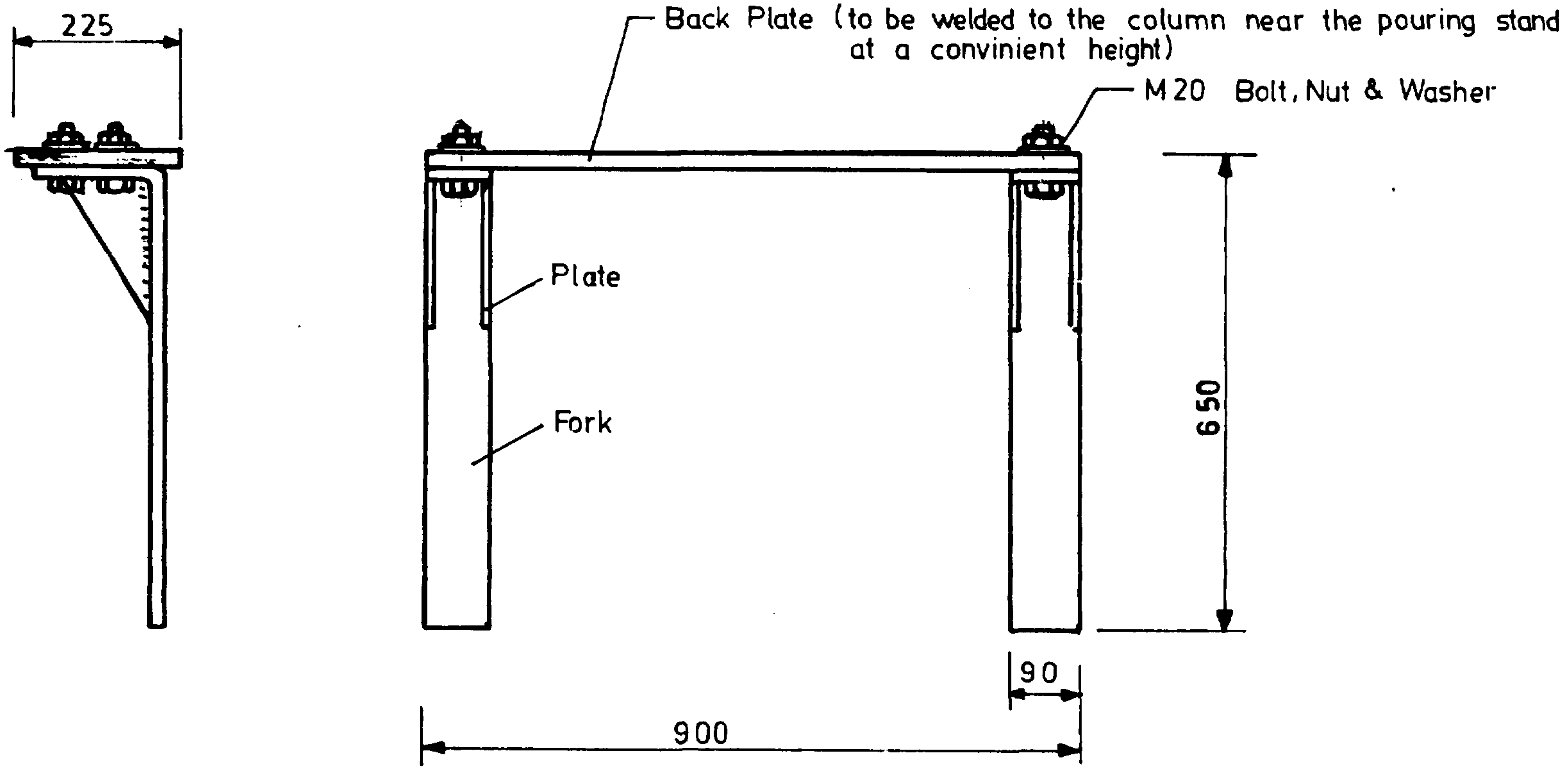


Fig. 75(a) - Arrangement for removing & replacement of Tundish Cover.



Fic. 75(b) - Tundish Cover Stand

References

1. Ductile Iron, American Foundryman's Society; Molten Metal Processing

2. AFS - Molten Metal Processing Committee - 12-H

3. Improved Ladle Treatment of Ductile Iron by means of the Tundish Cover, R.D. Forest, AFS Transaction V 88, 1980, P. 421

4. The progress and Industrial Acceptance of the covered Ladle for Ductile Iron Production J. British Foundrymen V.75, Part 4.

APPENDIX

Appendix I - Technical Conditions for acceptance of S.G. Iron Castings

Appendix II - Procedure for trial melting of S.G. Iron

Appendix III - Schedule for trials of S.G. Iron Production

Appendix IV - Manufacturing Data - S.G. Iron Castings

Appendix V - Expert opinion - M/s. Sorel Metal

Appendix VI - Expert opinion - M/s. Zetor

* * *

APPENDIX - I

This technical conditions of acceptance covers castings of Spheroidal Graphite Iron (also called Nodular or Ductile Iron) which is defined as cast iron with the graphite substantially spheroidal in shape and essentially free from other forms of graphite.

The castings will be accepted by the quality control department in the foundry based on the inspection of the following:

A. Chemical analysis, mechanical properties and metallurgical conditions. However, the chemical analysis and metallurgical conditions are not binding unless otherwise agreed upon between the foundry and mechanical workshop.

B. External surface defects of the castings inspected with naked eye and with magnetic flaw detector/dye penetrant.

C. Internal soundness of the castings by using Ultrasonic/X-Ray Equipment.

D. Dimensional accuracy inspected with gauges and measuring instruments.

EXPLANATIONS

A. 1. The chemical composition of S.G. Iron varies with the type of casting, dimensions of the casting and the production method. Hence, the chemical composition is not a binding condition for the acceptance of the casting.

2. The mechanical properties should be as per the following table:

Grade of Casting	Tensile Strength Minimum N/mm^2	0.2% Proof Stress Minimum N/mm^2	Elongation Minimum %	Hardness HBN
42/12	420	280	12	150-200
42/5	420	280	5	150-200

3. The graphite should be substantially spheroidal in shape and essentially free from other forms of graphite. The matrix should be predominantly ferrite.

Remarks

- The above tests will be carried out on test sample pieces supplied along with the castings.
- The test samples for tensile testing should be cast as per ISO 1083, U-Block Type II b.
- The test sample should be cast separately.
- The test sample should be poured from the same ladle of metal as that used to produce the castings.
- The test sample should be cast in dry sand moulds and stripped at a temperature not exceeding 500°C.
- One test sample should be supplied for each batch of casting. A batch consists of castings poured from the metal magnesium treated at one time.
- The castings and test samples should be identified with suitable marking so that the castings whose samples do not comply with the requirements can be easily identified and removed.

- In the case of carrying out heat treatment for the castings, the test sample should also be subjected to the same heat treatment along with the castings.
- By agreement between the foundry and manufacturing section/quality control section, hardness can be tested at any particular location on the casting.
- In case for any reasons it is not possible to get reliable results for mechanical properties from the sample piece, an actual casting may be used for the testing.
- The required mechanical and metallurgical properties may be also obtained by heat treatment.

B. 1. The surface of the castings shall be free from mould and core sands and shall be reasonably smooth. Runners, risers, fins and other cast-on pieces shall be removed.

2. In the absence of any requirement to the contrary, minor casting defects such as small sand spots and slaggy patches, small cold shuts, minor buckles and blemishes may either be left as they are or removed by dressing out.

3. The maximum amounts of projection or depression on the surface after removing the risers, feeders, fins, etc., should not exceed the values given in the following table:

Maximum Dimension of the casting mm	On surfaces with no machining		On surfaces to be machined	
	Height of Projection mm	Depth of Depression mm	Height of Projection mm	Depth of Depression mm
Upto 200	3	2	2.5	1.5
201-500	4	3	3.5	3.5
500	5	4	5.0	6.0

4. Cutting-off of risers, feeders, fins, etc. by flame is not recommended. However, if flame cutting is adopted the casting has to be suitably heat treated after cutting to ensure that the proper mechanical and metallurgical properties are retained.

5. The casting should be free from chilled edges and distortion.

6. Minor surface defects (except in critical portions of the castings) can be repaired by welding. However, the suitable procedure for the welding of SG Iron should be followed and the castings should be subjected to suitable heat treatment after welding.

C. 1. The castings should be free from blow holes and other internal flaws.

2. Castings will be rejected if the porosity depth exceeds 25% of the casting wall thickness, diameter exceeds double the depth and the total area is more than 10% of the total area of corss section of the casting.

3. The depth of porosity on the surfaces to be machined should not exceed the machining allowance.

D. 1. The dimensions of the casting should be as per drawing. The maximum allowable deviations on dimensions where there is no machining are given in the table shown below. In the case of dimensions with machining allowance, the deviation should be less than 2/3rd of the machining allowance.

The maximum dimension of casting - mm	The allowable deviation for casting - mm
Upto 200	1.5
200-400	2.0
> 400	4.0

2. The maximum deviation allowed for holes which are to be machined is 2/3rd of the machining allowance.

APPENDIX - II

PROCEDURE FOR TRIAL MELTING OF S.G. IRON

First Trial

The metal of the first trial should be used for the cleaning of the furnace and ladles and also for checking the melting losses, time required for pouring, cooling rate of molten metal etc. Though this melt cannot be used as S.G. Iron production, the melting, treating and pouring procedures stipulated below should be strictly followed.

Raw Material Charging

The weights of the raw materials to be charged are given below. These weights are for a melt of 1500 Kg.

Sorel metal	-	1200 Kg.
Steel scrap (S35C from screw shop)	-	300 Kg.
Graphite (Broken pieces of electrode size 6-20 mm)	-	13 Kg.
Ferrosilicon (75% Silicon)	-	39 Kg.

The raw materials should be weighed correctly using accurate balances (accuracy min ± 20 Kg. for pig iron & steel scrap and ± 0.10 Kg. for other materials). The steel scrap should be taken directly from the screw shop so that is no chance of any mix-ups with other scraps.

Melting

The furnace to be used should be basic lined. The hearth should be lined with pure magnesite (Mgo) bricks instead of chrom magnesite bricks. The furnace should be as clean as possible from the previous melt. The properly weighed charge should be loaded into the furnace using the drop bottom loading device.

As soon as the melting is completed (at about 1250°c) samples should be taken for chemical analysis. The carbon and silicon should be checked first. If the carbon and silicon percentages are low necessary correction should be made by adding graphite pieces/ferrosilicon. But as far as possible, the correction should be avoided and the required composition should be obtained by the proper control of the charge. (For testing the silicon the rapid silicon determinator from the Institute should be shifted to SEMI as the silicon tester in SEMI is not working).

After the correction of carbon and silicon, a final sample is taken and analysed for C, Si, S, P, Cr, Mn, Ni, Pb and Cu. The composition of the metal should be

C	Si	Mn	P	S
3.5 - 3.8%	1.6-1.8%	0.4%	0.06%	0.02%
Cr	Ni	Cu	Pb	
0.10%	0.10%	0.10%	0.002%	

Only the carbon and silicon are adjusted to be within the range and the percentages of other elements should be below the maximum limit as melted.

Desulphurisation

In case the sulphur percentage exceeds 0.02, desulphurisation should be done. It is very difficult to carryout desulphurisation in an arc furnace. Hence in this case, the sulphur content of the melt should be obtained below 0.02% by the proper selection of raw materials so that no desulphurisation is needed.

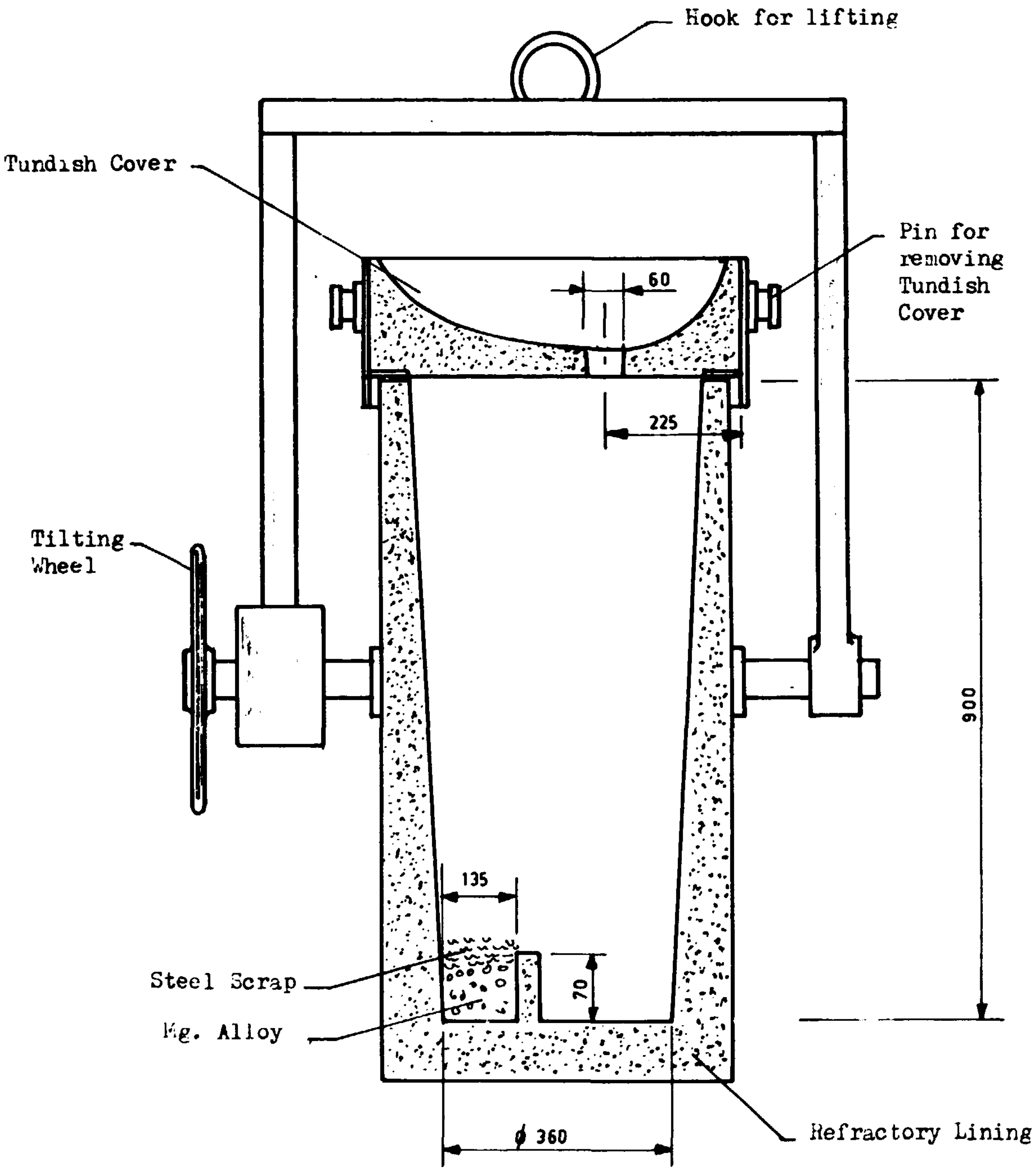
However, if for any reason the desulphurisation has to be done, then the following procedure should be used. The desulphurisation has to be done in the furnace before the tapping of the metal. 9 Kg. of metallurgical grade of calcium carbide should be added into the furnace and allowed to react with molten metal. After 15 minutes, the reaction will be completed and sludge will float on the surface. When the reaction is complete, there will be a drop in temperature. The metal should be heated to the required tapping temperature. After the desulphurisation a sample should be taken to analyse the chemical composition.

Tapping

After the desulphurisation is completed and the metal composition is found to be alright, the metal should be heated to the required tapping temperature. The temperature should be checked with the immersion thermo-couple and the tapping should be done at a temperature of 1500°C. The tapping temperature is worked out assuming certain cooling rate for the molten metal and certain time lapse between the tapping and pouring so that the pouring temperature will be between 1360°C and 1420°C. In case a difference is observed in the pouring temperature, the tapping temperature should be corrected accordingly. 500 Kg. of metal should be tapped directly into the magnesium treatment ladle, using a suitable accurate balance for weighing the molten metal.

Magnesium Treatment

The special ladle for magnesium treatment should be manufactured as per drawing No.001. The ladle should be clean and well pre-heated. At the bottom of the ladle, in the pocket, 7.0 Kg.. of Ferrosilicon-magnesium alloy containing 9% Magnesium, 45% silicon and 0.5% Ce should be placed. The alloy should be covered with 7.5 Kg. . of clean steel scrap or small pieces of steel plates. The alloy should be weighed correctly using an accurate balance. The tundish cover should be placed on the ladle, ensuring



SPECIAL LADLE FOR Mg. TREATMENT

TUNDISH COVER METHOD - CONVENTIONAL

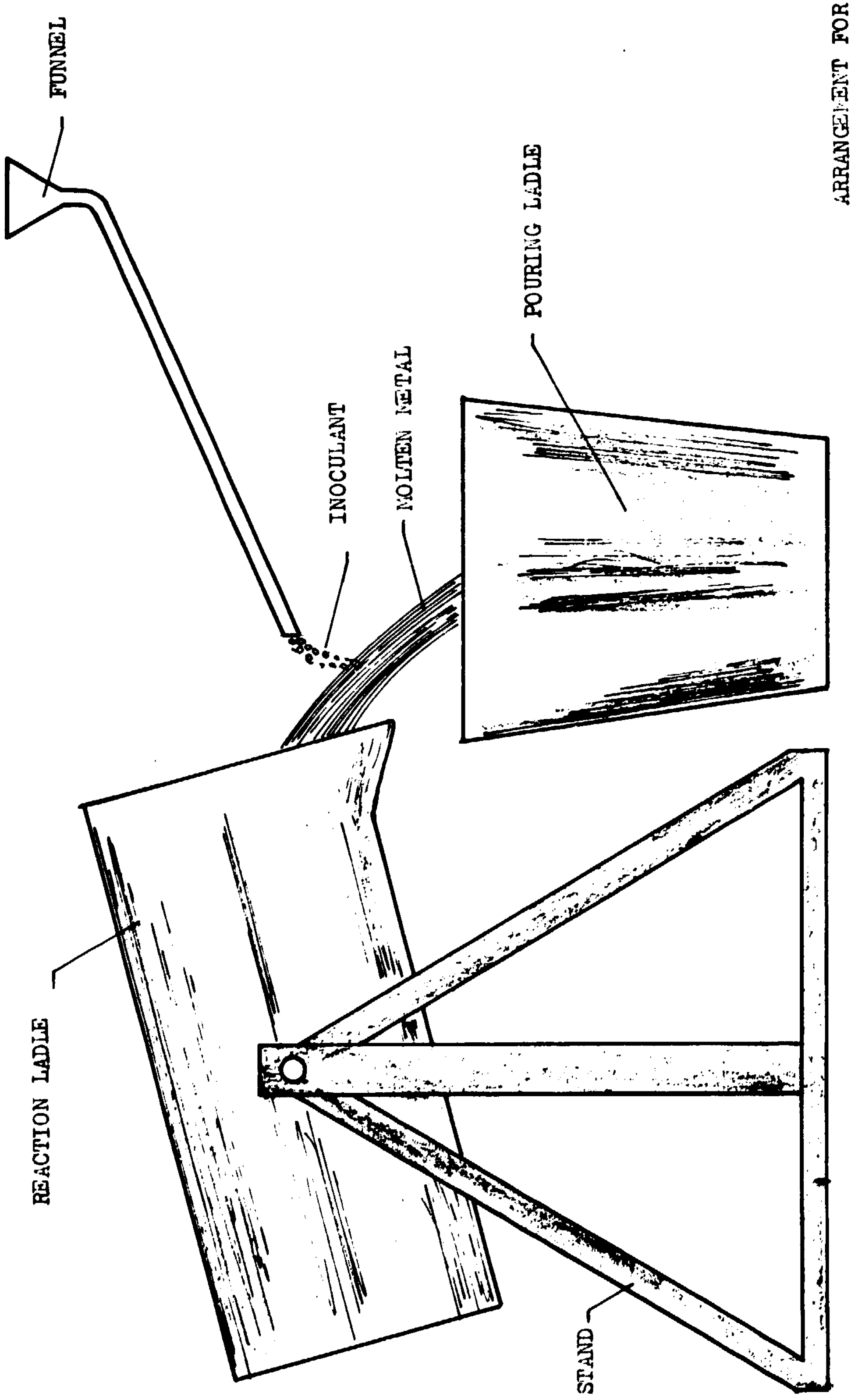
DRG. NO. 001

that the hole in the pouring basin of the cover is not directly above the Mg alloy pocket, but on the opposite side.

The tapping time should be approximately 20 Secs. The temperature of the metal at the time of treatment ie. at the time of tapping into the tundish cover should be measured with an optical pyrometer. The temperature should be within the range 1480 - 1500°C. The magenesium reaction time is about 25 seconds and after the reaction the tundish cover should be removed and the slag skimmed off thoroughly. The metal is now ready for being transferred into the pouring ladles.

Inoculation

The metal after magnesium treatment should be inoculated before pouring into the moulds. The inoculation should be done during the transfer of the metal from the reaction ladle (stream inoculation). The arrangement is shown in drawing No.OC2. The inoculant to be used is ferrosilicon with 75% silicon content and the particle size should be 4 - 12 mm. 160 Kg. of the metal should be transferred into the pouring ladle and this should be inoculated with 1,6 Kg. of the ferrosilicon alloy. Care should be taken to ensure that the addition of the alloy starts only after the pouring started and is completed before the pouring of the metal into the pouring ladle is finished.



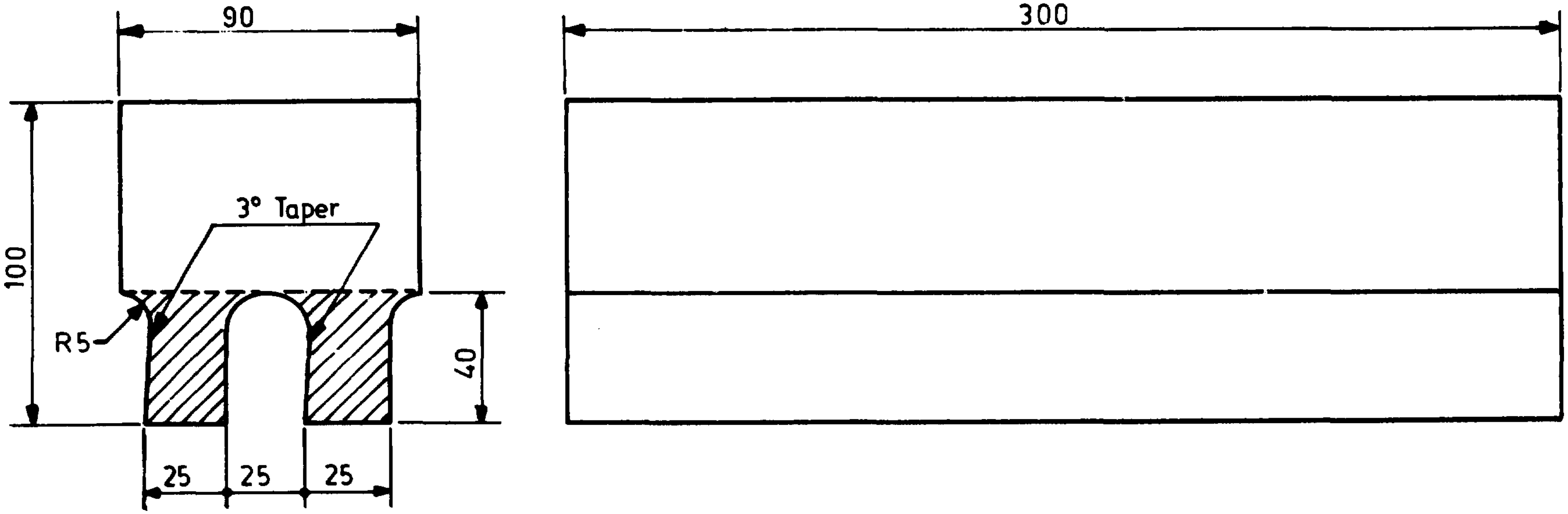
ARRANGEMENT FOR STREAM INOCULATION

DRG. NO. 002

Pouring

After the inoculation, the ladle is taken for pouring into the moulds. The metal after magnesium treatment and inoculation should not be subject to much turbulance as it will cause faster fading of the inoculation effect. Also the pouring should be done fast as long times will cause fading of the magnesium treatment/ inoculation. All the moulds should be kept ready for the pouring to avoid any delay. The ladle should be completely poured into the moulds and if any balance metal remains in the ladle, it should be poured outside. This is to ensure that the ladle is clean before the next usage. Before pouring into the first mould and after completing the pouring of the last mould, sample pieces as per drawing No.003 should be poured. Sample pieces should also be cast for chemical analysis. Immediately after the pouring is complete, the pouring ladle should be taken to the magnesium treatment ladle for collecting the next batch of metal for pouring. More than one pouring ladle should be used at a time so that the total time required for pouring the metal after magnesium treatment does not exceed 12 minutes. Each time after pouring the ladle should be cleaned completely.

The temperature of the metal at the time of pouring into the first mould and last mould should be checked correctly with an optical pyrometer.



The test pieces shall be machined from the keel (ie. Cross hatched section)

U TYPE TEST SAMPLE
FOR S.G. IRON

ISO 1083 - 1976 (E)
TYPE IIb

DRG. NO. 003

In the same way as described above, the next batch of 500 Kg. of metal should be tapped and treated with magnesium alloy. Thus the total quantity of 1500 Kg. of metal can be treated in 3 batches. Care has to be taken to ensure that the complete quantity of the metal from the reaction ladle should be removed before using for the treatment of next batch.

Testing the S.G. Iron

Two sample pieces should be cast for each of the pouring ladles, one before pouring into the first mould and the other after pouring into the last mould. All these samples should have serial numbers for identification. The sample pieces should then be analysed for chemical composition, microstructure and mechanical properties. The chemical composition, should be

C%	Si%	Mn%	S%	P%
3.5 - 3.8	2.6 - 2.8	0.4	0.01	0.06
Cr%	Ni%	Cu%	Mg%	Ce%
0.10	0.10	0.10	0.03-0.05	0.05

The residual magnesium content is important. If the percentage of magnesium is not within the limits 0.03 to 0.05, it shows that the magnesium treatment is not correct.

The microstructure should show fine spheroidal graphite. Actual size of the graphite spheroids can be obtained by measuring the nodule count. The matrix structure should be predominanantly ferrite and very less pearlite. Carbides should not be present in the structure.

The mechanical properties should be tested with a test bar as given in drawing No.004. The tensile strength should be minimum 42 Kg/mm^2, 0.2% proof stress should be minimum 28Kg/mm^2 and hardness should be between 140 and 200 HBN.

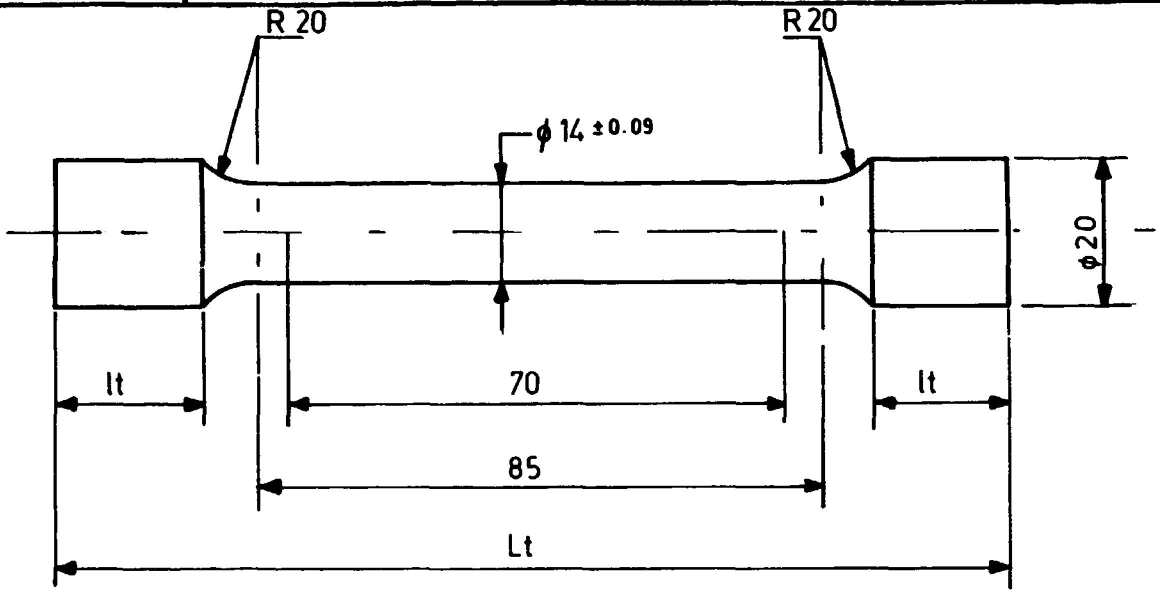
Recording

Details of each melt regarding charge, base metal composition, magnesium treatment, mechanical and metallurgical data etc. should be recorded in the form given in Table-I enclosed.

Probable Failures and Methods of correction

(a) Graphite not spherical

If the graphite particles are not spherical it shows that the magnesium treatment is not effective. This can happen due to insufficient quantity of FeSi Mg alloy or inefficient treatment procedure and the resultant low magnesium recovery. Too high a treatment temperature will also reduce the magnesium recovery. The efficiency of the magnesium treatment can be



lt = value of lt will depend upon the method of gripping in the testing machine

Lt = depend on the value of lt

Note:

1. The test bar should be free from transverse tool marks
2. The transition between the ends and the parallel length shall be smooth without under cutting or sudden step down in diameter.
3. The test bar with defective machining or obvious lack of continuity in the metal shall be discarded.

ISO 1083-1976(E)

TENSILE TEST PIECE

FOR S.G. IRON

DRG. NO. 004

determined from the residual Mg content in the casting. If the Mg content in the casting is between 0.03 and 0.05% it shows that the treatment is good.

The other reason for not getting graphite in spheroidal form is the presence of trace elements in the base metal which prevent nodule formation. Analysis of the base metal should be carried out to find out the percentage of trace elements like Pb, Sb, Bi and Ti. If these elements are present in quantities higher than the figures given below nodularisation will not take place.

Pb ≤ 0.002%
Sb ≤ 0.002%
Bi ≤ 0.002%
Ti ≤ 0.010%

One way of avoiding the detrimental effect of these elements is to add about 0.05% of Cerium metal before magnesium treatment. But the cerium addition will be effective only if the impurities content is less than a particular value. If the percentage of impurities is more such that the cerium addition is also not effective, then the raw materials should be changed to avoid these impurities.

A third reason for insufficient nodularisation is that the effect of the Mg treatment would have faded before the pouring. The metal after magnesium treatment should be poured in 15 minutes. In case it is not possible to complete the pouring in 15 minutes, the remaining metal should be poured back into the furnace and the treatment process repeated.

(b) Graphite is Coarse

If the graphite nodules are large and few, it indicates that the inoculation is not effective. Reasons for poor inoculation are

i) Quantity of inoculant not sufficient

ii) Size of the inoculant particles is either too coarse or too fine

iii) The inoculant has not mixed properly with the metal

and iv) Fading of the inoculation effect due to delay in pouring

Thus the defect of coarse graphite can be corrected by proper inoculation practice avoiding the reasons mentioned above.

(c) Matrix structure is not predominantly ferritic but contains more pearlite and some carbides

The reason for the presence of carbides and excessive amounts of pearlite in the structure is that the metal contains carbide stabilising elements such as Mn, Cr, Cu, V and Mo in percentage above the maximum values given in the chemical composition of the metal. This can be corrected by using a raw material charge containing very less percentage of the above elements. Another way of correction is to anneal the castings to produce ferritic structure.

(d) Low value for Elongation

Low elongation values will be obtained if the matrix structure does not contain predominantly ferrite, which can be corrected as described in (C). Of course the graphite should be spheroidal and fine.

Heat Treatment of S.G. Iron

Annealing to obtain ferritic structure

The annealing can be done by any of the following ways:

1. Heat to 900°C for 1 hr. plus 1 hr. per 25 mm thickness of the casting, cool to 690°C and hold for 5 hrs. plus 1 hr. per 25 mm thickness and then cool in the furnace or in the air.
2. Heat to 900°C for 1 hr. plus 1 hr. per 25 mm thickness of casting, cool slowly in the furnace to 650°C at a cooling rate not exceeding 20°C per hour and then cool fast in the furnace or in the air.

3. Sub critical anneal by heating to 705°C and holding for 5 hrs. plus 1 hour per 25 mm thickness. Furnace cool to atleast 600°C. Afterwards the castings can be further cooled in the furnace or in the air.

General Precautions

1. The production of S.G. Iron requires very strict control of the entire process and hence maximum care should be taken in melting, treating and pouring of this iron.
2. Time is a very important consideration in the production of S.G. Iron. Hence all the processes such as melting, treating, pouring etc. should be carried out at the shortest time possible.
3. The furnaces, ladles and other containers used for carrying the molten metal should be very clean and free from slag and other materials.
4. The raw materials and other treatment alloys should be weighed correctly using accurate balances.
5. The particle size of Mg treatment alloy and inoculation alloy should be maintained same to achieve consistent results.

6. All the procedures, materials and parameters such as weights, temperatures compositions, time etc. should be maintained identical for each melting to ensure that consistent results are obtained.

APPENDIX - III

SCHEDULE FOR TRIALS OF SG IRON PRODUCTION

Year - 1983

	ACTIVITY	DURATION IN WEEKS	PERSONNEL RESPONSIBLE	JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
				1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1.	Design of tundish cover	2	S.I.E.I. Mr. Balakrishnan		■	■																					
2.	Manufacture of tundish cover (Fabrication only)	4	S.I.E.I. Mr. Hamid Majid Mr. Hamudi Jasim			■	■	■																			
3.	Refractory lining of tundish cover	3	S.E.M.I. Mr. Salah Wetwet					■	■																		
4.	Design of Mg treatment ladle of 500 kg. capacity and to modify the existing ladle to suit the above design and design & manufacture of suitable stand	7	S.E.M.I. Mr. Salah Wetwet			■	■	■	■																		
5.	Design of special inoculation device	1	S.I.E.I. Mr. Balakrishnan			■																					
6.	Manufacture of special inoculation device	2	S.I.E.I. Mr. Hamid Majid Mr. Hamudi Jasim			■	■																				
7.	Modifications of pattern, moulds, etc. wherever necessary to suit S.G. Iron castings	6	S.E.M.I. Mr. Salah Wetwet			■	■	■																			
8.	Locating raw materials in SEMI and Huttin	2	TEAM			■																					
9.	Analysis of raw materials	4	TEAM				■	■																			
10.	Checking the Arc Furnace lining	1	S.E.M.I. Mr. Salah Wetwet						■																		
11.	Making available facilities and equipments such as temperature measuring instruments, balances for raw materials, Mg alloy, and inoculant	2	S.E.M.I. Mr. Salah Wetwet			■																					
12.	Fabrication of small containers for Mg alloy, inoculant and steel scrap for covering Mg alloy	4	S.I.E.I. Mr. Hamid Majid Mr. Hamudi Jasim				■	■																			
13.	Preparation of graphite pieces of 10-20 mm size	2	S.E.M.I. Mr. Salah Wetwet				■																				
14.	Calibration of spectrometer	2	Quality Control SEMI			■																					
15.	Manufacture of pattern for sample casting as per ISO specifications	4	Mr. Salah Wetwet Mr. Hamudi Jasim			■	■																				
16.	Preparation of technological process	6	S.I.E.I. Mr. Balakrishnan				■	■	■																		
17.	Specifying ISO Standards suitable for the tractor parts	1	TEAM			■																					
18.	Checking up the availability and suitability of the equipments and facilities required for the trial using arc furnace	2	TEAM							■																	
19.	Transporting of raw materials and chemicals etc. to the melting section	1	S.E.M.I. Mr. Salah Wetwet								■																
20.	FIRST TRIAL MELTING with arc furnace for the cleaning of furnace ladle etc.	3	TEAM									■	■														
21.	Studying the micro-structure and mechanical properties for sample piece and actual parts	2	TEAM									■	■														
22.	Second Trial - with changes found necessary from first trial (Samples and actual parts)	3	TEAM										■	■													
23.	Further trials with arc furnace (Samples & actual parts)	4	TEAM												■	■											
24.	Checking the induction furnace and relining if found necessary	4	S.E.M.I. Mr. Salah Wetwet									■	■														
25.	Trials with Induction Furnace	8	TEAM													■	■	■	■								
26.	Study of the metallurgical & mechanical properties	8	TEAM													■	■	■	■								
27.	Report on the results and recommendations	8	TEAM																	■	■	■	■				
28.	Ordering and purchasing of 50 tons of Sorelmetal	12	S.E.M.I.			■	■	■	■	■	■																
29.	Productionising of S.G. Iron	4	SEMI/TEAM																					■	■		

APPENDIX - IV

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(a)

Date : 5.5.1983	Melt No : 1	Grade of S G : 42/12	Tapping Temperature : 1570°C
Furnace No : 3	Lining : BASIC	Starting Time : 10:20 AM	Duration of Tapping : 45 to 60 Secs.
Casting No : 51113301: Front Axle Bracket	Pattern No : M131	No. of Pcs. Cast : 4	Tapping Time : AM/PM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	1200	1200	C I Scrap (SG)	-	-
Steel Scrap	300	300	Graphite	24	24
FerroSilicon (75% silicon)	39	39	Ferro Manganese	-	-

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	CE %	Additions
Plan	3.5-3.8	1.6-1.8	< 0.4	< 0.02	< 0.06	< 0.10	< 0.10	< 0.10	4.1 to 4.4	
Initial	3.93	2.09	0.10	0.005	-	0.10	-	-	4.62	NIL
Final	3.75	2.04	0.42	-	-	0.15	-	-	4.43	

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH. PROPERTIES			
	C %	Si %	Mn %	S %	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg.	Steel scrap	FeSi Kg				UTS Kg/mm^2	YP Kg/mm^2	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	< 0.4	< 0.01	< 0.06	< 0.10	< 0.10	< 0.10	0.03 to 0.05	500	7.000	7.500	1.200	1420-1360	10-20		42.0	28.0	12 min.	150-200
I Reaction Ladle										500	7.000	7.500								
Pouring - Ladle I	3.55	2.52	0.671	0.004	0.045	0.337	0.058	-	0.035				1.200				60.1		11.42	255
Pouring - Ladle II	3.60	2.57	0.671	0.003	0.127	0.337	0.067	-	-				1.200				65.1		10.00	207
Pouring - Ladle III	3.56	2.55	0.616	0.002	0.042	0.329	NIL	-	-				1.200				*50.74			
II Reaction Ladle										500	7.000	7.500				Pearlite 50%				
Pouring - Ladle IV	3.54	2.51	0.605	0.001	0.054	0.355	NIL	-	-	-	-	-	1.200			Ferrite 50%	67.95		8.57	269
Pouring - Ladle V	3.50	2.54	0.594	0.006	0.047	0.349	0.191	-	0.033	-	-	-	1.200			Nodularity	69.53		8.58	269
Pouring - Ladle VI	3.48	2.54	0.561	0.004	0.039	0.337	0.564						1.200			105-297N/mm^2	*65.26		7.14	222
III Reaction Ladle										500	7.000	7.500								
Pouring - Ladle VII	3.52	2.55	0.616	0.004	0.056	0.355	0.566						1.200				71.75		4.3	255
Pouring - Ladle VIII													1.200							
Pouring - Ladle IX													1.200							

* Sample Defective (porous)

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 10
2	Reaction Ladle II	Mts 7
3	Reaction Ladle III	Mts 8

Heat treatment : NIL

Remarks :

(1) The temperature measurement was not correct

(2) The furnace was used previously for melting high manganese steel

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(b)

Date 14.5.1983	Melt No. 2	Grade of S G : 42/12	Tapping -Temperature °C
Furnace No 2	Lining : Basic (Newly lined-pure Magnesite)	Starting Time : 10:50 AM	Duration of Tapping : 24-30 Secs
Casting No 5611 2801 : Rear Axle Housing	Pattern No : M301	No of Pcs. Cast : 10	Tapping Time : 4.15 PM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig iron	1200	1200	C I Scrap (SG)	-	-
Steel Scrap	300	300	Graphite	24	24
FerroSilicon (75% silicon)	39	39	Ferro Manganese	-	-

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	C E %	Additions
Plan	3.5-3.8	1.6-1.8	<0.4	<0.4	<0.02	< 0.06	<0.10	< 0.10	4.1 to 4.4	
Initial	3.21	1.60	0.35	0.01	0.12	0.05				
Final	3.66	2.20	0.40			0.10				Sorel metal 125 kg. Graphite 10 kg.

Ladle Details	CHEMICAL COMPOSITION C %	Si %	Mn %	S %	P %	Cr %	Ni %	Cu %	Mg %	Metal weight Kg	ADDITIONS FeSi Mg Kg.	Steel scrap	FeSi Kg.	Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES UTS Kg/mm²	YP Kg/mm²	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	<0.4	<0.01	<0.06	<0.10	<0.10	< 0.10	0.03 to 0.05	500	7.000	7.500	1.600	1420 - 1360	10-20		42.0	28.0	12 min.	140 - 200
I Reaction Ladle										500	7.000	7.500								
Pouring - Ladle I	3.346	2.81	0.143	0.009	0.055	0.113	0.039	-	-	160			1.600				49.27		15.57	170
Pouring - Ladle II	3.338	2.82	0.143	0.006	0.039	0.113	0.052	-	0.0457	160			1.600				48.89		20.00	170
Pouring - Ladle III	3.374	3.09	0.143	0.006	0.130	0.130	0.083	-	-	160			1.600				52.14		20.00	179
II Reaction Ladle										600	7.000	7.500								
Pouring - Ladle IV	3.420	2.96	0.176	0.006	0.027	0.086	0.061	-	-	160			1.600				53.19		15.57	179
Pouring - Ladle V	3.349	3.07	0.143	0.005	0.035	0.121	0.093	-	-	160			1.600				50.95		2[illegible].28	179
Pouring - Ladle VI	3.433	3.05	0.187	0.003	0.046	0.133	0.110	-	-	160			1.600			Pearlite 2-15%	51.88		15.57	170
III Reaction Ladle										500	7.000	7.500				Ferrite 85-98%				
Pouring - Ladle VII	3.398	3.04	0.198	0.005	0.069	0.02	0.069	-	0.0357	160			1.600			Nodularity -	51.26		20.00	179
Pouring - Ladle VIII	3.451	2.95	0.121	0.004	0.035	0.035	0.083	-	-	160			1.600			126-263 N/mm²	52.18		2[illegible].00	170
Pouring - Ladle IX																				

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 10
2	Reaction Ladle II	Mts 8
3	Reaction Ladle III	Mts 9

Heat treatment : NIL

Remarks :

Temperature measurement system was not working. Hence, no temperature measurement was done.

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(c)

Date 17.5.1983	Melt No. : 3	Grade of S G : 42/12	Tapping Temperature : 1540°C
Furnace No 2	Lining : Basic	Starting Time : 11:20 AM	Duration of Tapping : 40 secs.
Casting No :	Pattern No :	No of Pcs. Cast :	Tapping Time : 4.15 PM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	900	900	C I Scrap (SG)	-	-
Steel Scrap	600	600	Graphite	43	43
FerroSilicon (75 % silicon)	40	40	Ferro Manganese	-	-

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	C E %	Additions
Plan	3.5-3.8	1.6-1.8	<0.4	<0.02	<0.06	<0.10	<0.10	<0.10	4.1 to 4.4	
Initial	3.36	2.2								
Final	3.51	2.19								Sorel Metal 175 kg.

Ladle Details	CHEMICAL COMPOSITION C %	Si %	Mn %	S %	P %	Cr %	Ni %	Cu %	Mg %	Metal weight Kg	ADDITIONS FeSi Mg Kg.	Steel scrap	Fe Si Kg.	Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES UTS Kg/mm^2	YP Kg/mm^2	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	< 0.4	<0.01	<0.06	<0.10	< 0.10	< 0.10	0.03 to 0.05	500	7.000	7.500	1.600	1420-1360	10-20	Pearlite 5-15%	42.0	28.0	12 min.	140-200
I Reaction Ladle										500	7.000	7.500				Ferrite 85-95%				
Pouring - Ladle I	3.17	2.79	0.198	0.004	0.021	0.355	0.004	-	-	160			1.600	1390		Nodularity:	*60.34		8.54	207
Pouring - Ladle II	3.17	2.96	0.198	0.004	0.023	0.268	0.026	-	-	160			1.600			154-351 N/mm^2	59.39		14.57	196
Pouring - Ladle III	3.16	2.97	0.165	0.003	0.021	0.268	0.033		0.043	160			1.600				*60.38		12.85	207
II Reaction Ladle																				
Pouring - Ladle IV																				
Pouring - Ladle V																				
Pouring - Ladle VI	3.33	2.95	0.187	0.004	0.015	0.355	0.042	..	-	160			1.600				*56.71		8.57	196
III Reaction Ladle																				
Pouring - Ladle VII																				
Pouring - Ladle VIII	3.16	2.97	0.165	0.003	0.015	0.277	0.022	-	0.042	160			1.600				58.73		15.0	196
Pouring - Ladle IX	3.38	2.92	0.198	0.004	0.032	0.355	0.012	-	-	160			1.600				*50.54		4.28	196

* Sample piece defective (porous)

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 11
2	Reaction Ladle II	Mts 9
3	Reaction Ladle III	Mts 9

Heat treatment : NIL

Remarks :

(1) The thermocouple was giving wrong temperature reading

(2) The same cover used for 2nd trial was used again. The lining was completely damaged.

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(d)

Date . 30.5.1983	Melt No. : 4	Grade of S G : 42/12	Tapping Temperature 1590°C
Furnace No : 2	Lining : Basic	Starting Time :	Duration of Tapping : Secs
Casting No :	Pattern No :	No of Pcs Cast : 16	Tapping Time :

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	900	900	C I Scrap (SG)		
Steel Scrap	600	600	Graphite	38	38
FerroSilicon (75 % silicon)	39	39	Ferro Manganese		

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	CE %	Additions
Plan	3.5-3.8	1.6-1.8	< 0.4	< 0.02	<0.06	< 0.10	<0.10	< 0.10	4.1 to 4.4	
Initial	3.8	2.40	0.15			0.05				CaC2 : 15 kg.
Final										SiC : 5 kg.

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES			
	C %	Si %	Mn %	S%	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg.	Steel scrap	Fe Si Kg.				UTS Kg/mm^2	YP Kg/mm^2	Elong %	HBN
PLAN	3.6-3.8	2.6-2.8	<0.4	<0.01	<0.06	< 0.10	< 0.10	< 0.10	0.03 to 0.05	500	7.000	7.500	1.600	1420-1360	10-20	Pearlite 2-5%	42	28	12 min.	140-200
I Reaction Ladle										500	7.000	7.500				Ferrite 95-98%				
Pouring - Ladle I																Nodularity :				
Pouring - Ladle II	3.51	3.05	0.124	0.017	0.049	0.29	0.039						1.600			178-283 N/mm^2	*53.2		10	187
Pouring - Ladle III	3.46	2.99	0.30	0.006	0.067	0.20	0.006		0.035				1.600				52.8	-	20	187
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV	3.42	3.24	0.07	0.011	0.048	0.25	0.062						1.600				55.36		20.7	196
Pouring - Ladle V	3.54	3.23	0.084	0.006	0.098	0.29	0.004						1.600				55.67		12.8	196
Pouring - Ladle VI																				
III Reaction Ladle										500	7.000	7.500								
Pouring - Ladle VII	3.61	2.92	0.25	0.002	0.04	0.26	0.026						1.600				57.3		17.1	196
Pouring - Ladle VIII	3.53	3.09	0.19	0.006	0.037	0.24	0.025	-	0.030				1.600				52.83		15.7	217
Pouring - Ladle IX	3.47	3.02	0.10	0.005	0.073	0.22	0.035						1.600				52.12		15.7	207

* Sample defective (porous)

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts
2	Reaction Ladle II	Mts
3	Reaction Ladle III	Mts

Heat treatment : NIL

Remarks :

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(e)

Date 20.6.1983	Melt No : 5	Grade of S G : 42/12	Tapping Temperature :
Furnace No 2	Lining : Basic	Starting Time : 1.25 PM	Duration of Tapping . 29,32,39 Secs.
Casting No Front Wheel Flange, Wheel hubs, Base connection	Pattern No :	No of Pcs. Cast :	Tapping Time : 5.20 PM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	750	750	CI Scrap (SG)	-	-
Steel Scrap	750	750	Graphite	44	44
FerroSilicon (75 % silicon)	35	35	Ferro Manganese	-	-

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	CE %	Additions
Plan	3.5-3.8	1.6-1.8	< 0.4	< 0.02	< 0.06	< 0.10	< 0.10	< 0.10	4.1 to 4.4	
Initial	4.2	0.66	0.05			0.02				CaC_2 : 15 kg. SiC : 5 kg.
Final		1.1							4.43	Steel Scrap : 130 kg.

Ladle Details	CHEMICAL COMPOSITION C %	Si %	Mn %	S %	P %	Cr %	Ni %	Cu %	Mg %	Metal weight Kg	ADDITIONS FeSi Mg Kg	Steel scrap	FeSi Kg	Pouring temp. C°	Pouring time Secs	Microstructure	MECH PROPERTIES UTS Kg/mm²	YP Kg/mm²	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	< 0.4	< 0.01	< 0.06	< 0.10	< 0.10	< 0.10	0.03 to 0.05	500	7.000	7.500	1.600	1420-1360	10-20		42	28	12 min.	150-200
I Reaction Ladle										500	7.000	7.500				Pearlite 10-20%				
Pouring - Ladle I	3.78	2.79	0.62	0.002	0.024	0.762	0.042						1.600		30	Ferrite 80-90%	68.94		6.4	240
Pouring - Ladle II													1.600		8	Nodularity				
Pouring - Ladle III	3.9	2.57	0.63	0.001	0.024	0.770	0.08						1.600		7	209-259 N/mm²	69.46		7.1	240
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV	3.8	2.53	0.67	0.003	0.03	0.73	0.047		0.033				1.600		14		70.18		10.0	228
Pouring - Ladle V	3.84	2.76	0.41	0.002	0.034	0.73	0.05						1.600		12		70.98		6.4	228
Pouring - Ladle VI	3.97	2.27	0.54	0.003	0.024	0.74	0.076						1.600		4		*70.45			240
III Reaction Ladle										500	7.000	7.500								
Pouring - Ladle VII	3.76	2.61	0.54	0.003	0.028	0.73	0.42						1.600		20		70.22		6.4	228
Pouring - Ladle VIII	3.9	2.78	0.48	0.004	0.025	0.76	0.09						1.600		10		72.26		5.7	240
Pouring - Ladle IX	3.96	2.42	0.74	0.004	0.039	0.755	0.06		0.033				1.600		5		68.35		4.2	240

* Sample piece defective (porous)

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 9
2	Reaction Ladle II	Mts 8
3	Reaction Ladle III	Mts 9

Heat treatment :

Remarks :

Final carbon could not be checked as the instrument was not working. Two CrMgo bricks fell into the melt from the roof and hence the Cr percentage is high.

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(f)

Date 1.8.1983	Melt No. : 6	Grade of S G : 42/12	Tapping Temperature : 1540°C
Furnace No 2	Lining : Basic	Starting Time : 5.00 AM	Duration of Tapping :
Casting No :	Pattern No. :	No of Pcs. Cast :	Tapping Time : 11.05 AM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig iron	750	750	C I Scrap (SG)		
Steel Scrap	750	750	Graphite	38	38
FerroSilicon (75% silicon)	35	35	Ferro Manganese		

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	C E %	Additions
Plan	3.5-3.8	1.6-1.8	< 0.4	< 0.02	<0.06	<0.10	<0.10	<0.10	4.1 to 4.4	
Initial	3.36	2.35	0.2			0.3			4.34	Sorelmetal : 140 kg.
Final	3.37	2.24	0.15			0.4			4.1	

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES			
	C %	Si %	Mn %	S%	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg.	Steel scrap	Fe Si Kg.				UTS Kg/mm²	YP Kg/mm²	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	< 0.4	<0.01	<0.06	<0.10	<0.10	<0.10	0.03-0.05	500	7.000	7.500	1.600	1420-1360	10-20	Pearlite 15-30%	42.0	28.0	12 min.	150-200
I Reaction Ladle										300	7.000	7.500				Ferrite 70-85%				
Pouring - Ladle I	3.38	3.17	0.28	0.006	0.037	0.52	0.057	-	-	160			1.600			Nodule Count :	*57.51		2.8	228
Pouring - Ladle II										140			1.600			134-157 N/mm²				
Pouring - Ladle III																				
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV	3.50	2.97	0.30	0.005	0.047	0.52	0.059			160			1.600				65.61		11.4	196
Pouring - Ladle V	3.80	2.77	0.16	0.005	0.051	0.51	0.051			160			1.600				61.55		12.8	207
Pouring - Ladle VI										160			1.600							
III Reaction Ladle										500	7.000	7.500								
Pouring - Ladle VII	3.52	2.99	0.25	0.005	0.047	0.53	0.047			160			1.600				62.98		8.5	207
Pouring - Ladle VIII	3.36	2.33	0.16	0.006	0.039	0.52	0.039	-		160			1.600				62.86		8.5	207
Pouring - Ladle IX										160			1.600							

* Sample porous

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 10
2	Reaction Ladle II	Mts 12
3	Reaction Ladle III	Mts 12

Heat treatment : NIL

Remarks :

There was heavy slag in the metal. The first tapping was not correct as the pit was not clean and the bottom of the laddle was touching the floor. The cover was damaged due to excessive slag.

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(g)

Date 18.8.1983	Melt No. : 7	Grade of S G : 42/12	Tapping Temperature .
Furnace No 3	Lining : Basic(Pure Magnesite)	Starting Time : 10.00 AM	Duration of Tapping : 40,60 & 45 Secs.
Casting No :	Pattern No :	No of Pcs. Cast :	Tapping Time : 1.35; 1.57 and 2.15 PM

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	750	750	CI Scrap (SG)		
Steel Scrap	750	750	Graphite	38	38
FerroSilicon (75% silicon)	30	30	Ferro Manganese		

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	CE %	Additions
Plan	3.5–3.8	1.6–1.8	< 0.4	< 0.02	< 0.06	< 0.10	< 0.10	< 0.10	4.1 to 4.4	
Initial	3.8	0.64	0.35	-	-	0.1	-	-	3.56	Before adding FeSi added 10 kg.
Final	3.9	2.3	0.35	-	-	0.05	-	-	4.4	CaC_2

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES			
	C %	Si %	Mn %	S%	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg.	Steel scrap	Fe Si Kg.				UTS Kg/mm²	YP Kg/mm²	Elong %	HBN
PLAN	3.5–3.8	2.6–2.8	< 0.04	< 0.01	< 0.06	< 0.10	< 0.10	< 0.10	0.03–0.05	500	7.000	7.500	1.600	1420–1360	10–20	Pearlite 15–30%	42.0	28.0	< 2 min.	140–200
I Reaction Ladle										500	7.000	7.500				Ferrite 70–85%				
Pouring - Ladle I										160			1.600			Nodule Count:				
Pouring - Ladle II	3.2	2.61	0.24	0.005	0.039	0.15	0.041	-	-	160			1.600			55–116 N/mm²	*50.69		5.7	170
Pouring - Ladle III	2.98	2.88	0.25	0.001	0 05	0.13	0.026	-	-	160			1.600				*48.02		7.1	163
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV										160			1.600							
Pouring - Ladle V	3.2	2.79	0.31	0.007	0.02	0.19	0.033	-	-	160			1.600							
Pouring - Ladle VI	2.8	2.6	0.23	0.005	0.039	0.15	0.035	-	-	160			1.600				*53.56		7.1	170
III Reaction Ladle										500	7.000	7.500								
Pouring - Ladle VII										160			1.600							
Pouring - Ladle VIII	3.2	2.6	0.31	0.004	0.03	0.13	0.037	-	-	160			1.600				*47.44		7.0	170
Pouring - Ladle IX	3.16	3.2	0.24	0.008	0.03	0.18	0.01			160			1.600				*44.85		4.2	179

* All the moulds for sample were damaged. So the sample pieces are taken from the risers.

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 12
2	Reaction Ladle II	Mts 14
3	Reaction Ladle III	Mts 9

Heat treatment : NIL

Remarks :

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(b)

Date 28.9.1983	Melt No : 8	Grade of S G : 42/12	Tapping Temperature : 1500°C
Furnace No 2	Lining : Basic	Starting Time : 11.00	Duration of Tapping : 45–60 Secs.
Casting No :	Pattern No :	No of Pcs Cast :	Tapping Time : 15.50

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig Iron	750	750	C I Scrap (SG)		
Steel Scrap	750	750	Graphite	38	38
Ferro Silicon (75% silicon)	35	35	Ferro Manganese		

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	C E %	Additions
Plan	3.5–3.8	1.6–1.8	< 0.4	< 0.02	<0.06	<0.10	<0.10	< 0.10	4.1–4.4	
Initial	3.30	2.36	0.35			0.05			3.84	Graphite : 10 kg.
Final	3.4	2.20	0.15			0.05			3.90	Sorel Metal: 25 kg.

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES			
	C %	Si %	Mn %	S %	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg	Steel scrap	Fe Si Kg				UTS Kg/mm^2	YP Kg/mm^2	Elong %	HBN
PLAN	3.5–3.8	2.6–2.8	<0.4	<0.01	<0.06	<0.1	<0.1	<0.1	0.03–0.05	500	7.000	7.500	1.600	1420–1360	10–20		42.0	28.0	12 min.	140–200
I Reaction Ladle										500	7.000	7.500								
Pouring - Ladle I	3.10	2.87	0.16	0.005	0.045	0.22	0.039			160			1.600				46.79		7.8	196
Pouring - Ladle II																				
Pouring - Ladle III	3.28	2.71	0.17	0.002	0.040	0.22	0.033			160			1.600				51.43		16.4	217
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV	3.15	2.93	0.12	0.002	0.042	0.24	0.043			160			1.600				51.47		14.2	196
Pouring - Ladle V																				
Pouring - Ladle VI	3.10	2.85	0.18	0.004	0.032	0.23	0.033			160			1.600				50.54		11.4	196
III Reaction Ladle										500	7.000	7.500				Pearlite 5–30%				
Pouring - Ladle VII	3.22	2.85	0.18	0.002	0.025	0.22	0.043			160			1.600			Ferrite 70–95%	49.53		12.8	196
Pouring - Ladle VIII																Nodule Count:				
Pouring - Ladle IX	3.20	2.91	0.16	0.003	0.025	0.22	0.047			160			1.600			34–68 N/m^{-2}	48.14		10.0	207

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts 8
2	Reaction Ladle II	Mts 10
3	Reaction Ladle III	Mts 11

Heat treatment : NIL

Remarks :

Used newly relined furnace.

MANUFACTURING DATA - S G IRON CASTINGS

Appendix IV(i)

Date 29.9.1983	Melt No. : 9	Grade of SG : 42/12	Tapping Temperature :
Furnace No 2	Lining : **Basic**	Starting Time :	Duration of Tapping .
Casting No :	Pattern No :	No of Pcs. Cast :	Tapping Time :

CHARGE COMPOSITION

	Plan Kg	Actual Kg		Plan Kg	Actual Kg
Pig iron	750	750	CI Scrap (SG)		
Steel Scrap	750	750	Graphite	38	38
FerroSilicon (75% silicon)	28	28	Ferro Manganese		

BASE METAL COMPOSITION

	C %	Si %	Mn%	S %	P %	Cr %	Ni %	Cu %	CE %	Additions
Plan	3.5-3.8	1.6-1.8	<0.4	<0.02	<0.06	<0.10	<0.10	<0.10	4.1-4.4	
Initial	3.3	0.015	0.4			0.05				
Final	3.6	2.1	0.1			0.05				

Ladle Details	CHEMICAL COMPOSITION									Metal weight Kg	ADDITIONS			Pouring temp. C°	Pouring time Secs.	Microstructure	MECH PROPERTIES			
	C %	Si %	Mn %	S%	P %	Cr %	Ni %	Cu %	Mg %		FeSi Mg Kg.	Steel scrap	FeSi Kg.				UTS Kg/mm^2	Impact Kg/m/cm^2	Elong %	HBN
PLAN	3.5-3.8	2.6-2.8	<0.4	<0.01	<0.06	<0.10	<0.10	<0.10	0.03-0.05	500	7.000	7.500	1.600	1420-1360	10-20		42.0		12 min.	140-20
I Reaction Ladle										500	7.000	7.500								
Pouring - Ladle I	3.36	2.4	0.1	0.005	0.034	0.069	0.23			160			1.600				*57.19	0.5	5.7	170
Pouring - Ladle II										160			1.600							
Pouring - Ladle III	3.35	2.82	0.1	0.003	0.02	0.061	0.37			160			1.600				53.55	0.75	15.7	170
II Reaction Ladle										500	7.000	7.500								
Pouring - Ladle IV	3.2	3.0	0.1	0.006	0.03	0.061	0.04			160			1.600				51.58	1.50	21.0	163
Pouring - Ladle V										160			1.600							
Pouring - Ladle VI	3.1	2.83	0.12	0.008	0.02	0.069	0.10			160			1.600				52.17	1.50	18.5	170
III Reaction Ladle										500	7.000	7.500				Pearlite 5-15%				
Pouring - Ladle VII										160			1.600			Ferrite 85-95%				
Pouring - Ladle VIII	3.1	2.64	0.10	0.005	0.02	0.059	0.026	-		160			1.600			Nodule Count:	*52.21	1.50	11.0	170
Pouring - Ladle IX										160			1.600			43-113 N/mm^2				

* Sample porous

Total time taken after Mg treatment till pouring is complete

1	Reaction Ladle I	Mts
2	Reaction Ladle II	Mts
3	Reaction Ladle III	Mts

Heat treatment : NIL

Remarks :

Heavy slag was present. Probably due to the fact that they have not removed the slag completely after the previous melt.

APPENDIX - V

DUE TO THE CONFIDENTIAL NATURE OF THIS [illegible]
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Sorelmetal®

RESEARCH DEPARTMENT

TECHNICAL SERVICE REPORT NO. 31-83

METALLURGICAL EXAMINATION OF NODULAR IRON SAMPLES SUBMITTED BY H.M.T. INTERNATIONAL

Investigator: Martin Gagné
MARTIN GAGNÉ

Foundry Metallurgist: JOHN B. WHEELDON

Date: JUNE 15TH, 1983

QIT

MG:mb

QIT-FER ET TITANE INC.

1. INTRODUCTION

A metallurgical investigation has been carried out on four ductile iron specimens submitted by H.M.T. International. The specimens were taken from test castings produced to evaluate the suitability of such materials for the fabrication of tractor axle beams and steering joints. The objectives of this investigation are to characterize their microstructures and to discuss their suitability for the fabrication of the above mentionned components.

2. CASTING BACKGROUND

The charge materials, which are listed in table 1 were melted in a 1.5 t arc furnace, Mg-treated in a covered ladle with 1.4% Fe Si Mg 9% and then inoculated with 1% Fe Si 70. The castings were cooled in the moulds to a temperature lower than 300°C.

		CHARGE MATERIALS	
SPECIMEN	TEST	SORELMETAL	STEEL
A	I	80%	20%
B	II	80%	20%
C-1	III	65%	35%
C-2	III (Ladle)	65%	35%

Table 1. DESCRIPTION OF THE SPECIMENS

Mechanical tests performed by the customer provided the following values for material produced in Test III:

Tensile strength:	45-52 kg/mm^2 (64290 psi)
Elongation:	15-22%
Hardness:	170-180 BHN

3. CHEMICAL COMPOSITION

A detailed chemical analysis was performed on specimens A, B and C-1. The results are grouped in table 2.

ELEMENT	CONCENTRATION (WT %)		
	A	B	C-1
C	3.28	3.09	3.35
S	0.011	0.012	0.009
Si	2.92	3.21	2.82
Mn	0.49	0.18	0.12
P	0.036	0.035	0.037
Cr	0.30	0.29	0.066
V	0.028	0.027	0.028
Ni	0.054	0.053	0.054
Cu	0.037	0.032	0.033
Al	0.015	0.021	0.018
Ti	0.029	0.021	0.016
Mo	0.005	0.004	0.004
Mg	0.037	0.053	0.052

TABLE 2. CHEMICAL COMPOSITION OF THE SPECIMENS.

The chemical analysis figures obtained are surprising taking into account the charge make-up. In particular, the high manganese and chromium contents in sample A which were produced from a charge consisting of 80% SORELMETAL would indicate that the composition of the steel scrap used was extremely high in these two elements. The high manganese and chromium contents in sample A would be expected to produce significant proportion of pearlite and possibly carbides in the structure of the matrix. Great care must be taken to avoid the use of such highly alloyed or contaminated steel scrap.

4. HARDNESS

Table 3 groups the results of Brinell hardness measurements performed on the specimens.

SPECIMEN	BHN
A	255
B	197
C-2	177

TABLE 3. HARDNESS MEASUREMENTS.

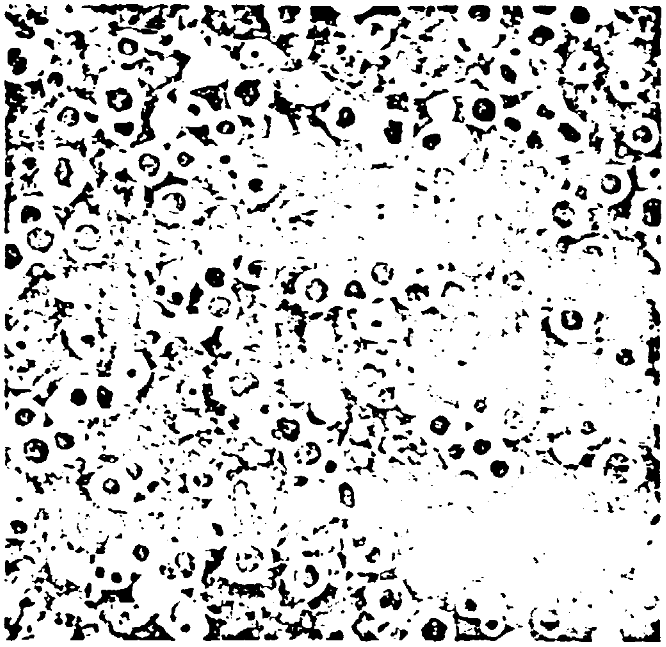
5. METALLOGRAPHY

Figures 1 to 4 present the typical microstructures of the specimens. In every sample, the graphite particles exhibit a high degree of nodularity. However, as expected from the results of the chemical analysis, the casting A displays a pearlitic matrix, while the castings B and C contain only a few percent of pearlite in their structure.

6. DISCUSSION AND CONCLUSION

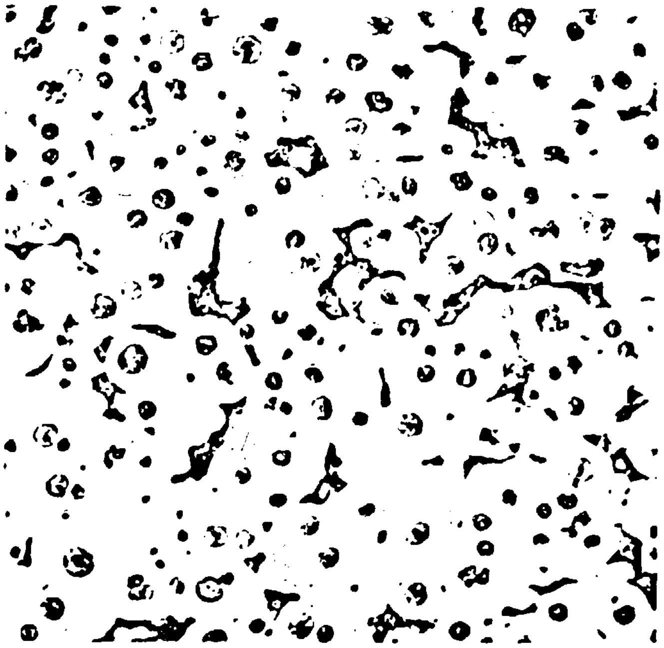
The microstructures of the four specimens examined are of a high quality. No structural defects were revealed by this investigation and the mechanical properties of castings with similar structure will be essentially controlled by the constituents of the matrix. Then, based on the observations described in this report, the sample A should meet the requirements for an ASTM 85-55-06 nodular iron grade while the specimens B, C-1 and C-2 should exhibit the tensile properties of an ASTM 60-40-18 nodular iron grade.

For the intended application viz tractor axle beams and steering joints where quite severe working conditions and impact loading are involved, a fully ferritic grade of ductile iron is required. From a structural and compositional point of view, sample C-1 is the most suitable of the materials produced and compares favourably with ductile iron produced on a regular commercial basis for similar applications.



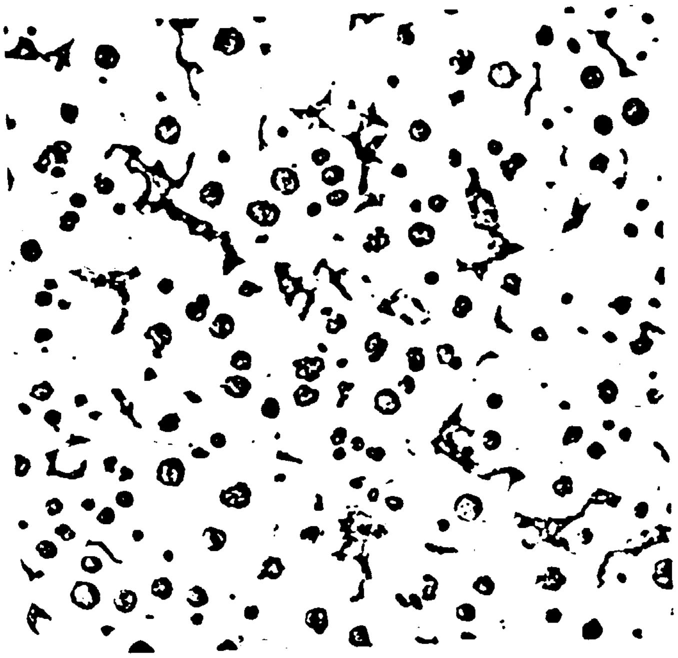
nital etched 100X

Figure 1. Typical microstructure of the sample A.



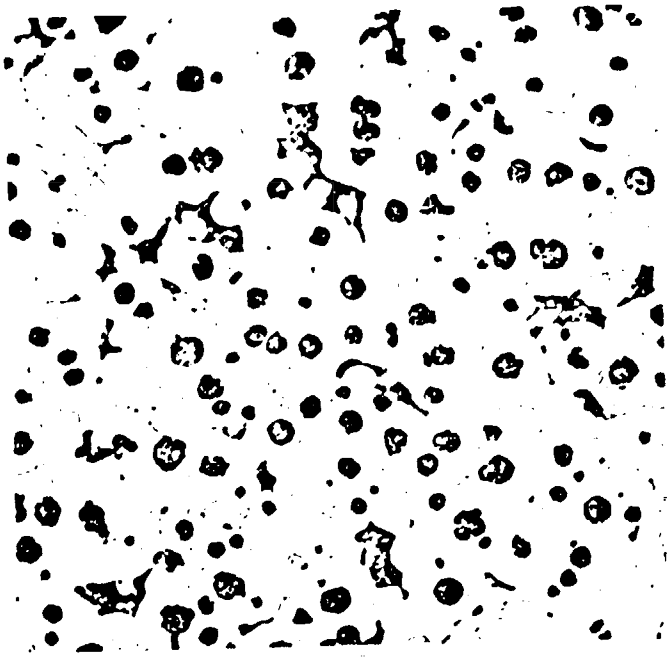
nital etched 100X

Figure 2. Typical microstructure of the sample B.



nital etched 100X

Figure 3. Typical microstructure of the sample C-1.



nital etched 100X

Figure 4. Typical microstructure of the sample C-2.

QIT

JOHN B. WHEELDON
4. SCHOOL ST., UPPERMILL
OLDHAM, OL3. 6HB ENGLAND
PHONE-04577-6808

17th August 1983

Mr. Salah Sahib Mahdi
Foundry Technology Manager
State Enterprise for Mechanical
Industries
SEMI
Iskandariyah
Iraq

Dear Sir

Thank you for the courtesy and cooperation given to me during my visit to SEMI, Iskandariyah. I can see that you have made good progress with SG iron and that with the assistance of your colleagues, the technical institute and HMTI, you will soon become a regular producer.

As you can see from QIT Technical Service Report 31-83 (enclosed) the SG iron produced during my visit and in the previous trials supervised by HMTI and the Technical Institute is of high quality. The report also confirms that this material is suitable for the manufacture of various tractor components presently produced as steel castings, forgings and weldments. The use of SG for these and similar applications is now commonplace worldwide. I am sure that with your present facilities and with a few minor modifications to the ladles you can now produce enough SG iron for 25 to 30 tractors per day.

In order that you may start regular production of SG iron, as soon as possible, we wish to give you are best technical advice and cooperation. Please let us know what further assistance you require.

I will be available to visit you again during the period November 21st to December 2nd, 1983 and would be obliged if you will send a letter to your Embassy in London requesting them to issue me with a visa (passport details attached).

.../2

QIT-Fer et Titane GmbH

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Telefon 06 11 - 72 02 36
Telex 04-14305 qit
Telegramme: Sorber

Geschäftsführer	Sitz der Gesellschaft	Amtsgericht	Bankverbindung
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In the meantime, please write to Mr. L. Ehrnborg in Frankfurt with any enquiries regarding how to proceed with your SG iron developments.

Best regards to you and your colleagues.

Yours faithfully

J.B. Wheeldon
Technical Representative

copy: L.J. Ehrnborg
R.D. Forrest
HMTI, Baghdad

Encl.

PASSPORT DETAILS

Name	John Berry Wheeldon
Date of Birth	5.12.1932
Place of Birth	Oldham U.K.
Passport No.	B 146996
Place and date of issue	15.1.1982 U.K.
Profession	Engineer

APPENDIX - VI

Agrozet. Zetor
koncernový podnik
BRNO
výrobní náměstek

~~[illegible] PODNIK BRNO ★ ZÁVODY [illegible] ★ NOSITEL ŘÁDU PRÁCE~~
[illegible] NÁMĚSTEK

Brno 29. 11. 1983
VN/DLK

Mr.
BASIL M, AL-DURRA, Eng.,
technical director of
State Enterprise for Mechanical
Industries in Iskandariyah

Dear Sir,

Reffering to our negotiations held in Iraq from October 7th, till 13th, I am sending you enclosed Report No. 295 (Camparison of the results of ductile cast iron analyses carried out by Messrs. SEMI - IRAQ and our enterprise on the same sample No. 6 /our certificate M 613 and evalution of the results of ductile cast iron analyses performed by Messrs. SEMI/).

Yours Faithfully

Ing. Ladislav Klenovits
production director

Enclosure: Report No. 295 2 pcs.
Orig. SEMI report

1. Introduction

On 24th October 1983, we received 8 test reports of Messrs. SEMI to evaluate and carry out analysis on a cast iron sample supplied and to compare the own analysis with that of Messrs. SEMI.

The above analysis refer to ductile cast iron intended to replace gradually steel used for castings in Messrs. SEMI's Works. The reason for the above replacement lies in the fact that ductile cast iron has a number of advantages over steel, i.e. a higher damping capacity, a reduced notch sensitivity, better foundry properties and a better machinability can be obtained, mechanical properties being comparable.

Prior to the proper evaluation, it is necessary to stress that ductile cast iron is evaluated according to its mechanical properties depending - first of all - on its basic structure.

2. Analysis of the Test Reports worked out in Messrs. SEMI Laboratories

The test reports submitted give the number of the respective melting, chemical composition, mechanical properties as well as structure types of obviously different sorts of ductile cast iron. A serious drawback of the above test reports is the fact that they do not inform in detail about individual samplings designated with numbers I to III, do not specify whether all the 3 samples were cut out of one material piece or not. An exact evaluation of the chemical composition for comparison purposes would be only possible if we could carry out our proper analysis on original samples from which the chemical composition in question was determined.

Material sheets do not reveal an exact chemical composition, they rather give mean values of individual element amounts /as laid down in para 3/.

When evaluating the obtained values of tensile strength, elongation and hardness, we found a number of discrepancies. It is necessary todraw your attention to a direct dependence of mechanical properties on a certain type of structure. So for instance in cast iron having a higher content of pearlite in the structure, higher values of hardness may be expected, similarly also a higher value of tensile strength and on the other hand a lower value of elongation may be obtained.

From the test reports of Messrs. SEMI, however, the above dependences do not follow. The values of hardness do not sometimes correspond with those of tensile strength. This fact cannot be ascribed to an error occured during measuring but mechanical values might be rather affected by casting defects /e.g. by blow holes. porosity and the like/ or by an inadmissibly rough surface of the test specimen used in the tensile strength test.

A metallographic evaluation of the structure type and a determination of the percentage of pearlite and ferrite could not be carried out due to a bad quality of the photographs attached to SEMI's test reports. The photos are not good enough and in most cases the non-etched samples do not differ from the Nital etched ones.

In the photographs it is possible to recognise prevailingly nodular graphite, the type of graphite corresponding with that being given in test reports. The pictures also reveal a tearing of graphitic grains occuring during grinding and polishing of metallographic polished samples.

In the future it is necessary that Messrs. SEMI employees take more care of grinding and polishing metallographic samples so that the majority of graphitic grians remain in the metallic matrix since the preparation of a perfect polished sample together with a correct sample etching are basic conditions for a correct structure evaluation.

3. Informative Survey of Ductile Iron Sorts produced in Czechoslovakia

An informative survey is given for Messrs. SEMI employees to enable them to compare the values obtained in mechanical tests with those specified in our Standards / OSN/

Our Czechoslovak Standards divide ferritic-pearlitic cast iron into five groups - See Tab. I. Individual groups differ from one another by the content of pearlite and ferrite in the structure and thus also by their mechanical properties. The Czechoslovak Standards do not specify the chemical composition of cast irons.

4. Analysis of the Cast Iron Sample supplied, designated as No. 6

The analysis was carried out under the number M 613.

a/ Chemical composition: %

C	Mn	Si	Cr	Ni	Cu	P	S	Mg
3.38	0.15	2.80	0.47	0.07	0.02	0,036	0.008	

b/ Values obtained in mechanical tests:

- Hardness test

HB/5/750		HB/10/300	
215	core	218	core
211	surface	208	surface

- Tensile strength

was carried out on a cylindrical test piece /bar/ provided with threaded leads. The shape of the above test piece /bar/ is specified in CSN 42 0316.

Values obtained

Tensile strength   Rm - 614.3 MPa   /=62.5 kp/mm²/

Ductility A_5 - 11.[illegible] %

c/ Metallographic analysis:

for wall thickness of 2[illegible] to [illegible]0 mm

The sample supplied was evaluated according to CSN 42 0461 in the height of 1/3 to 1/4 of the wall thickness.

Cast iron characteristics - ferritic-pearlitic structure with containing prevailingly nodular graphite.

Matrix - ferritic-pearlitic matrix. Fine,

- lamellar and nodular pearlite, ferrite deposited mostly around graphite in the form of ferritic clusters.

Ferrite amount - 50 to 60 %

Pearlite amount - 50 to 40 %

Graphite - present both as perfect grains and as nodular and vermicular graphite /the latter two graphite types contained up to 30 % of the total amount of grains/.

Number of graphitic grains per 1 mm² - 10[illegible] to 1[illegible].

Photographs:

Fig. No. 1 - not etched, Mag.: X100

- illustrates distribution and shape of graphite.

Fig. No. 2 - etched with 0.5% of HNO_3 solution in ethanel, Mag.: X100

- illustrates ferritic clusters around graphite grains and distribution of pearlite in the structure.

Fig. No. 3 - etched with 0.5 % of HNO_3 solution in ethanol, Mag.: X400. It enables a more detailed observation of the basic metallic matrix and graphitic grains.

5. Comparison of our own Analysis on Cast Iron Sample Designated as No.6 with that carried out by Messrs. SEMI

For the sake of an easier observation and a better illustration, the values given in Messrs. SEMI test reports and those obtained in our enterprise were listed in Tab. II.

From Tab. II, it follows:

- the chemical composition determined in Messrs. SEMI laboratories as well as that of the sample supplied /No. 6/ determined in our laboratories do not basically differ from each other.

- values obtained in the hardness test are more or less analogous,

- mechanical values obtained in the tensile strength test are very similar to those of the sample II /melting 6/ given in Messrs. SEMI test report, but differ substantially from those of the sample I. /A more detailed analysis could not be performed since the test reports did not inform of individual samplings/,

- evaluation of the metallic matrix in metallographic analysis of the Cast Iron sample supplied /No. 6/ corresponds with that of the sample I and II., but is completely different from that of the sample III.

The evaluation of the percentage of ferrite and pearlite based on the photographs 31 to 36 is impossible due to their bad quality.

When evaluating the graphite type the results of Messrs. SEMI do not differ from those obtained in our analysis.

Tab. I Mean values of the chemical composition /%/

										Mechanical properties			Matrix
Standard	C	Si	Mn Max.	P Max.	S Max.	Mg	Ni Max.	Cu Max.	Rm /MPa/	A5 %	Hardness HB	Content of ferrite and pearlite %
CSN 42 2303	3.4-4.1	2.3-2.8	0.5	0.10	0.02	0.03-0.10	0.5	0.2	370	17	140-180	Pe - P6 Fe - Fe 94
CSN 42 2304	3.4-4.1	2.3-2.8	0.15	0.10	0.02	0.03-0.10	0.5	0.2	400	12	150-200	Pe - P6 Fe - Fe 94
CSN 42 2305	3.4-4.0	2.3-2.8	0.15-0.26	0.10	0.02	0.03-0.10	0.5	0.2	500	7	170-240	P45 - P 70 Fe 55 - Fe 30
CSN 42 2306	3.4-4.1	2.3-2.8	0.4 0.6	0.10	0.02	0.03-0.10	1.0	0.2	600	3	190-270	P 70 - P 85 Fe 30 - Fe 15
CSN 42 2307	3.4-4.1	2.3-2.8	0.4-0.6	0.10	0.02	0.03-0.10	1.0	0.2	700	2	230-300	P 85 - P Fe 15 - Fe 0

Explanation of abbreviations used:

Rm .... tensile strength /min. value/
A_5 .... elongation /min. value/
P .... pearlite
Fe .... ferrite
N .... mean values of the chemical composition are based on material sheets "Material Catalogue of Ductile Cast Iron" published in Krakew in 1981

Tab. II

Melting No.6	Chemical composition %									Mechanical Properties		
										Rm	A5	Hardness
Sample No.	C	S	P	Si	Mn	Ni	Cr	Cu	Mg	kp/mm^2	%	HB 10/3000
I. /Messrs SEMI/	3.38	0.006	0.04	3.17	0.28	0.057	0.52	-	-	57,51	2.8	228
II. /Messrs SEMI/	3.7	0.005	0.05	2.8	0.25	0.055	0.51	-	-	63.0	12.0	200
III./Messrs SEMI/	not given									not given		
IV./Messrs ZETOR/	3.38	0.008	0.036	2.8	0.15	0.07	0.47	0.02	-	62.5	11.8	208-218

Structure

Matrix		No.of graphitic grains/mm	Graphite type	Photo	
I. /Messrs.SEMI/	ferrite 50% pearlite 50%	140	spherical	31.32	
II. /Messrs SEMI/	ferrite 50% pearlite 50%	120	spherical + seme pseudelamellac	33.34	
III./Messrs SEMI/	ferrite 10%	90	spherical + seme pseudelamellac	35.36	
IV./Messrs ZETOR/	ferrite 50-60% pearlite 50-40%	100-115	perfectly nodular + imperfectly nodular + vermicular	1.2	

ANNEXURE-II

HEAT TREATMENT HAND BOOK
(FERROUS MATERIALS)

14102
(4 of 4)

UNIDO-HMT (INTERNATIONAL)
CONTRACT NO.T81/80 HR

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CHAPTER I

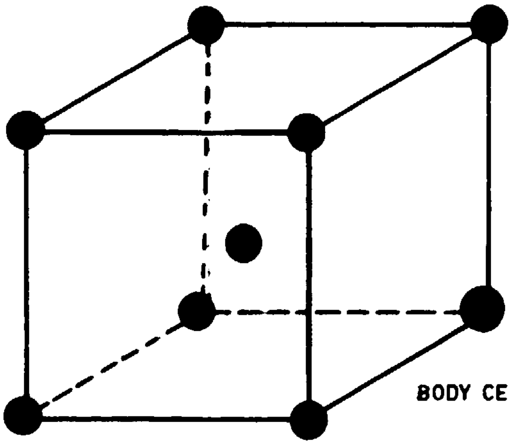
Metallurgical Terms & Explanations

1. METALLURGICAL TERMS AND EXPLANATIONS

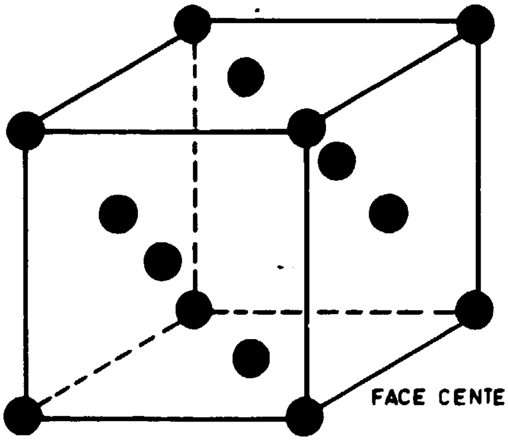
Table of contents

1.1 Crystal Structure

Steel, like any other metals, exists in crystalline form. Because of the very small sizes of the crystals, a powerful X-Ray Diffraction Equipment is necessary to examine the crystal structures. There are two basic forms of crystal structure; the body centered cubic (b.c.c) crystal and the face centered cubic (f.c.c) crystal. Arrangement of atoms in the above two types of crystals is shown in Figure 1.1.



BODY CENTERED CUBIC CRYSTAL (b.c.c.)



FACE CENTERED CUBIC CRYSTAL (f.c.c.)

FIG. 1.1 FORMS OF CRYSTAL STRUCTURE IN STEEL

It is possible to change the crystal structure by heating/cooling. This transformation of crystals is the basic phenomenon which makes it possible to heat treat steel to obtain different mechanical properties.
In the pure form iron exist as body centered cubic crystals upto 910°C and when heated

above this temperature it is transformed into face centered cubic structure. The b.c.c form of iron is called α - Iron (Ferrite) and the f.c.c form is called γ - Iron (Austenite)

In the case of steel the transformation temperature of α - iron to γ - iron depends upon the percentage of carbon.
The relationship between the transformation temperature and percentage of carbon in steel is represented by the Iron Carbon Equilibrium Diagram given in Fig. 1.2.

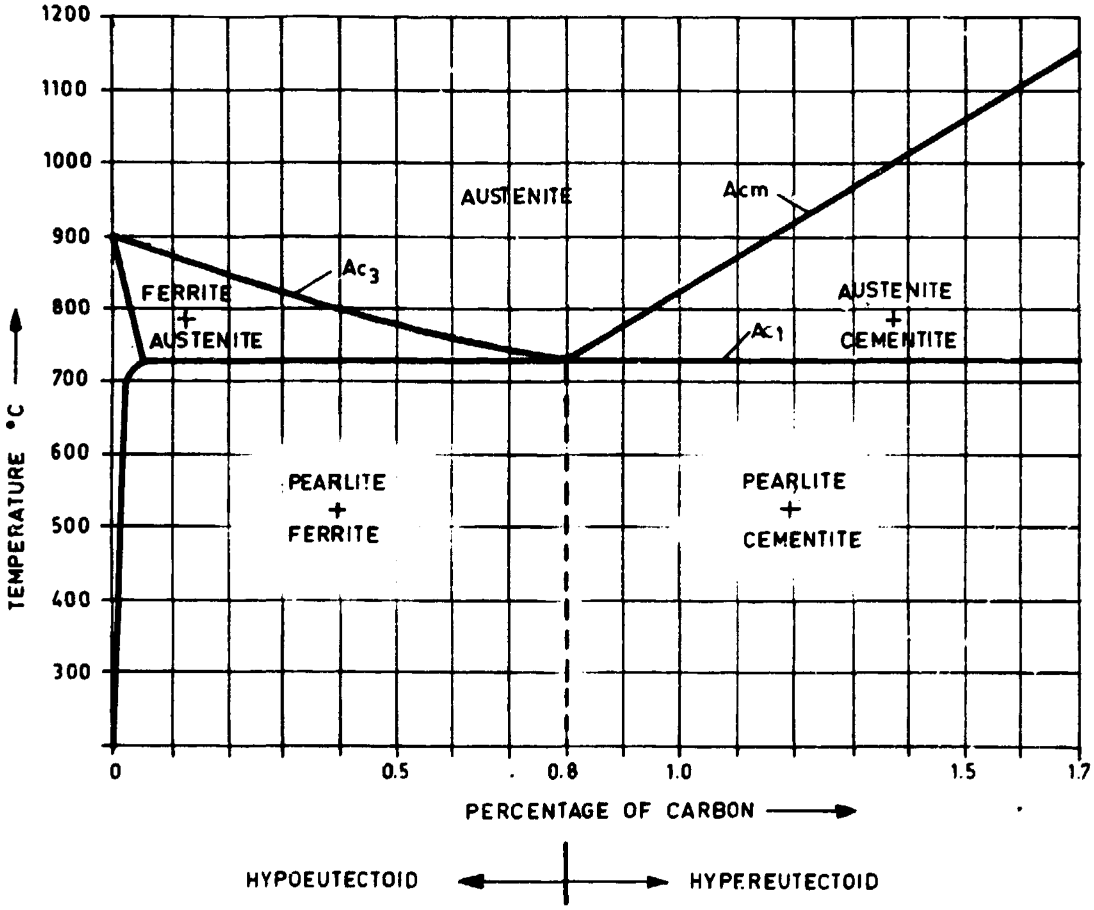


FIG. 1.2 IRON CARBON EQUILIBRIUM DIAGRAM

1.2 Iron Carbon Equilibrium Diagram

The iron carbon equilibrium diagram is the foundation on which all heat treatment of steel is based. Fig. 1.2 gives the iron carbon equilibrium diagram for carbon contents upto 1.7% which is the normal limit for steel. Ac1 is the temperature at which transformation of ferrite into austenite starts and Ac3 and Acm show the temperatures when the transformation to austenite is complete. Ac1 is called the lower critical point and Ac3 and Acm are called the upper critical points. S is the point where Ac1 and Ac3 meet, and the composition corresponding to this point (0.8%C) is called the eutectoid composition. This composition consists entirely of pearlite. Below this percentage of carbon, ie. 0.8%C, the structure will contain pearlite and ferrite and above this, ie. above 0.8%C, the structure will contain pearlite and cementite. Steels containing less than 0.8%C are called hypoeutectoid steels and those containing more than 0.8%C are called hyper-eutectoid steel.

The iron carbon equilibrium diagram shows the transformation of steels containing iron and carbon only; but in practice steels contain other alloying elements also, which affect the transformation characteristics. Further the iron-carbon diagram represent behaviour of steel under conditions of extremely slow heating and cooling and does not account for structural changes due to rapid cooling as encountered in heat-treatment operations. Hence the iron carbon equilibrium diagram should be used only as a guide. The variation of the critical points (Ac1 and Ac3) due to the presence of alloying elements can be approximately calculated using the following formulae:

$$Ac3\ ^\circ C = 910 - 203\sqrt{C} - 15.2Ni + 44.7\ Si + 104V + 31.5\ Mo + 13.1\ W$$

$$Ac1\ ^\circ C = 723 - 10.7\ Mn - 16.9\ Ni + 29.1\ Si + 16.9\ Cr + 290\ As + 6.38\ W$$

Where C, Ni etc. represent the percentage of the element by weight present in the steel.

1.3 Constituents of Microstructures

1.3.1 Ferrite

Ferrite is practically pure iron. It is crystalline with a body centered cubic structure. It is also called alpha iron. It is magnetic. When heated to high temperatures (~800 - 900°C) it gets converted to non-magnetic austenite (γ- iron). A typical photograph of ferrite is given in Fig. 1.3.

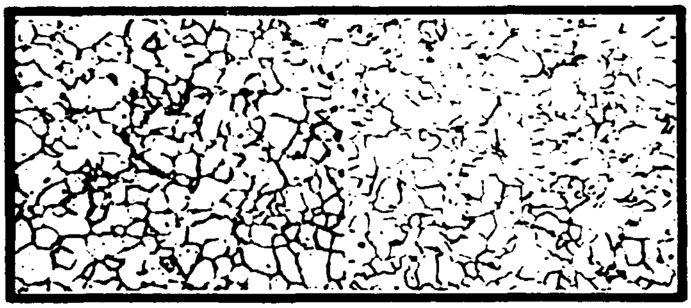


FIG 1.3 FERRITE IN LOW CARBON (X 100)

Ferrite is produced when steels containing low percentages of carbon (below 0.8%C) are cooled slowly. It is very difficult to get a structure with only ferrite as there will be always some carbon present in the steel which will form another structure called pearlite. The principal heat treatment operations which produce ferritic structure are annealing and normalising. Ferrite is soft, ductile and relatively weak. Hence, the presence of large amounts of ferrite in steel makes it soft and ductile. Steel is easily machinable in the ferritic condition, but when the ferrite is very coarse the machinability is reduced and the surface finish after machining will be very poor. Commercially pure ferrite has a tensile strength of about 28 to 35 Kg/mm^2 with an elongation of about 40%. Its hardness is about 90 HBN.

1.3.2 Pearlite

The iron and the carbon present in steel combine in a fixed ratio to form a new constituent called pearlite. Pearlite appears as a dark etching constituent in the microstructure. Under very high magnifications it can be seen that pearlite consists of alternate plates of ferrite and cementite. Typical microstructure of pearlite is given in Fig.1.4.

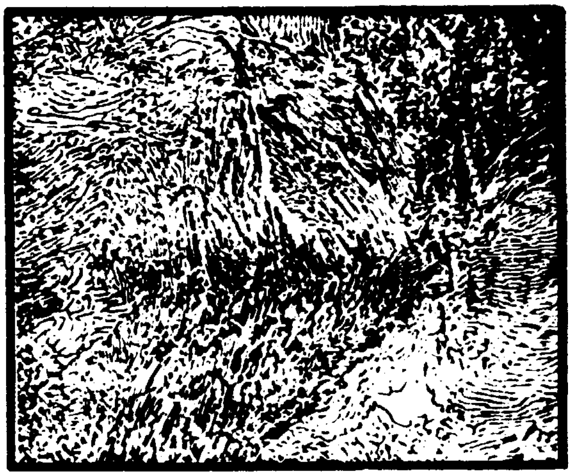


FIG 1.4 PEARLITE IN STEEL (X 500)

Pearlite occurs in slowly cooled steels. In eutectoid steels the structure will be fully pearlitic; in hypoeutectoid steels pearlite will be present along with ferrite and in hypereutectoid steels it will be present along with cementite.

Operations such as full annealing and normalising produce pearlite in the structure. Pearlite is not stable at high temperatures and gets converted to austenite when heated above the critical point.

Pearlite is a tough constituent with a tensile strength of approx. 88-105 Kg/mm^2 and about 10% elongation. Its hardness is 250-300 HBN, depending the fineness of its structure. Hence steels with pearletic structure have higher hardness and wear resistance when compared to ferritic structure. The machinability of pearlitic steels depend upon the percentage of ferrite or cementite present along with pearlite and also on the grain size of the pearlite, ie. fine grained or coarse grained. Normalising produces fine grains whereas full annealing produces coarse grains.

1.3.3 Cementite

Cementite is a very hard and brittle carbide of iron ($Fe3C$) which is found in steel as a constituent of pearlite and sometimes in the free condition. It will be present in the free condition in steels containing carbon higher than eutectoid composition. Free cementite is found in globular, massive or network form. Fig. 1.5 shows free cementite in the network form present in grain boundaries of martensite.

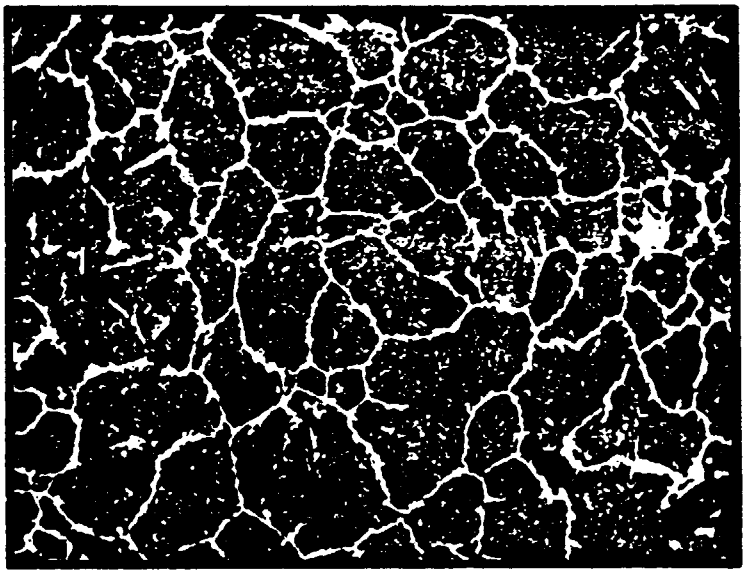


FIG 1.5 FREE CEMENTITE AROUND GRAINS OF MARTENSITE (X 100)

Cementite network formed on grain boundaries provide an easy fracture path and renders the steel brittle. By full annealing such continuous carbide networks are broken up into separated spherical carbide particles which reduces the brittleness and increases the machinability. Normalising also breaks-up the carbide network. In the spherodised steel, the cementite is present in fine spherical shape, which gives high ductility and good machinability. Fig. 1.6 shows fine spherodised cementite in 1 percent carbon steel.

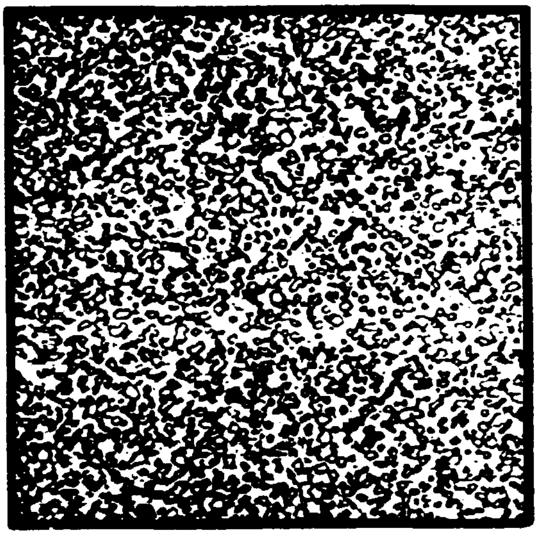


FIG 1.6 SPHERODISED CEMENTITE IN 1% CARBON STEEL (X 500)

The hardness of cementite is about 650 HBN and it is extremely brittle. Other mechanical properties of cementite could not be determined as it is not possible to prepare pure cementite in test bar form. It is expected that the tensile strength of cementite should be around 227 Kg/mm^2.

1.3.4 Austenite

Austenite is the solid solution of carbon in iron. It has a face centered cubic crystal structure and it is non-magnetic. The art and science of heat-treatment is based on the formation of austenite when steels are heated. Austenite is not stable at room temperatures, except in the case of austenitic stainless steels. As the crystals of austenite contain more atoms due to the face centered cubic structure, it is more dense when compared to the α - iron (ferrite) with body centered cubic structure. Hence volume expansion occurs when austenite is cooled to form body centered structures. Fig. 1.7 shows the photograph of typical austenite.

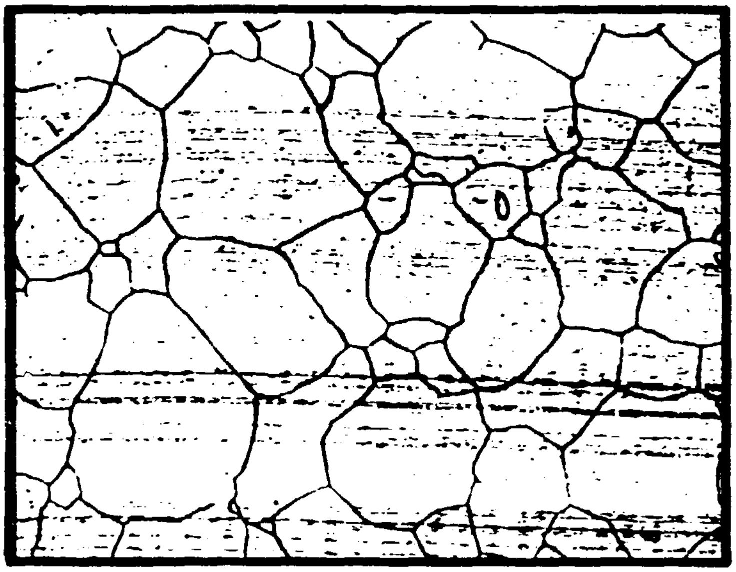


FIG 1.7 AUSTENITE IN STEEL (X 100)

Austenite is formed in all steels when it is heated above its critical point. The temperature at which austenitic transformation takes place will depend upon the percentage of carbon and other alloying elements present in the steel.

The size of the austenitic grains is important in obtaining the required mechanical properties in heat-treated steel. The finer the grain size, the better the mechanical properties. Higher temperatures and longer soaking times cause coarsening of the austenitic grain size. Alloying with small amounts of aluminium, vanadium or niobium produces very fine austenitic grains.

1.3.5 Martensite

FIG 1.8 DARK NEEDLES OF MARTENSITE IN AUSTENITE MATRIX (X 1000)

Martensite is the supersaturated solid solution of carbon in iron formed by transforming austenite below the Ms temperature. It is the essential constituent of fully hardened steel and is the hardest that can be obtained by quenching. Martensite has a body centered tetragonal crystal structure. The needle like structure of martensite is shown in Fig. 1.8.

Martensite is produced by the quenching of steel from the austenitising temperature. In the as quenched condition the martensite is brittle and should be tempered to reduce the brittleness. Upon reheating to temperatures below 200°C, the structure of primary martensite begins to release the carbon held in supersaturated solution, permitting the crystals to decrease in tetrangonality. This carbon tends to precipitate within the martensite grains in the form of hexagonal iron carbide called the epsilon (E) carbide. Further heating causes the gradual conversion of martensite to ferrite and cementite.

1.3.6 Bainite

Bainite is the microstructural constituent formed under continuous cooling or isothermal transformation conditions intermediate to those of pearlite and martensite formation. It is produced when steel is austempered. Bainite is a mixture of phases ferrite and cementite. The hardness of bainite is in between the hardness of martensite and pearpite. The internal stress accompanying quenched martensite is not present in bainite. Therefore it is not necessary to temper bainitic structures.

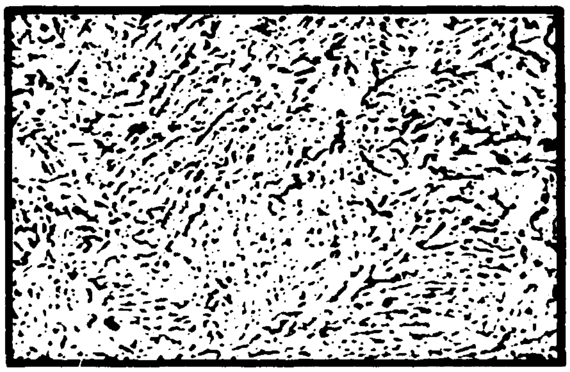


FIG 1.9a UPPER BAINITE (X 1200)

FIG 1.9b LOWER BAINITE (X 1200)

There are two types of bainites called the upper bainite and the lower bainite. The photographs of upper and lower bainites are given in Figs. 1.9a and 1.9b. Upper bainite is produced when austenite is transformed at higher temperatures (close to pearlite transformation range) and lower bainite is formed when the transformation takes place at lower temperatures (close to the martensite transformation range). The upper bainite has lower hardness when compared to lower bainite. Bainitic structures give higher strength when compared to tempered martensitic structures having the same hardness.

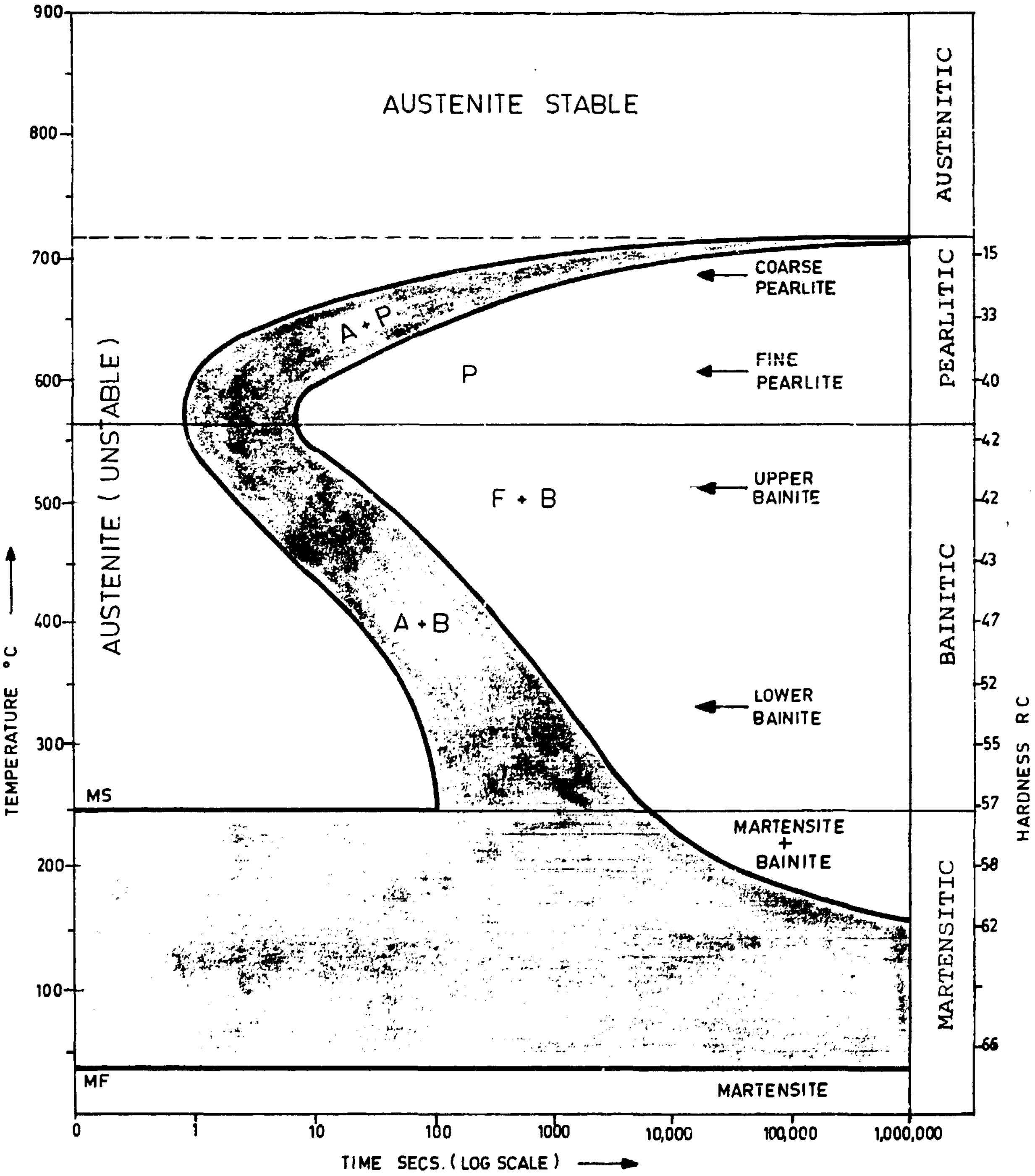
1.3.7 Retained Austenite

When steels containing higher percentages of carbon or alloying elements are quenched from the austenitising temperatures, the austenite will not completely get transformed into martensite. A part of the austenite remains frozen as austenite and this is called the retained austenite. Drastic quenching such as water quenching produces less retained austenite when compared to other slow quenching methods such as air cooling. Similarly alloying elements chromium, manganese etc. also favour the formation of more retained austenite. High alloy steels such as 12% Cr steels, when air cooled from austenitising temperature can have upto 30% retained austenite.

The retained austenite present in the steel gets slowly converted to martensite over the life of the part. As martensite transformation is accompanied with volume change, it causes small distortion to the finished part. Hence high precision components should not contain retained austenite. Retained austenite is converted to martensite by sub-zero treatment of parts immediately after hardening.

1.4 T.T.T Diagrams

Most of the heat-treatment operations depend upon the transformation of austenite into desired structures or mixtures of structures by adopting suitable cooling rates/cooling cycles. The T.T.T diagram shows the relationship between time, temperature and transformation product for the particular steel. Because this curve in many cases resemble 'S' it is also called 'S Curve'. A typical T.T.T diagram is shown in Fig.1.10. Since the diagram is prepared by studying the transformation of austenite at fixed temperatures, it is also called the isothermal transformation diagram. In the diagram logarithmic scale is used to represent time in order to make the diagram compact. The transformation products shown are the structures obtained when austenite is held at particular temperatures.



A = AUSTENITE; P = PEARLITE; F = FERRITE; B = BAINITE

FIG. 1.10 ISOTHERMAL TRANSFORMATION DIAGRAM (TTT DIAGRAM) FOR 0.8%C STEEL

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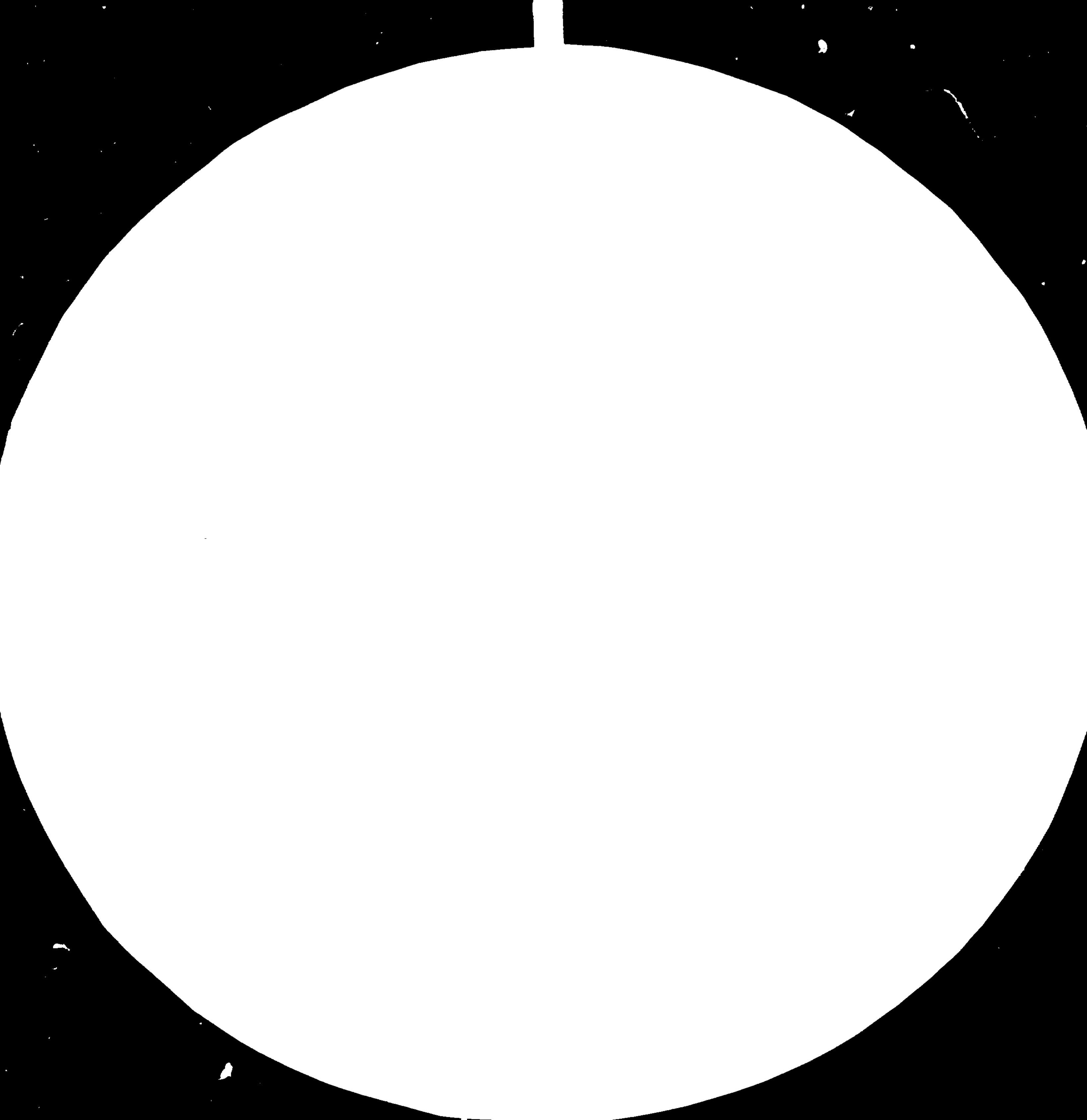
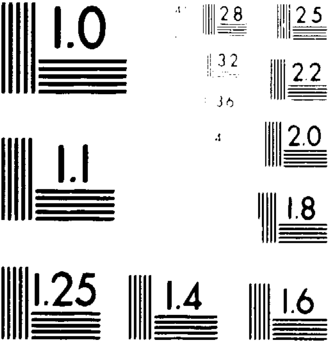




MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

(ANSI and ISO TEST CHART No. 2)

The transformation products obtained at a particular cooling cycle is found out by drawing a curve corresponding to the cooling rate (Time Vs Temp) on the T.T.T diagram. Products of transformation will depend upon where this curve cuts the T.T.T diagram (See Fig.1.11). In the Fig.1.11, the water quenching curve cuts the T.T.T curve at the Ms. range only. Therefore the entire structure will be martensite. But the oil quenching curve cuts the T.T.T curve near its nose and about 65% pearlite transformation takes place at this area. Afterwards the cooling curve cuts the T.T.T curve at the martensite area only and hence the remaining 35% will be martensite. Similarly the air cooling curve cuts the T.T.T curve completely at the pearlitic region and hence the structure as cooled will be completely, pearlitic. Thus using this curve the transformation products for different cycles of quenching can be determined.

The T.T.T curve is different for different steels. With the addition of alloying elements the shape of the curve changes considerably. For steels with higher hardenability, the nose of the T.T.T curve is shifted to the right enabling the use of slower quenching mediums such as oil, air etc., to produce martensitic structures.

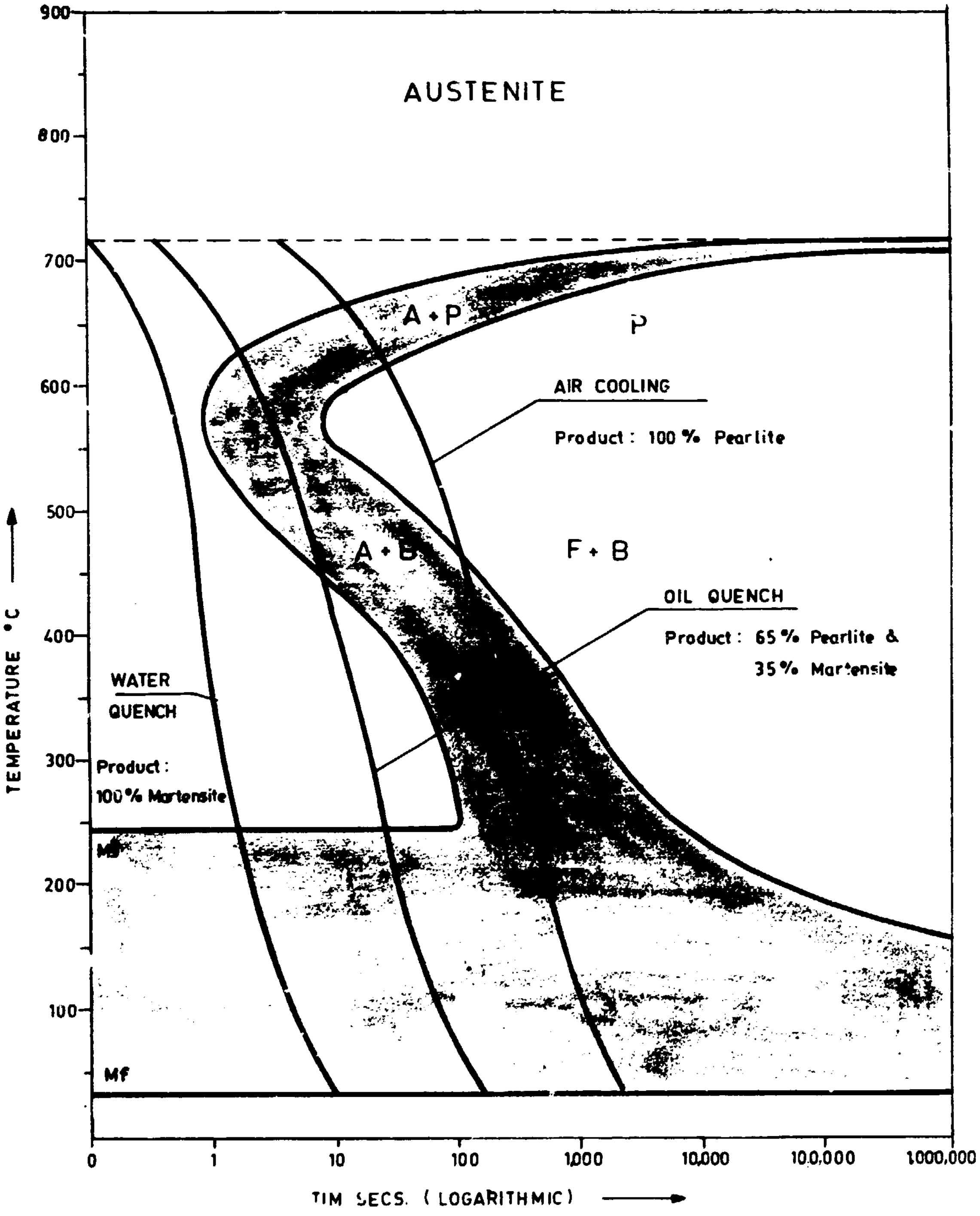


FIG. 1.11 TYPICAL TTT-DIAGRAM SHOWING THE PRODUCTS OF QUENCHING AT DIFFERENT RATES

1.5 Continuous Cooling Transformation Diagrams

The T.T.T diagram represents the transformations under constant temperatures (isothermal). But in practice very few commercial heat treatments occur in this manner. In almost all cases, the metal is heated to the austenite range and then continuously cooled to room temperature with the cooling rate varying with the type of treatment and the size and shape of the specimen. Therefore, curves are prepared showing the transformation under continuous cooling, which are called continuous cooling transformation diagrams. These diagrams vary slightly from the T.T.T Diagram and the difference in the case of 0.8%C steel is shown in Fig.1.12. It will be noted from the figure that the austenitepearlite transformation range is shifted to the right in the continuous cooling transformation diagram. The reason for this is that the Austenite Pearlite transformation delay period in T.T.T diagram is obtained when the steel is held at the particular temperature. Where as in C.C.T diagram the steel is cooled from higher temperatures and not maintained at the particular temperature and the A - P transformation delay period is longer at higher temperatures. Another difference is the absence of the bainite regeon in the C.C.T diagram. This gap represents the range where no transformation takes place

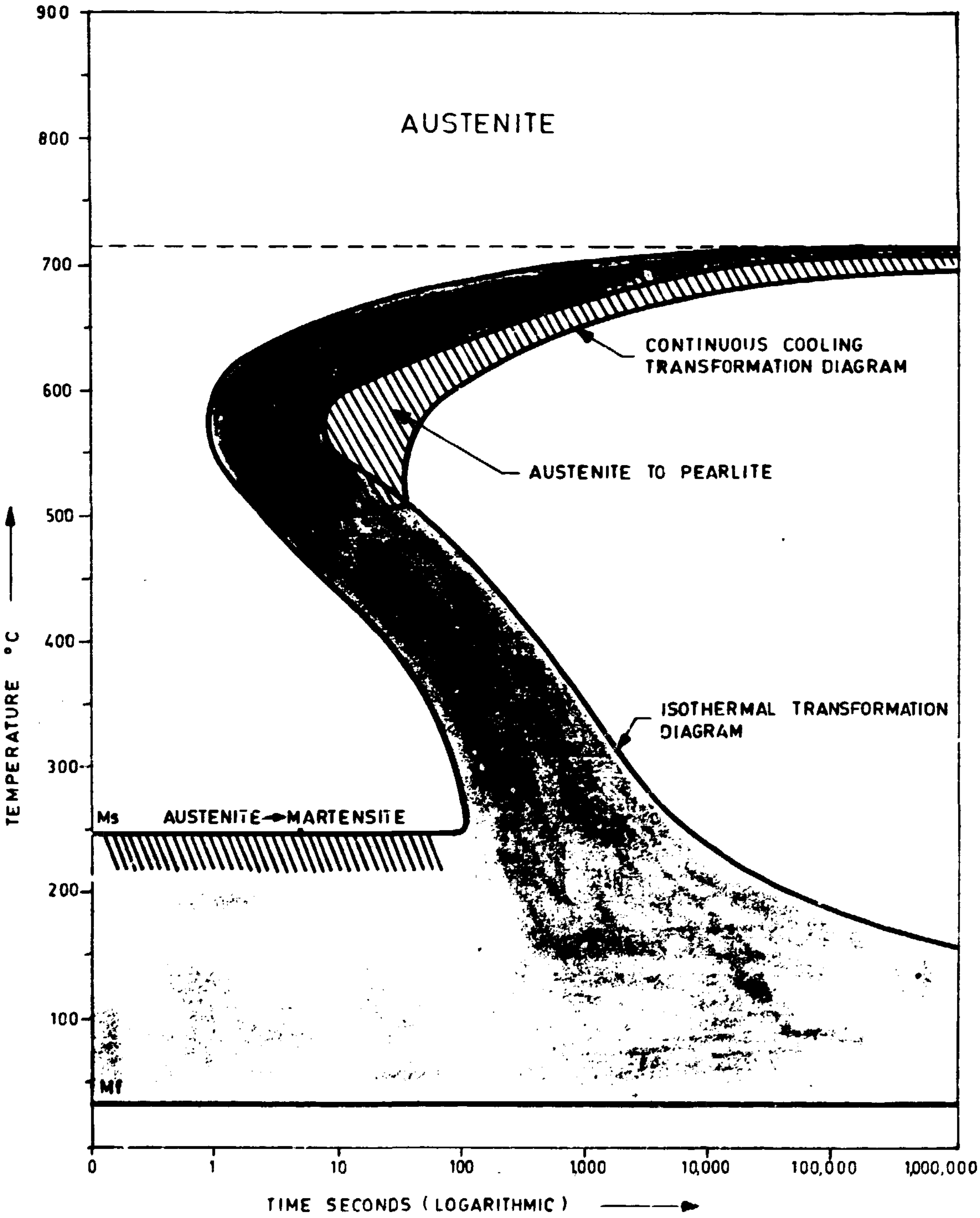


FIG 1.12 TYPICAL CONTINUOUS COOLING TRANSFORMATION DIAGRAM SUPERIMPOSED ON THE ISOTHERMAL TRANSFORMATION DIAGRAM (TTT DIAGRAM)

because on slow and moderate rates of cooling austenite is completely converted to pearlite before the cooling curve reaches the bainite transformation range. The continuous cooling transformation diagram gives more correct information about the structures produced at various cooling rates, when compared to the T.T.T diagram. Hence, the C.C.T diagram is more useful in practical applications.

The C.C.T diagrams described above is the basic form, which does not show the effect of section thickness. Hence, the diagram generally used by heat treaters is slightly different. In this type of diagram, the X-axis shows three different scales representing the diameters for which the particular structure will be obtained on air cooling, oil qunching and water quenching. Such a diagram for plain carbon steel is shown in Fig.1.13. To find out the structure obtained for a particular diameter (say 10 mm) when quenched at the three different quenching rates, three vertical lines are drawn corresponding to the diameter (say 10 mm) on X-axis for air, oil and water quenching and from the positions where these lines cut the C.C.T. curves, the structure can be read. For example, in Fig. 1.13 (a), the vertical line corresponding to 10 mm dia. for water quenching cuts the curves in the martensite range only. Hence, the structure will be entirely martensitic.

The oil quench line cuts the curves in the bainite and martensite regions so that the structure will contain bainite and martensite. Similarly, air cooling will produce a mixture of ferrite pearlite and little bainite. The C.C.T diagrams for different steels can be obtained from books such as "Atlas of Continuous Cooling Transformation Diagrams for Engineering Steels" (Ref.8), "Atlas of Isothermal Transformation and Cooling Transformation Diagrams" by American Soceity for Metals.

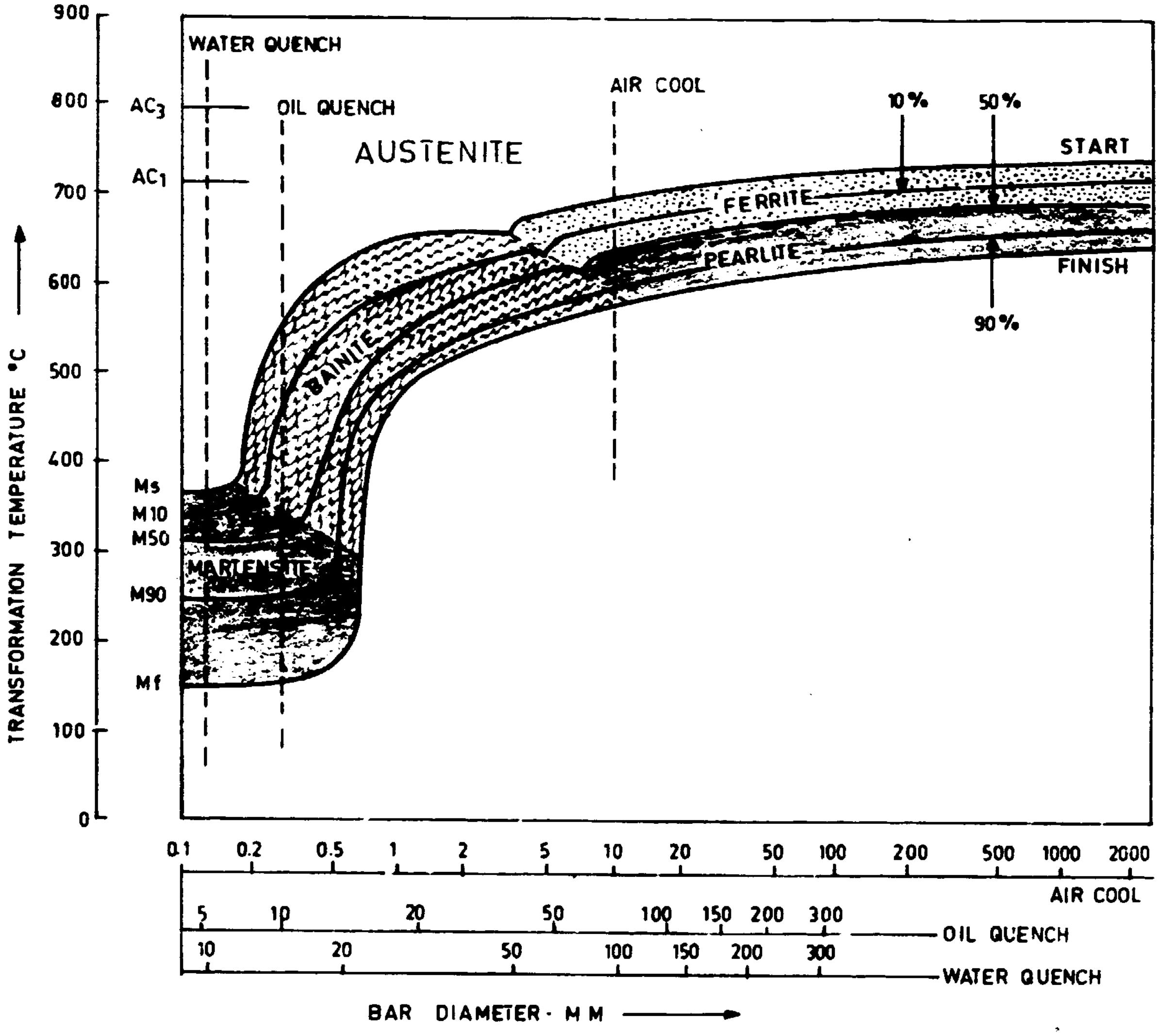


FIG. 1.13 CCT DIAGRAM FOR 0.38%C AND 0.7% Mn WITH BAR DIAMETERS

1.6 Hardenability

Hardenability is defined as the property in ferrous alloys that determines the depth and distribution of hardness produced by quenching. The hardenability of steel depends on

i) the quenching medium and the method of quenching
ii) composition of steel and the method of manufacture
and iii) section thickness of the steel

It is necessary to know the hardenability of steels in order to select the proper quenching medium and to predict the effect of section thickness on the hardness value obtained.

There are many methods of testing and representing the hardenability. The most commonly used method is the Jominy Test. In the Jominy test, a 25 mm dia. bar 100 mm long is heated to the normal hardening temperature, then inserted in a std. jig and a 12.5 mm dia. jet of water at 24°C is directed against one end of the test piece. When cold, hardness measurements are made along flats on the bar and these are plotted against distance from the quenched end. Typical Jominy hardenability curves for three different steels are given in Fig. 1.14.

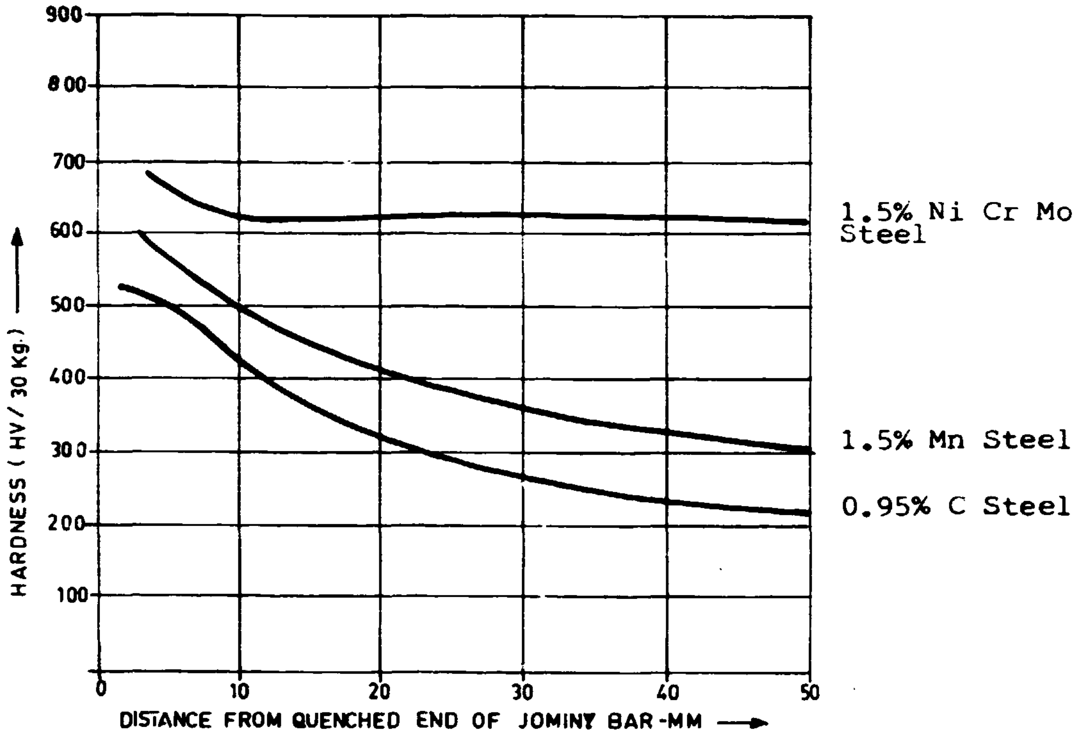


FIG. 1.14 TYPICAL JOMINY HARDENABILITY CURVE FOR 3 DIFFERENT STEELS

The hardenability of the same grade of steel will vary from lot to lot even though the chemical composition is within the limits of the specifications. For example Fig.1.15 shows the hardenability band for medium carbon steels supplied to nominal range 0.35 - 0.45% C., 0.7 - 1.2% Mn. Hence when the properties after heat treatment are critical, along with the chemical composition of the steel the minimum and maximum range for the hardenability also should be specified at the time of ordering the steel.

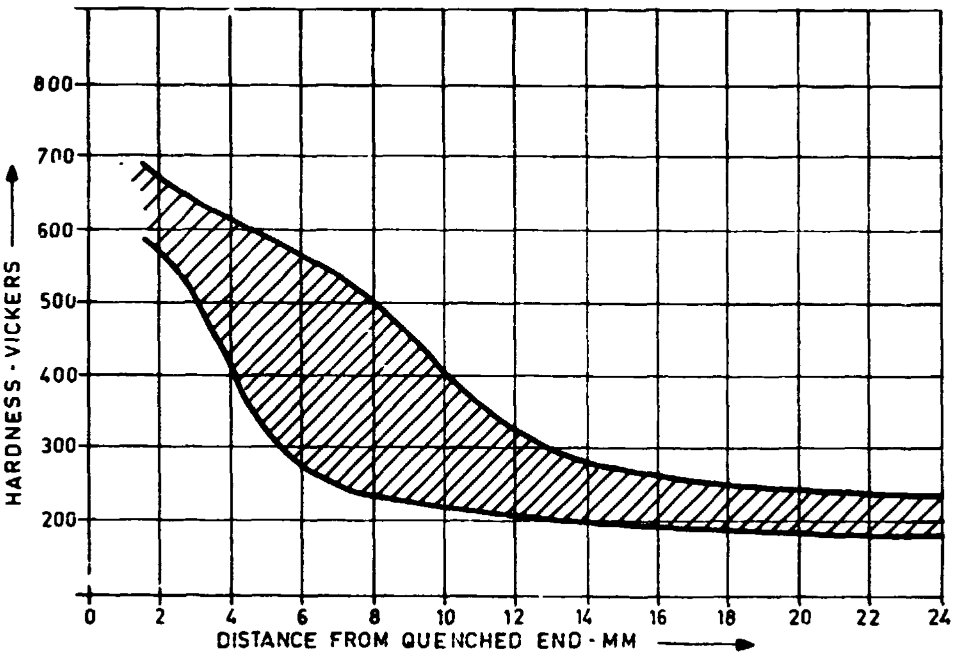
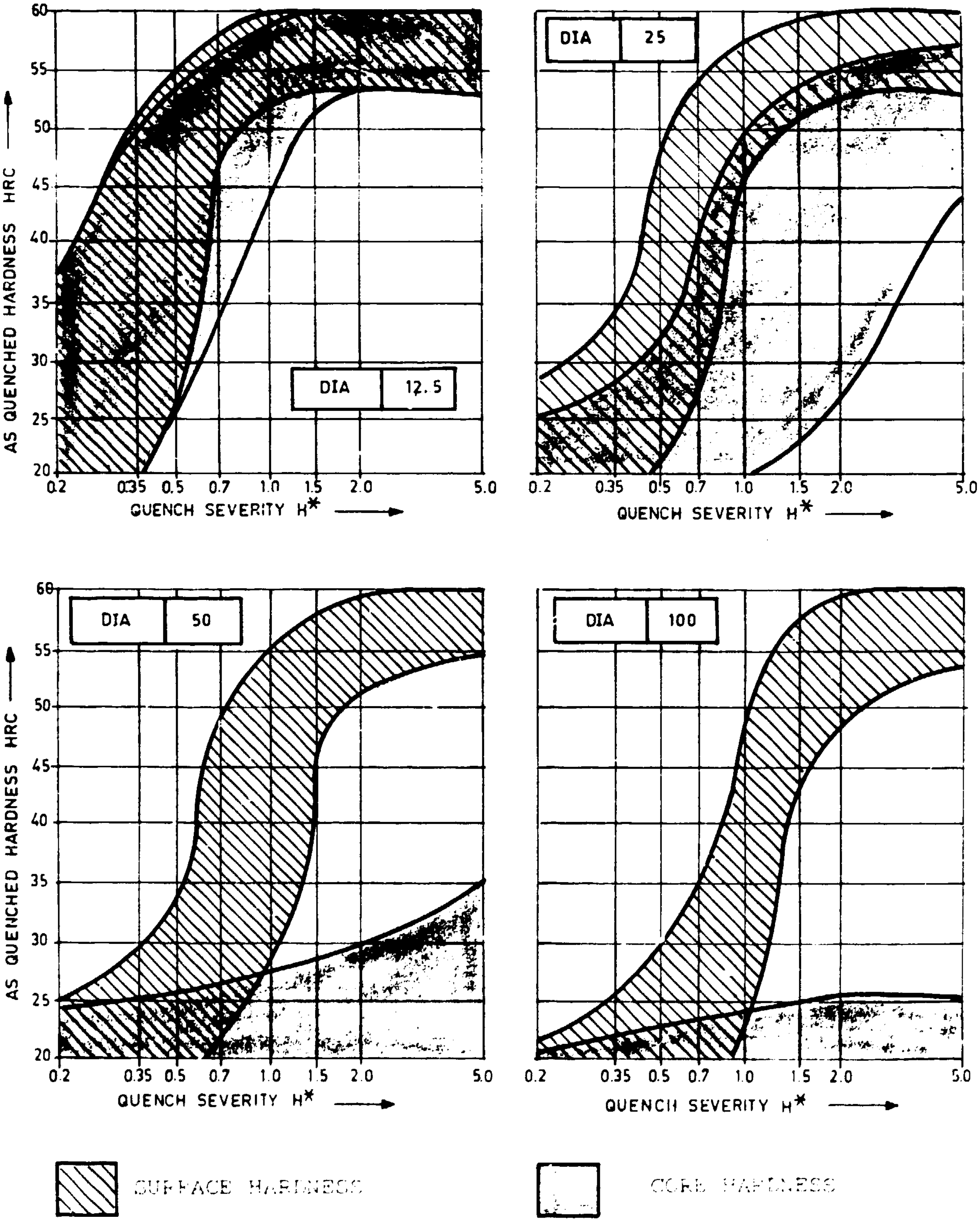


FIG. 1.15 HARDENABILITY BAND OF MEDIUM CARBON STEEL
0.35-0.45%C, 0.7-1.2% Mn

The Jominy test hardenability curves do not take into consideration the effect of section thickness and the severity of quench. For example it is difficult to predict from the hardenability curve the surface and core hardness of a low hardenability steel with say 100 mm diameter and using oil quenching. Hence, a new type of chart has been recomended by the Wolfson Heat Treatment Centre (Heat Treatment of metals 1975.1, p 7-10) which enables the prediction of surface and core hardnesses easily and more accurately. This new method of representation consists of a series of graphs showing the relationships between the surface and core hardness and different quenching rates.

Separate graphs are presented for various section thicknesses eg. for section thicknesses 12.5 mm, 25 mm, 37.5 mm, 50 mm, 70 mm, 100 mm etc. The X-axis of the graphs show the H value, which represents a measure of the severity of quench. The H values corresponding to different quenching mediums are given in a separate table (See Table 1.1). A typical representation of such graphs is given in Fig.1.16. Thus with these charts it is easy to predict the hardness values achievable after hardening and also it is easy to choose the correct quenching medium for particular steels.



* See Table 1.1

FIG. 1.16 PREDICTED HARDENING RESPONSE OF C45 STEEL

QUENCHANT	AGITATION	H VALUE
Oil	No	0.20
Oil	Moderate	0.35
Oil	Good	0.50
Oil	Strong	0.70
Water	No	1.0
Water	Strong	1.5
Brine	No	2.0
Brine	Strong	5.0

TABLE 1.1 TYPICAL H VALUES FOR OIL AND WATER BASED QUENCHANTS

1.7 Effect of Alloying Elements

The influence of alloying elements on the properties of steel is given in Table 1.2. Apart from getting improved properties, alloying is done to increase the hardenability of the steels. The main alloying elements which increase the hardenability are Cr, Mo, V, Mn and Ni. Alloying elements permit greater wear resistance at the same hardness by promoting the formation of hard and wear resistant carbides that increase in relation to the total carbon and alloy content. Also alloying

ALLOYING ELEMENT	MECHANICAL PROPERTIES								Cooling rate	Carbide formation	Resistance to wear	Forgeability	Machinability	Scaling	Nitrability	Resistance to corrosion	MAGNETIC PROPERTIES				
	Hardness	Strength	Yield point	Elongation	Reduction of area	Impact value	Elasticity	High temp. stability									Hysteresis	Permeability	Coercive force	Remanance	Loss of watt
Silicon	↑	↑	↑↑	↓	∽	↓	↑↑↑	↑	↓	↓	↓↓↓	↓	↓	↓	↓	–	↓↓	↑↑	↓↓	–	↓↓
Manganese-pearlitic steels	↑	↑	↑	∽	∽	∽	↑		↓		↓↓	↑	↓	∽	∽	–					
Manganese-austenitic steels	↓↓↓	↑	↓	↑↑↑	∽	–	–	–	↓↓	–	–	↓↓↓	↓↓↓	↓↓	–	–	Not magnetic				
Chromium	↑↑	↑↑	↑↑	↓	↓	↓	↑	↑	↓↓↓	↑↑	↑	↓	–	↓↓↓	↑↑	↑↑↑			↑	↑↑	
Nickel-pearlitic steels	↑	↑	↑	∽	∽	∽	–	↑	↓↓	–	↓↓	↓	↓	↓	–	–			↑↑	↑↑	
Nickel-austenitic steels	↓↓	↑	↓	↑↑↑	↑↑	↑↑↑	–	↑↑↑	↓↓	–	–	↓↓↓	↓↓↓	↓↓	–	↑↑	Not magnetic				
Aluminium	–	–	–	–	↓	↓	–	–	–	–	–	↓↓	–	↓↓	↑↑↑	–			↑↑	↑↑	
Tungsten	↑	↑	↑	↓	↓		–	↑↑↑	↓↓	↑↑	↑↑↑	↓↓	↓↓	↓↓	↑	–			↑↑↑	↑↑↑	
Vanadium	↑	↑	↑	∽	∽	↑	↑	↑↑	↓↓	↑↑↑↑	↑↑	↑	–	↓	↑	↑					
Cobalt	↑	↑	↑	↓	↓	↓	–	↑↑	↑↑	–	↑↑↑	↓	∽	↓	–	–		↑↑	↑↑↑	↑↑↑	
Molybdenum	↑	↑	↑	↓	↓	↑	–	↑↑	↓↓	↑↑↑	↑↑	↓	↓	↑↑	↑↑	–			↑		
Copper	↑	↑	↑↑	∽	∽	∽	–	↑	–	–	–	↓↓↓	∽	∽	–	↑					
Sulphur	–	–		↓	↓	↓	–	–	–	–	–	↓↓↓	↑↑↑	–	–	↓					
Phosphorus	↑	↑	↑	↓	↓	↓↓↓	–	–	–	–	–	↓	↑↑	–	–	–					

↑ Increase ↓ Decrease ∽ Approx Constant – Not characteristic or Unknown

Several Arrows - More Intensive Effect

TABLE 1.2 THE EFFECT OF ALLOYING ELEMENTS ON THE PROPERTIES OF STEEL elements permit higher toughness at the same hardness in small sections.

Alloying elements also cause changes in the critical points. The relationships between the percentage of alloying elements and the critical points AC1 and AC3 are given in page 1.5. All the alloying elements except Cobalt and Aluminium decrease the Ms point. Due to the lowering of Ms point, alloying elements favour the formation of retained austenite.

All alloying elements reduce the eutectoid percentage of carbon, marked influence being produced by Ti, V, Mo and W. (Fig.1.17) Due to the lower percentage of carbon in the eutectoid, the alloying elements increase the amount of undissolved carbides, which gives these steels high wear resistance properties.

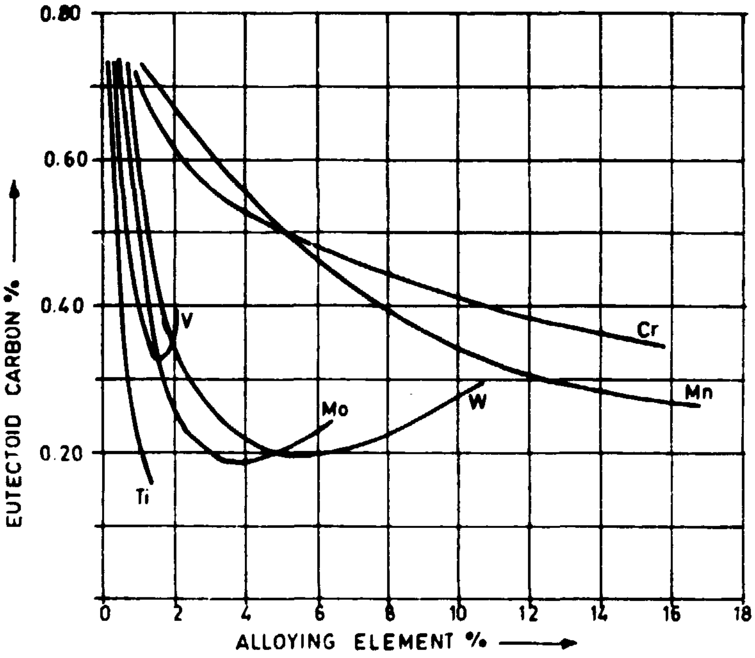


FIG. 1.17 EFFECT OF ALLOYING ELEMENTS ON EUTECTOID CARBON PERCENTAGE

All the alloying elements except cobalt increase the hardenability of steel, by virtue of their effect in retarding the rate of the austenite to pearlite reaction. The interaction of the alloying elements and the formation of complex carbides makes prediction of individual and overall effects of alloying elements on hardenability somewhat uncertain. However, the relative effect of low alloy additions can be represented as given in Fig.1.18 using multiplication factors. The effect of alloy additions on the base hardenability is obtained by applying multiplying factors for each element present, so that the product of those factors and the base factor for carbon and grain size results in an equivalent figure.

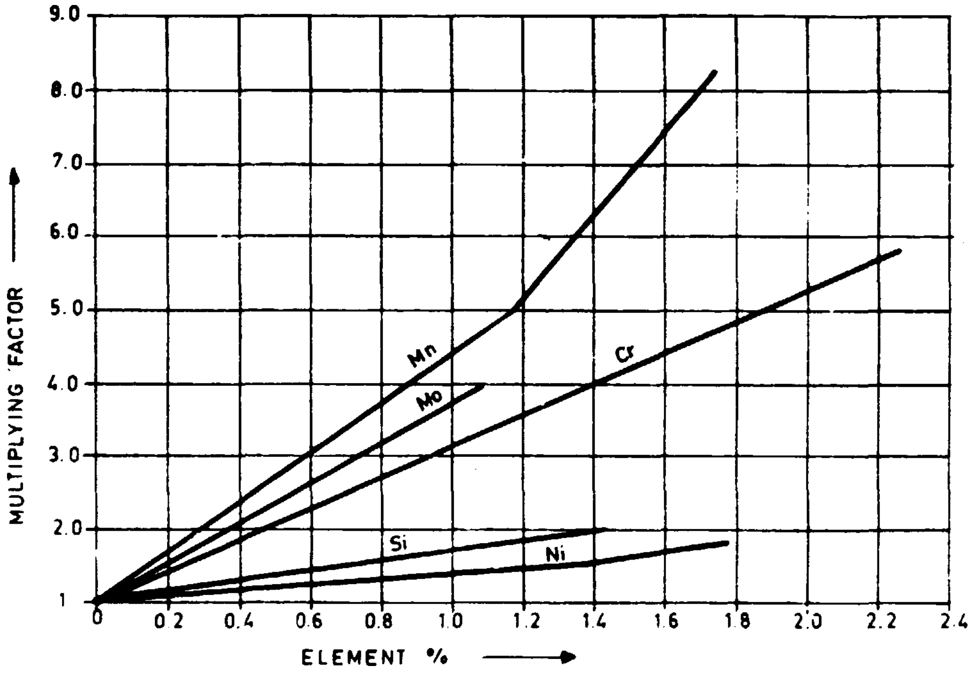


FIG. 1.18 EFFECT OF ALLOYING ELEMENTS ON THE HARDENABILITY OF STEEL

CHAPTER II

Heat Treatment Process

2. HEAT TREATMENT PROCESSES

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2.1 Stress Relieving

Stress-relieving operation is carried out to reduce the internal stresses that remain locked in the structure of metals as a consequence of rolling, casting, forging, machining, welding etc. The presence of large amounts of internal stresses cause excessive distortion. or cracking during post heat treatment and also affect the accuracies of precision parts. No structural change takes place due to stress-relieving. The two methods of stress-relieving. commonly followed are i) Thermal stress-relieving and ii) Vibratory stress relieving.

2.1.1 Thermal Stress-relieving

Thermal stress-relieving consists of heating uniformly the parts to a temperature below the transformation range (AC_1 for ferritic steels), holding at this temperature for a particular length of time and then cooling slowly in the furnace. The process followed for stress-relieving is to load the parts in the furnace and then gradually raising the temperature of the furnace. The normal temperature at which stress relieving is done is 600-650°C for steel and 500-550°C for cast iron. The soaking time required will be one hour for every 25 mm thickness of the part. After the soaking, the furnace is put-off and the parts are allowed to cool slowly in the furnace. The furnace door can be opened when the temperature reaches about 150°C and the parts can be further cooled in the air. Typical time-temperature cycle for stress-relieving is given in Fig. 2.1.

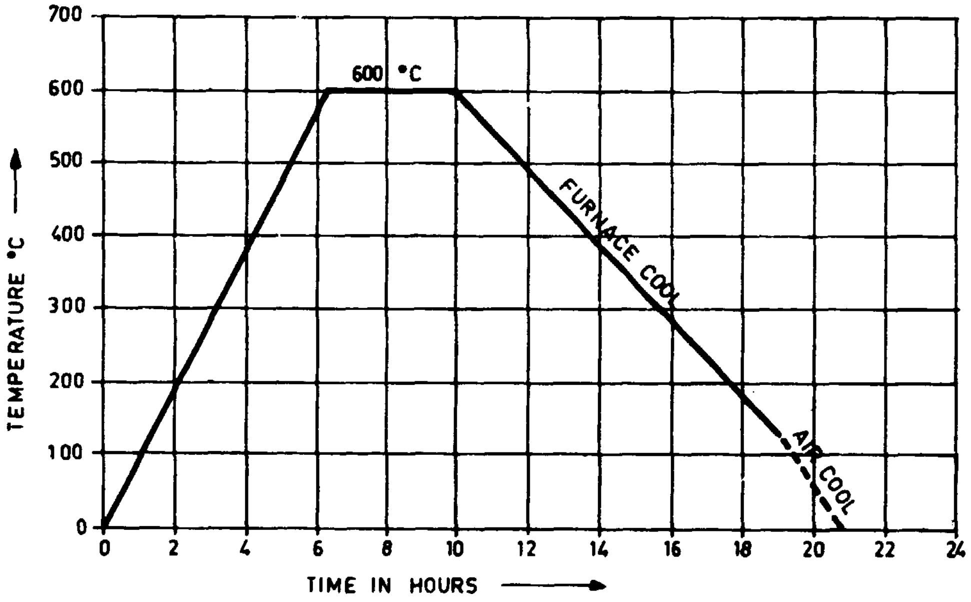


FIG.2.1 TYPICAL TIME TEMPERATURE CYCLE FOR STRESS RELIEVING

Stress-relieving can be done also at lower temperatures, but will need longer soaking times and the maximum percentage of relief of internal stresses achieved will be less. The relationship between time and temperature in the relief of residual stresses in steel is given in Fig. 2.2.

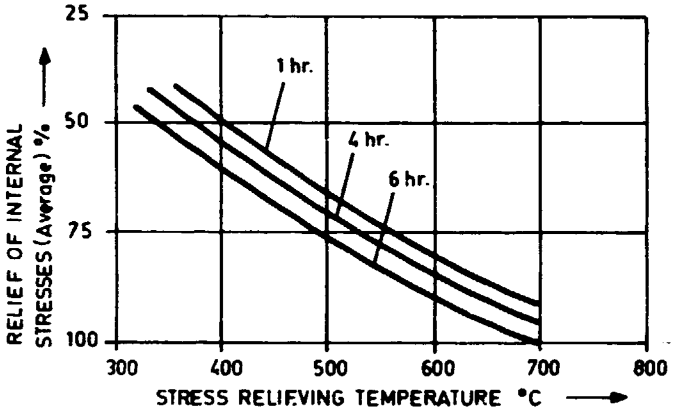


FIG.2.2 **RELATION BETWEEN STRESS RELIEVING TEMP. AND AMOUNT OF STRESS RELIEVED**

The equipments commonly used for thermal stress-relieving are air circulated furnaces, chamber furnaces and bogie hearth furnaces. Since the temperature required for stress-relieving is not high enough for good thermal conduction, it is preferable to have air circulation inside the furnace. It is not essential to have atmosphere controlled furnaces since the stress-relieving temperature is low.

Relieving of stress in other words mean allowing parts to assume its natural shape free from any stress. Hence stress relieving naturally causes distortion and to compensate for this parts should have sufficient machining allowance, to remove the distortion. The stress relieving should be done after rough machining before finish machining. As the parts have to take-up stress-free shapes, they must be loaded in the furnace in such a way that they are free to distort. For example, parts should not be loaded one over the other or kept in such a way restricting the freedom for distortion.

There is no practical method to inspect whether the parts have been stress relieved properly or not. Hence the best way to ensure proper stress relieving is to follow the procedure strictly.

2.1.2 Vibratory Stress Relieving

In this method parts to be stress relieved are subjected to vibrations at a frequency near to the resonant frequency of the part. For best results vibrations in two planes mutually parpendicular (bi-vectorial vibrations) are used. The amplitude of the vibrations will depend upon the rigidity of the parts. The vibratory stress relieving takes shorter times when compared to thermal stress relieving. Usually, the vibratory treatment needs only about 2 to 3 hours when compared with about 20 hours required for thermal stress relieving.

Unlike thermal stress relieving it is possible to determine the result of vibratory stress-relieving by checking the dimensional stability of the part after vibrating. Initially during the vibration parts will distort and after some time there will be no more distortion and at this point the stress relieving can be considered as complete.

2.2 Annealing

Annealing is a generic term denoting the heat treatment carried out to soften the materials. Steels may be annealed to facilitate cold working or machining, to improve mechanical or electrical properties or to promote dimensional stability.

2.2.1 Full Annealing

The full annealing process consists of heating the steel to a temperature slightly above the upper critical point, soaking for sufficient time and then cooling in the furnace slowly. The time-temperature relationship for full annealing is given in Fig.2.3. The cooling should be very slow; should not exceed 30-40°C per hour. The heating to annealing temperature also should be gradual to avoid thermal shocks. Hence the normal practice is to charge the material into the cold furnace and then heat the furnace to the required temperature. The soaking time required will be one hour for every 25 mm section thickness. After the soaking time is complete, the furnace is put-off and the charge inside the furnace is made to cool along with the furnace. The cooling rate of conventional furnaces is slow enough for proper annealing.

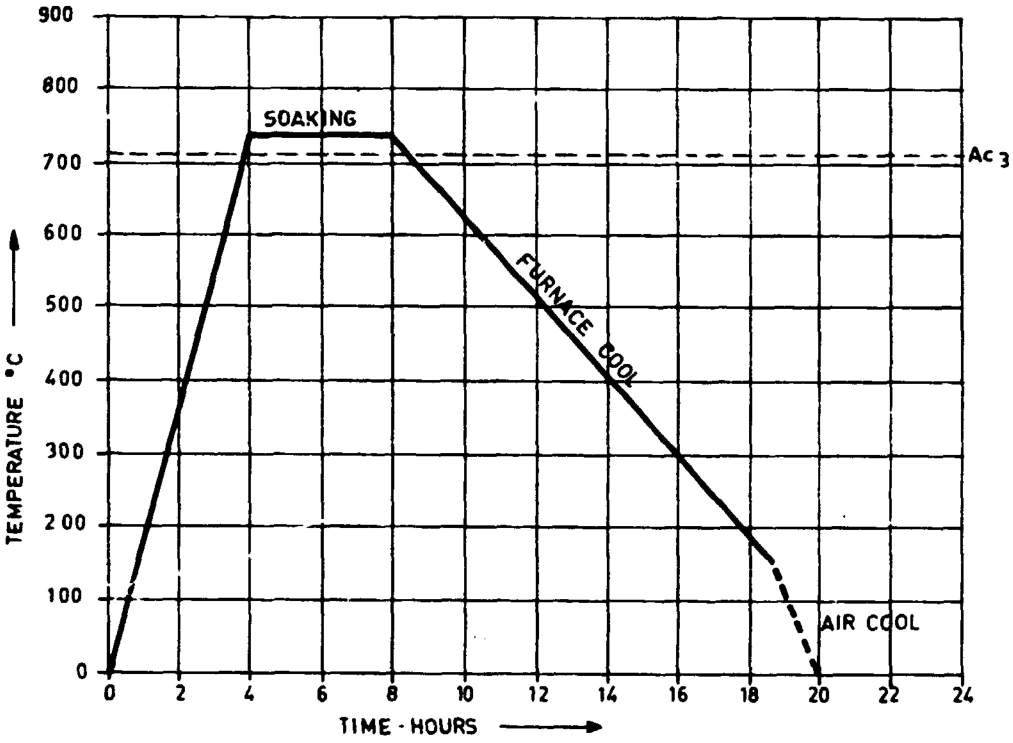


FIG.2.3 TYPICAL TIME TEMPERATURE CYCLE FOR FULL ANNEALING

For full annealing any type of furnace except molten baths can be used. Furnace atmosphere control is necessary if the parts should be free from decarburisation or scaling. As an alternative, the material can be packed in boxes with some inert material such as burnt cast iron chips, spent pitch coke etc. Inspection after full annealing is normally done by checking the hardness. The structure after annealing will be ferrite and pearlite or cementite and pearlite depending upon the percentage of carbon.

2.2.2 Isothermal Annealing

Isothermal annealing is adopted to reduce the cycle time of annealing and to obtain a structure with better machinability. The process consists of heating the steel just above the upper critical point (Ac_3) and then quickly transferring the steel to a salt bath maintained at a constant temperature below the critical range. The time of holding at the isothermal range should be sufficient to ensure complete transformation to pearlite, as indicated by the isothermal diagram for the particular steel. After the transformation is complete the steel can be furnace or air cooled. The normal temperature used for isothermal transformation is 650°C and the holding time is about 3 to 5 hours. Fig. 2.3(a) shows schematically the isothermal annealing cycle.

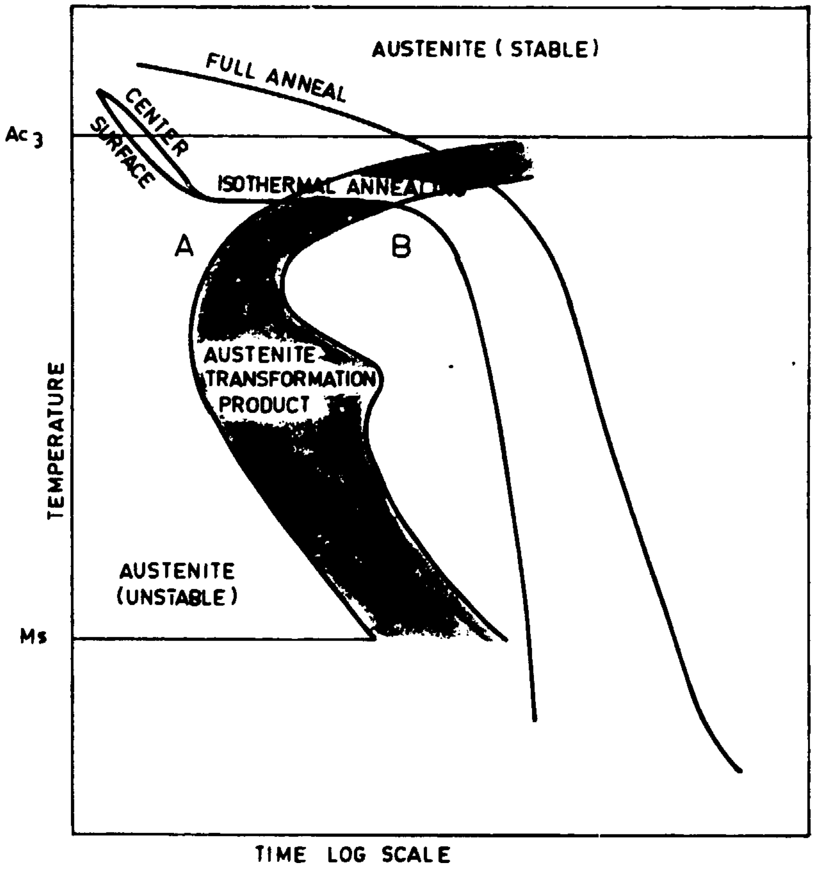


FIG.2.3(a) SCHEMATIC DIAGRAM SHOWING ISOTHERMAL ANNEALING

Molten salt bath furnaces are generally used for isothermal annealing. The hardness after isothermal annealing will not be as low as that after full annealing, but the type of structure produced by isothermal annealing is more machinable. Some alloy steels will not soften fully by isothermal annealing for a reasonable length of time and and are softened by tempering at 650°C. Alternatively they may be isothermally annealed as far as practicable, followed by air cooling and tempering at 650°C.

2.2.3 Spheroidise Annealing

Spheroidise annealing is done to get a microstructure consisting of spherical carbide particles uniformly dispersed in a ferrite matrix. In this condition the steel will be most ductile and soft. Spheriodisation also improves the machinability and produces a better end product after hardening.

Spheroidising is carried out normally by heating to a temperature just above or just below the lower critical point, soaking for sufficient time to complete the pearlite transformation and then cooling slowly. The usual range of temperature used in spheroidise anneal is given in Fig. 2.4. Best results are obtained when spheroidisation is done on hardened steels.(martensitic structure). A photograph of the structure obtained after spheroidise annealing is shown in Fig.1.6. (Chapter 1)

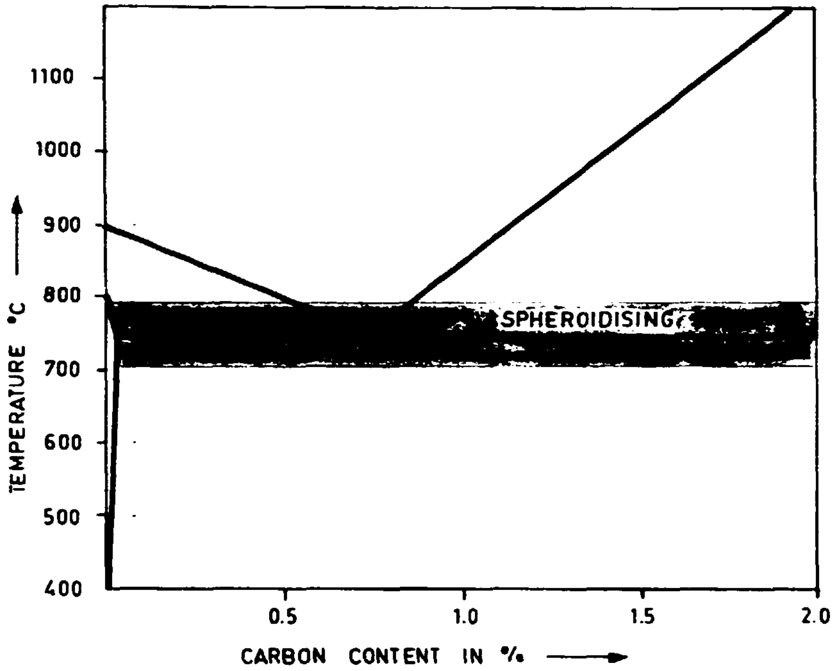


FIG.2.4 TEMPERATURE RANGE FOR SPHEROIDISE ANNEALING

2.3 Normalising

Normalising is usually done to refine grain structure that becomes very coarse during hot working at high temperatures. In hypereutectoid steels, normalising is also carried out to dissolve carbides and carbide networks that may have developed during prior processing. Normalised structures provide better response to subsequent hardening treatment.

The process of normalising consists of heating the steel or cast iron to about 55°C above the upper critical point and then cooling in air. The soaking time will depend upon the section thickness and the method of loading; but the general rule is to give one hour soaking for every 25 mm section thickness. Partial iron-carbon equilibrium diagram showing the typical normalising range is given in Fig.2.5. Cooling rate sometimes is enhanced purposely with fans, to increase strength and hardness of parts or to decrease the time required for cooling. Some medium carbon or high carbon steels and some low alloy steels are tempered after normalising at about 600-650°C to reduce the hardness.

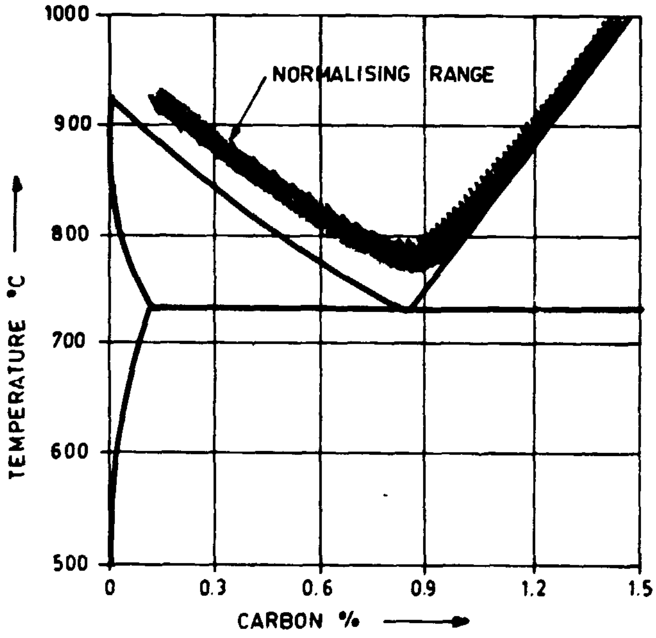


FIG.2.5 RELATIONSHIP OF NORMALISING TEMPERATURE WITH CARBON CONTENT

Any type of furnace including salt bath furnace can be used for normalising. Austenitic steels, stainless steels and maraging steels cannot be normalised. In the case of air-hardening steels, normalising produces the effect of hardening. Inspection after normalising is carried out by checking the hardness and the microstructure.

2.4 Hardening

Hardening consists of principally two stages as shown in Fig. 2.6.

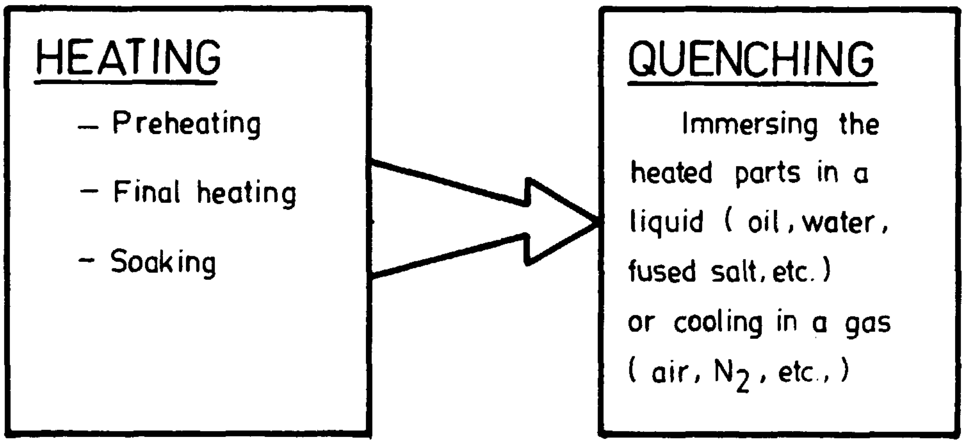


FIG.2.6 STAGES IN THE PROCESS OF HARDENING

2.4.1 Preheating

Preheating is carried out to avoid the danger of crack formation due to the thermal shocks caused by sudden heating to high temperature and also to remove traces of moisture or oil from the parts before immersion into salt baths.

The usual practice is to preheat the components at 400°C in an air circulated furnace. The heating time is not critical, however a minimum time of 45 minutes per 25 mm section thickness is normally allowed. From the preheating furnace the parts can be directly charged into the hardening furnace.

In the case of using chamber furnace for the final heating, it is not essential to preheat the parts, provided the hardening temperature does not exceed 900°C. For hardening high speed steels, a second preheating should be done at around 850°C. A third stage preheating at 1100°C is also recommended for the hardening of very critical and slender high speed steel parts.

Vertical shaft type furnaces with air circulation are generally used for preheating. Because of the low temperature operation it is not necessary to have furnace atmosphere control.

2.4.2 Final Heating & Soaking

Theoretically the heating and soaking times are to be considered separately since the heating time will vary depending upon the nature of heating whereas the soaking time remains the same. But in actual practice only the total time of heating and soaking is considered by heat treaters. The total times i.e., the treating times depend upon many factors such as weight and shape of the part, type of furnace used, available power, quantity loaded at a time etc. Hence it is not practicable to give the exact heating times for different steels. However Table 2.1 and Table 2.2 can be used as a guide for determining the treating times. Since high speed steels are normally hardened in salt baths, the timings given for high speed steels are for salt bath hardening. When using vacuum furnaces longer times are to be given since heat transfer in vacuum takes longer time.

Section thickness in mm	Treating Times in Minutes				
	High Carbon Hign Chrome Steel		Hot Die Steel		Carbon Steel and oil hardening steel. (Low and medium alloy steels)
	Pre-heating at 800°C	Heating at Hardening Temperature	Pre-heating at 800°C	Heating at Hardening Temperature	
6	6	15	6	12	12
12	12	25	12	20	25
20	15	35	15	30	35
25	20	40	20	35	40
38	30	50	30	45	60
50	40	60	40	55	70

Note: (i) Treating time = Heating time + Soaking time

(ii) For salt baths the timings can be reduced by approx. 25%

TABLE.2.1 TYPICAL TREATING TIMES FOR CHAMBER FURNACE

The types of furnaces generally used for hardening are chamber furnaces with atmosphere control and salt bath furnaces. Other types of furnaces which find application in hardening are the fluidised bed furnace and the vacuum furnace. Details of all the above types of furnaces are given in Chapter III.

Size in mm for square section	Immersion time in Secs.	Size (dia) in mm for Round Section	Immersion time in Secs.
6	40	6	35
10	75	10	70
13	90	13	80
20	140	20	130
25	180	25	160

Note: i) Immersion time = Heating time + Soaking time

ii) Times given are the hardening times required when the pre-heating is done at 400°C and 850°C

TABLE 2.2 TYPICAL IMMERSION TIMES FOR HSS HARDENING IN SALT BATH

2.4.3 Quenching

Quenching of steel or cast iron is the rapid cooling from the hardening temperature. This is accomplished by immersing the parts in any of the following quenching media.

Water (pure or brine)
Oils
Polymer Solutions
Molten salts or metals and
Gases or air

The medium can be still or agitated. Agitated mediums give higher cooling rate and better uniformity of hardness. As an alternate the job can be moved vigorously inside the quenching medium to get uniform quenching.

Oil is the most commonly used quenching medium. The main reason is that oil gives a cooling rate suitable for most of the steels. It is non-corrosive and does not cause rusting of parts quenched. The main disadvantage is that oil is inflamable and this necessitates large volumes for quenching. A generally used thump rule for calculating the amount of oil required is

> Volume of oil in litres equals the weight of quench load in kg multiplied by 10.

The above value can be reduced considerably if agitation or cooling is provided.

Instead of oil other quenching media such as polymer solutions are used now-a-days for quenching. The main advantages of polymer quenchant are that by varying the concentration, cooling rates of brine, water, oil or salt can be obtained and there is no fire hazard. The disadvantages are i) expensive ii) need close control of concentration and iii) disintegration of the polymer at high temperatures.

2.4.4 Austempering

Austempering is a hardening process designed to reduce distortion and cracking and to obtain higher toughness. The transformation product is bainite instead of martensite. Schematic representation of the austempering cycle is given in Fig.2.7.

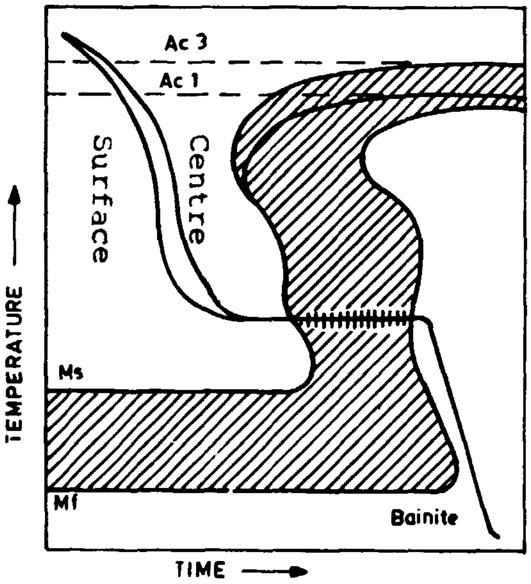


FIG.2.7 SCHEMATIC DIAGRAM OF AUSTEMPERING CYCLE SUPERIMPOSED ON A TTT DIAGRAM

The parts to be austempered are first austenitised and then quenched in molten salt held at a temperature above Ms point for sufficient time to complete the transformation to bainite. After that the parts are cooled in air or quenched in water. Soaking times required for the same steel is different at different austempering temperatures. Higher the austempering temperature, the shorter is the soaking time necessary and the lower the final hardness obtained. No tempering is necessary after austempering. Austempered parts will have more toughness than the hardened and tempered parts of the same hardness.

2.4.5 Martempering

Martempering or interrupted quenching is a hardening treatment that consists of quenching to a temperature slightly above the Ms, usually by quenching into a salt bath, holding for a time sufficient for the temperature to become uniform and then air cooling to room temperature. The main advantages of martempering as compared to oil quenching are (a) reduced distortion and (b) less risk of cracking. Schematic representation of martempering cycle is given in Fig.2.8. Parts should not be left in the martempering bath too long. After martempering, tempering has to be carried out as usual.

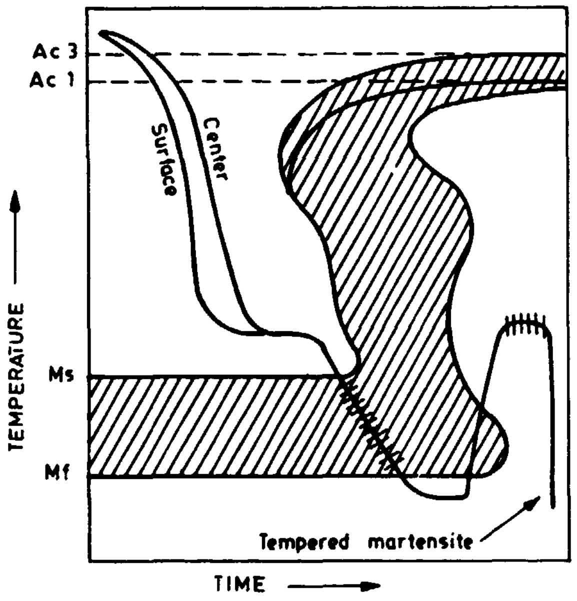


FIG. 2.8 SCHEMATIC DIAGRAM OF MARTEMPERING CYCLE

Martempering is done mostly in molten salt baths. In order to effect rapid cooling of the parts, the bath should be agitated well. Because of the slow rate of cooling, martempering is not applicable to water hardening steels or carburised carbon case hardening steels.

2.4.6 Sub-zero cooling

Alloy steels with low Ms temperature do not get completely converted into martensite when quenched from austenitising temperature. Part of the austenite remain without conversion which is called the retained austenite. Sub-zero cooling is done to complete the transformation of retained austenite into martensite. The process consists of cooling the parts after quenching to about - 80°C.

The equipment used can be any chamber with facility for cooling upto - 80°C. A powerful deep freeze can be used. As an alternate, dry ice (solid carbon-di-oxide) can be used for sub-zero cooling. The process consists of adding dry ice into ethyl alcohol contained in an insulated pot, allowing the alcohol to cool down to about - 70°C. Parts to be sub-zero cooled can then be immersed in the alcohol. The immersion time depends upon the section thickness (approx. one hour for every 25 mm thickness). After the soaking is over, parts are taken out and tempered immediately. It is better to carry out sub-zero cooling immediately after quenching. But in the case of slender and complicated parts, tempering is done before sub-zero cooling to avoid the risk of cracking.

Care has to be taken in handling dry ice and parts cooled in it. Direct contact with the skin will cause frost bites. Hence thick rubber gloves should be used.

2.5 Tempering

Virtually all steels and cast irons that are quenched for hardening are subjected to tempering treatment to relieve the quenching stress and to reduce the brittleness. The process of tempering consists of reheating the steel after quenching to a temperature below the lower critical range. The temperature at which tempering is to be carried out depends upon the type of steel and the final hardness required. For each steel there is a relationship between the tempering temperature and hardness obtained after tempering. (see Chapter IV)

The time required for tempering is about one hour for every 25 mm thickness; however, it is recommended that a minimum of one hour is given for all the parts. After the tempering, parts can be cooled in air. In the case of high speed steels and hot die steels, the tempering should be done at least two times. After the first tempering the parts are to be cooled to room temperature before charging for the second tempering.

Since the temperature involved in tempering is not high, ordinary furnaces with air circulation can be used. Salt baths and atmosphere controlled furnaces are also used when the job should be free from decarburisation and scaling.

Temper Brittleness:

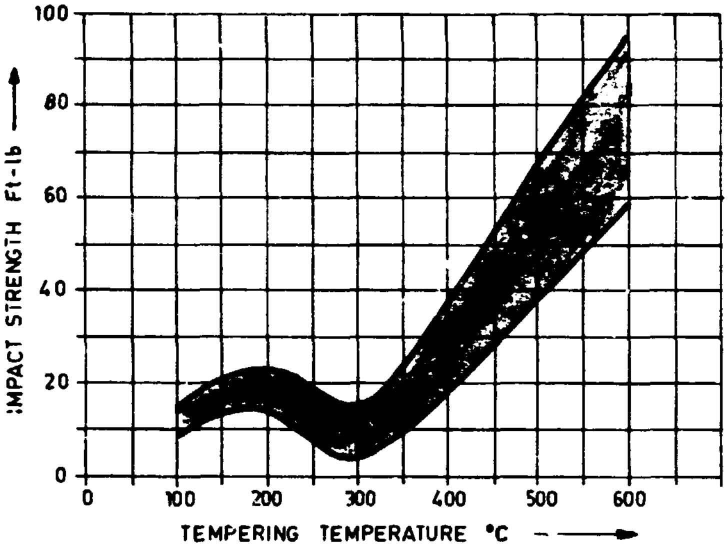


FIG. 2.9 IMPACT STRENGTH AS A FUNCTION OF TEMPERING TEMP. FOR 0.4%C STEEL

The relationship between tempering temperature and toughness for 0.4% C steel is given in Fig. 2.9. From this figure it can be seen that the toughness initially increases with increasing temperature, but suddenly becomes low around 260-370°C and then again increases. This sudden loss of toughness is called temper brittleness. Hence tempering at the temperature range 260-370°C or cooling slowly after tempering at this temperature range should be avoided in order to prevent temper brittleness. Also by alloying the steel with molybdenum upto 0.5%, the tendency for temper brittleness is reduced.

2.6 Case Hardening

Case hardening is the process of hardening the surface of low carbon steels, after inducing/diffusing carbon into the surface. It produces a hard and wear resistant surface and a less hard tough core. There are three methods of diffusing carbon into the surface of steel viz; (i) Gas Carburising (ii) Liquid or Cyanide Carburising and (iii) Pack Carburising.

2.6.1 Gas Carburising

In gas carburising, an unsaturated hydrocarbon gas such as methane (from natural gas) or propane is used as the source for carbon. In order to have effective control of the carburising reaction and also to allow for the slow diffusion of carbon, the hydro-carbon gases are diluted with a carrier gas, before introduction to the furnace. The most commonly used carrier gas is Endothermic gas. The endothermic gas is produced by the reaction of the hydro-carbon gas with controlled amounts of air over a catalyst maintained at about 1000°C. Details of the equipment used for producing endothermic gas are given in Chapter III. The reactions taking place in the generator are as follows:

$$2C_3H_8 + 3O_2 + 11.4N_2 = 6CO + 8H_2 + 11.4N_2$$

(Propane)

$$2CH_4 + O_2 + 3.8N_2 = 2CO + 4H_2 + 3.8N_2$$

(Methane)

The carbon monoxide thus produced reacts with steel diffusing carbon into it and the reaction is

$$2\,CO \rightleftharpoons C\ (\text{in steel}) + CO_2$$

The carbon-di-oxide then reacts with the hydrocarbon gas and produces carbonmonoxide as below:

$$CH_4 + CO_2 \longrightarrow 2CO + 2\,H_2$$
$$C_3H_8 + 3CO_2 \longrightarrow 6C + 4\,H_2$$

The carbon monoxide thus produced again reacts with the steel and the process of carburisation continues.

The carburising is done generally at 900-930°C. But it is also possible to carburise at higher temperatures in order to reduce the time cycle. The relationships between case depth and carburising times at different carburising temperatures are given Fig.2.10.

It is necessary to control the amount of carbon induced in the surface. Too high percentage of carbon in the case will cause defects such as cracking and peeling off of the carburised layer. The percentage of carbon induced in the case is called the carbon potential and for normal applications it is controlled within 0.9 to 1.1%. Methods of measuring and controlling the carbon potential are given in Chapter III.

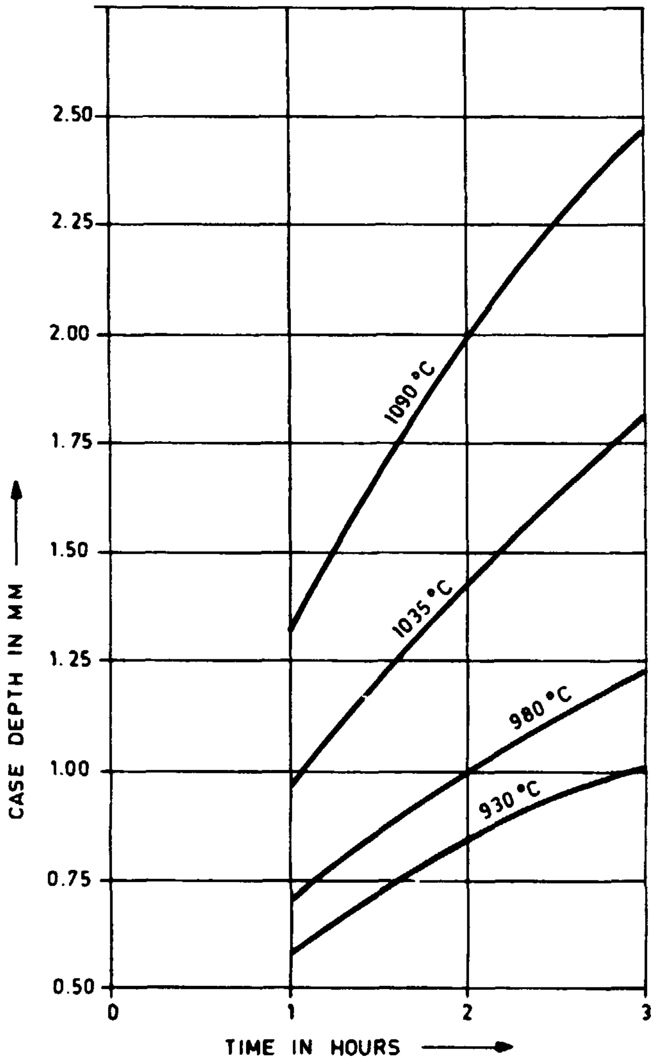


FIG.2.10 CARBURISING TIME VS CASE DEPTH AT DIFFERENT TEMPERATURES

The equipments normally used for gas carburising are pit type retort furnaces and sealed quench furnaces. Gas-tight retorts are used for loading the parts inside. A separate endothermic gas generator is used along with the furnace.

Vacuum or Low Pressure Carburising:

The latest development in gas carburising is the use of vacuum furnace for carburising. After preparing the vacuum, the carburising gas is introduced at very low pressure. The gas is fed directly without any generator. Carburising takes place very fast; in so little time as 30 minutes a case depth of 0.8 mm can be obtained. The quality of case produced is better than that obtained by conventional carburising.

Gas Carburising Using Hydrocarbon Liquids:

Undiluted hydrocarbon liquids such as terpenes, benzenes, alcohol, glycols etc., are fed into the furnace at controlled rates to produce carburising atmosphere. This method is suitable for small furnaces, of the batch type as it will produce soot in large furnaces. Control of carbon potential is difficult in this method. Since no carrier gas generator is required, the equipment cost is less.

Wax Carburising:

As an alternate to hydrocarbon liquid, the use of wax has been tried in Iraq and the results are found to be encouraging. The same equipment as for using hydrocarbon liquid is used and the wax is made to melt and flow uniformly into the furnace.

2.6.2 Liquid Carburising

Basically all liquid carburising media contain cyanide. Though some non-cyanide baths are developed, their application is not common.

The cyanide baths contain sodium cyanide (NaCN) in percentages varying from 10 to 50, with other neutral salts such as sodium chloride and barium chloride. Ready mixed salts with varying percentages of cyanides are available from the manufacturers of heat treatment salts. The relationship between depth of carburising and treatment time at different temperatures for a 10% cyanide bath is given in Fig. 2.11.

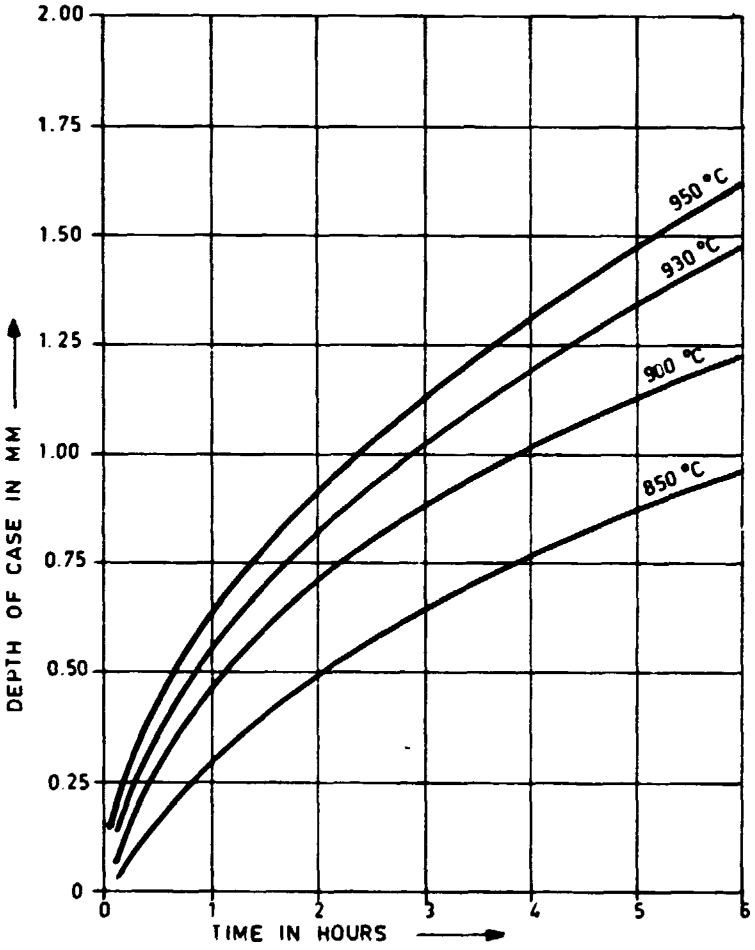


FIG.2.11 CASE DEPTH VS TIME FOR DIFFERENT CARBURISING TEMPERATURES (10% Cyanide Bath)

The active hardening agents in the cyanide baths are carbon monoxide and nitrogen. Molten cyanide decomposes in the presence of air at the surface of the bath to produce sodium cyanate, which in turn decomposes to sodium carbonate with products carbon monoxide and nitrogen. The reactions are:

$$2\ NaCN + O_2 = 2\ NaNCO,$$

$$4\ NaNCO = Na_2CO_3 + 2NaCN + CO + 2N.$$

$$2\ CO = CO_2 + C \text{ (in steel)}$$

$$NaCN + CO_2 = NaNCO + CO$$

Thus in cyanide hardening, in addition to carbon pick up, the steel is considerably enriched with nitrogen, creating a more abrasion-resistant surface skin.

Both externally heated and internally heated salt baths can be used for melting the salt. However, due to the high maintenance cost of externally heated salt baths, only internally heated salt baths are used for carburising. The salt bath should have a steel pot inside for cyanide baths.

The cyanide baths require daily checking of the cyanide percentage and necessary addition of cyanide salt. For this purpose a sample of salt should be taken from the bath and chemically analysed to find out the cyanide percentage. The value of the cyanide percentage should be adjusted to the recommended percentage by adding cyanide or neutral salt as the case may be. Special precautions should be observed in handling cyanide.

2.6.3 Pack Carburising

Pack carburising is a process in which steel is packed along with carbon in boxes and heated for sufficient time for the carbon to diffuse to the required depth. The medium used for packing is charcoal or coke with 10 to 20% alkali or other metal carbonate as energiser. Barium carbonate is the principal energiser (50-70% of the carbonate content) and the others are calcium carbonate, sodium carbonate etc.

The energiser is bound to the coke with oil, tar or molasses. The reactions within the carburising box are:

$$\mathrm{Ba\,CO_3 + C \rightleftharpoons BaO + 2\,CO}$$

$$\mathrm{2\,CO \rightleftharpoons CO_2 + C}\ \text{(in steel)}$$

$$\mathrm{BaO + CO_2 \rightleftharpoons BaCO_3}$$

The pack carburising process consists of first packing the parts along with the carburising medium in special boxes, in such a way that each part is surrounded by the compound by about 15-25 mm thickness. Long and slender parts are packed vertically to avoid distortion. After packing the box is closed with a lid and sealed with clay to avoid burning of the compound. It is preferable to have small boxes instead of large ones so that there will be more temperature uniformity inside the box.

After packing the boxes are loaded into the furnace and heated. The soaking temperature for pack carburising is from 815 to 955°C. The soaking time required depends upon the depth of case required and the soaking temperature. The approximate soaking times required for various case depths at 930°C are given in Fig.2.12. After completion of the soaking time, the box can be cooled in the furnace or can be taken out and the parts quenched.

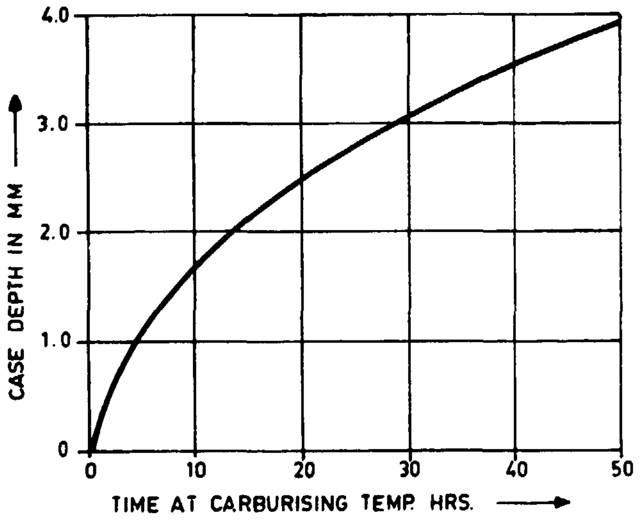


FIG. 2.12 CASE DEPTH VS TIME FOR PACK CARBURISING (930°C)

The carburising compound to be used every time need not be completely fresh. A mixture of about 80% old used power and balance 20% fresh powder can be used. After each treatment, the powder has to be sieved to remove the ashes and fines.

The types of furnaces commonly used for pack carburising are chamber furnaces, pit furnaces and car bottom furnaces. As the parts are packed in the medium, no atmosphere control is necessary. The material generally used for making carburising boxes are low carbon steel, aluminised steel and stainless steel. The low carbon steel is very cheap; but the life is very less. Similarly, the stainless steel is costly but longer life is obtained. By practice aluminised steel is found to be the most economical material for making carburising boxes.

2.6.4 Comparison of the advantages and disadvantages of Gas, Liquid and Pack Carburising

A comparison of the advantages and disadvantages of the gas, liquid and pack carburising is given in Table 2.3

	GAS CARBURISING	LIQUID CARBURISING	PACK CARBURISING
1.	Special furnace with suitable generator for carrier gas is necessary.	Salt bath furnace is required.	Any furnace can be used (except salt bath).
2.	Capital cost of equipment very high.	Capital cost of equipment is moderate.	Capital cost of equipment low.
3.	Clean atmosphere and surroundings.	Floors and surroundings not clean due to spillage of salt.	Very dirty atmosphere and surroundings.
4.	Easy control of carbon potential and it can be varied during the process.	Carbon potential can be corrected by adding salts, but can not be varied during process.	Very difficult to control carbon potential.
5.	Case depth can be controlled precisely. Hence even small case depths can be achieved.	Case depths can be controlled precisely. Hence even small case depths can be achieved.	Not possible to control case depths precisely. Hence cannot be used for small case depths.
6.	It is possible to quench parts directly from the carburising furnace.	Easy to quench parts directly from the furnace.	Difficult to quench parts directly from the furnace.
7.	Slow cooling after carburising in the furnace is possible to anneal the parts after carburising.	Slow cooling after carburising is not possible in the furnace.	Slow cooling in the furnace, is possible to anneal the parts after carburising.
8.	No special effluent disposal necessary.	Need special effluent treatment to dispose off the poisonous cyanide.	No special effluent disposal necessary.

TABLE 2.3 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF GAS, LIQUID AND PACK CARBURISING

2.6.5 Selective Carburising

It will be necessary for some parts only certain portions to be case hardened and the remaining portion to be soft. For example, machine tool gears are case hardened on the teeth and the bore is left soft for broaching after hardening. There are mainly three methods available for such selective case hardening as shown below.

i) to copper plate (min. 13 μm thickness) the areas those do not require hardness.

ii) to coat the area to be left soft with a special ceramic paint.

iii) to keep an extra thickness (about 3 mm) of metal on the areas needing to remain soft and removing this excess material layer by machining after carburise annealing. When these parts are hardened subsequently, the areas where the carburising allowance is removed will remain soft.

Among the above three methods, the most effective is the last method. First and second methods can not be used in cyanide carburising as they will not be effective and the coating material will contaminate the bath. However, selective carburising in salt bath can be done in some cases by dipping in the salt only that portion which requires case hardening.

2.7 Carbonitriding

Carbonitriding is a modified process of gas carburising with the introduction of nitrogen into the case along with carbon. This is obtained by adding 2 to 12 % of ammonia into the carburising atmosphere.

Because of the presence of nitrogen in the case, the carbonitrided parts have better wear resistance than the carburised case. Also,due to the lower temperature involved in carbonitriding, the distortion is less when compared to case hardening.

The process of carbonitriding is similar to gas carburising; but the temperature involved is less (870° C and below). Because of the lower temperature the rate of penetration also is low. Fig. 2.13 shows case depth against time for carbonitriding at different temperatures.

Any furnace suitable for gas carburising can be used for carbonitriding. The ammonia to be used should be of 99.9 % purity.

Carbonitriding is used for parts which require case depths upto 0.75 mm only due to the lower temperature involved and the danger of high retained austenite caused by the presence of nitrogen.

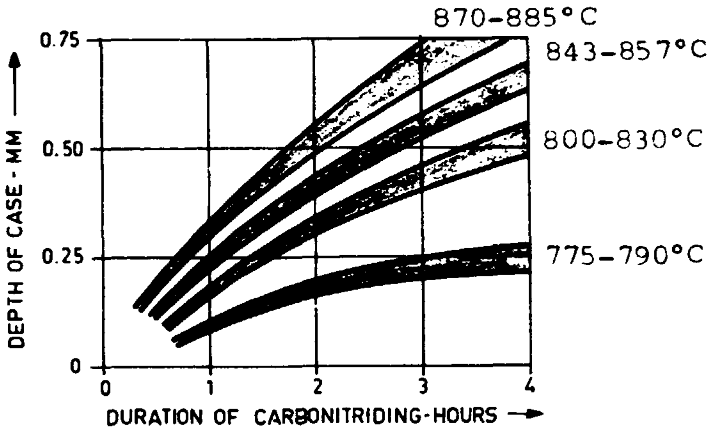


FIG. 2.13 TIME VS CASEDEPTH IN CARBONITRIDING

2.8 Boriding

Boriding is a process similar to carburising, where the element Boron is induced into the surface instead of carbon. Boriding gives a case of extremely high hardness (17-25KN/mm^2), compared to any other hardening process.

The method of boriding is similar to pack carburising. Parts to be borided are packed in heat resistant steel boxes with the boriding compound; taking care to see that the parts are covered with at least 10 mm thickness of boriding agent. The boriding agent used consists of boron carbide (B4C) as the source for boron, together with activators such as potassium borofluoride (KBF_4) and an extender.

The boriding temperature is between 800 - 1000°C, with 900°C being the temperature most frequently used. The soaking time depends upon the depth of case required. See Fig. 2.14.

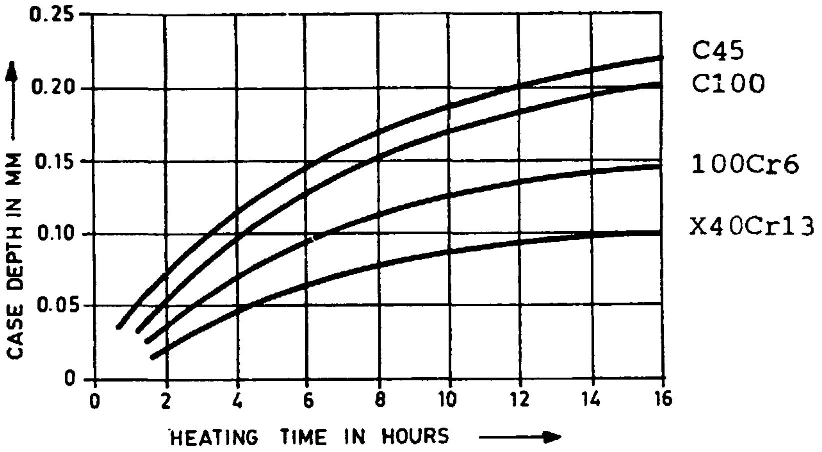


FIG. 2.14 HOLDING TIME VS CASE DEPTH IN BORIDING

After the completion of the soaking time the box can be cooled in the furnace or hardened directly by quenching into oil, furnace cooled pieces can be hardened by the usual method (austenitising temperature not to exceed 1050°C)

Any furnace used for pack carburising can be used for boriding also. The boriding compound can be used for repeated treatment with about 30 % being replaced by fresh compound.

Any steel whose austenitising temperature is below 1050°C can be used for boriding. Usually good results are obtained by using low and medium carbon steels.

Surfaces can be protected from boriding by using metallic sleeves or by screwing on of nuts or by copper plating.

2.9 Nitriding

Nitriding is a process similar to carburising, where nitrogen is induced into the surface instead of carbon. Two types of nitriding are commonly employed. They are gas nitriding and liquid nitriding.

The principal reasons for nitriding are :-

- to obtain high surface hardness
- to increase wear resistance and anti seizing properties
- to improve fatigue life
- to improve corrosion resistance and
- to obtain a surface that is resistant to the softening effect of heat at temperatures upto about 520°C.

Because of the absence of a quenching requirement and the comparatively low temperatures involved in the process, nitriding produces very less distortion compared to either carburising or conventional hardening.

2.9.1 Gas Nitriding

Gas nitriding is similar to gas carburising but lower temperatures are involved and ammonia is used instead of natural gas or propane. Ammonia is introduced into the sealed retort and at the furnace temperatures (about 525°C) the gas dissociates according to the following reaction.

$$\mathrm{NH3} \rightleftharpoons \mathrm{N} + 3\mathrm{H}$$

The resulting nascent nitrogen formed diffuses into the steel forming iron nitrides. The nitriding requires long hours of treatment (See Fig. 2.15). After the soaking time is over, the charge is cooled inside the furnace to about 150°C and then the parts are taken out and further cooled in air.

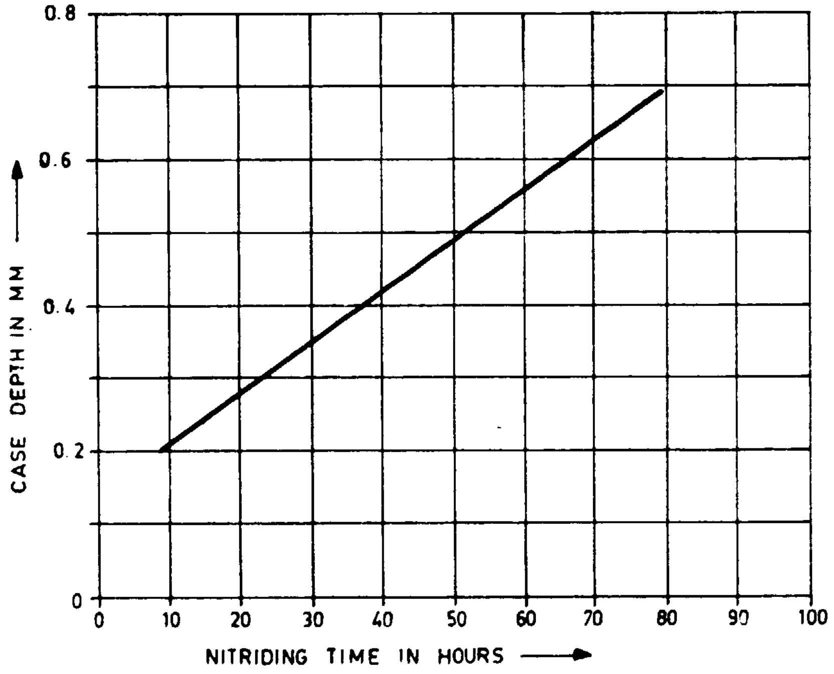


FIG. 2.15 TYPICAL CURVE SHOWING GAS NITRIDING TIME VS CASE DEPTH

One of the important factor to be controlled during gas nitriding is the percentage of dissociation of ammonia.

The normal range is 25 to 30 % dissociation. That means the atmosphere contains 70 to 75 % ammonia. The dissociation is determined by passing the exhaust gas through a manometer containing water and measuring the amount of gas dissolved in the water.

There will be a small extremely hard and brittle layer at the surface after nitriding. This is called the white layer. Due to its hard and brittle nature, for general applications this layer (usually less than 0.02 mm thickness) is removed by grinding or lapping. It is possible to reduce the thickness of white layer by double stage nitriding, that is first nitride at a lower dissociation rate and finally at a higher dissociation.

The steels generally used for gas nitriding are alloy steels containing one or more of the nitride forming elements such as aluminium, chromium, molybdenum, tungsten and vanadium.. Steels alloyed with aluminium give higher case hardness when compared to chromium or molybdenum steels. Unalloyed carbon steels are not well suited for gas nitriding, because they form an extremely brittle case.

Parts prior to nitriding should be hardened and tempered. The tempering temperature is usually at least 30°C above the temperature used for nitriding. The parts should be cleaned thoroughly and preferably degreased before gas nitriding. Selective nitriding can be done by coating the areas not requiring nitriding with copper or nickel by electroplating.

The furnaces used for gas nitriding are similar to the furnaces used for gas carburising. Instead of endogenerator, ammonia feeding arrangement is necessary.

Hardness of nitrided layer is measured under low loads such as Rockwell Superficial or Vickers 15 or 30 kg., load methods. The case depth can be measured by any of the methods described in Chapter V, for measuring carburised case depths.

2.9.2 Liquid Nitriding (Tufftriding)

Liquid nitriding utilises molten baths containing cyanide and cyanate, maintained at temperatures between 510 to 565°C. As the process requires aeration (circulation of air through the salt) and titanium pots, special furnaces are required for liquid nitriding.

The composition of the bath has to be checked daily and corrected by adding suitable salts. Now cyanide-free salts are also available for liquid nitriding. Cooling after liquid nitriding can be done in air or in another molten bath. With non-cyonide baths, special alkaline salt is used for quenching in order to remove the traces of cyanide produced in the nitriding bath during the treatment.

The relationships between the treatment time and case depth and between case depth and Vickers hardness are given in Figs. 2.16 and 2.17.

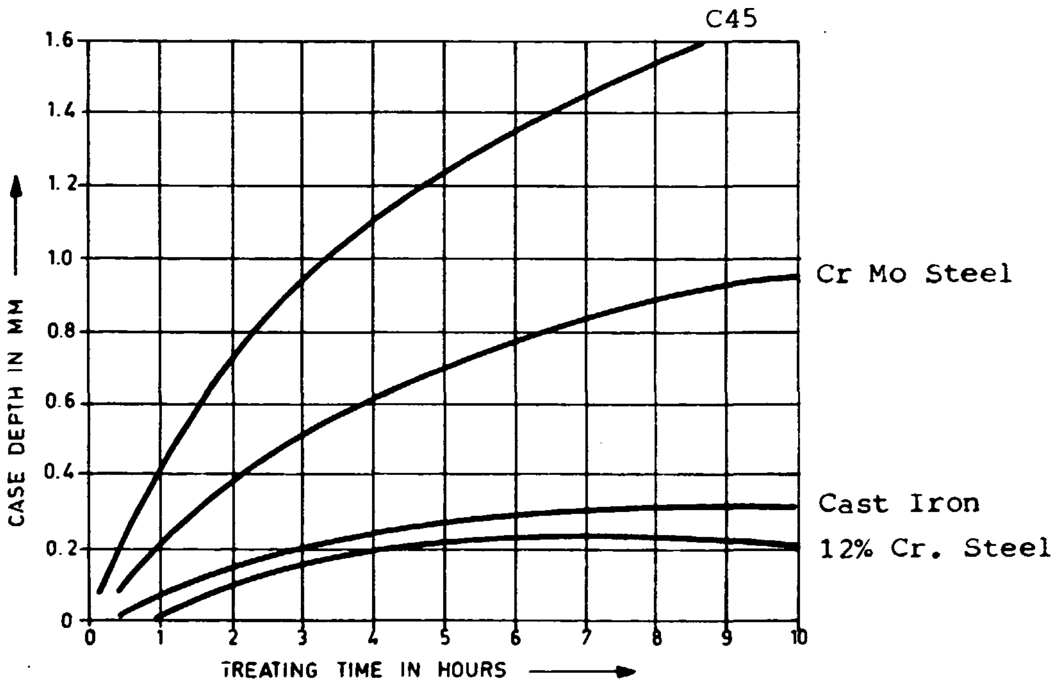


FIG. 2.16 CASE DEPTH Vs TREATING TIME FOR LIQUID NITRIDING

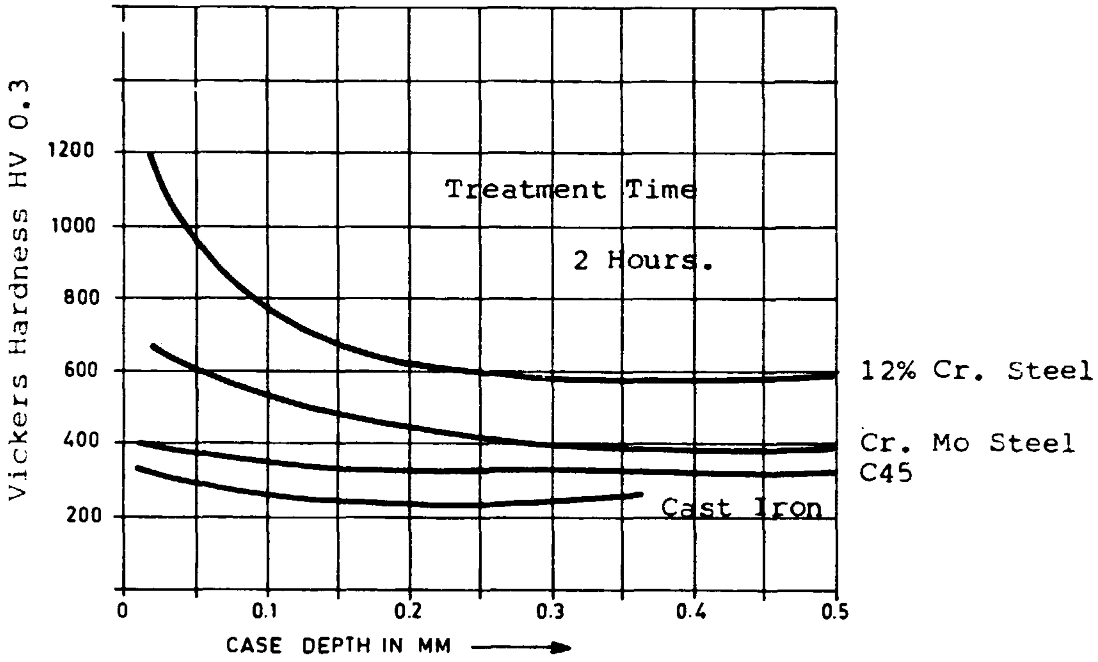


FIG. 2.17 CASE DEPTH VS HARDNESS FOR LIQUID NITRIDING

2.10 Ferritic Nitrocarburising (Nitemper)

Ferritic nitrocarburising is a gaseous process which produces results almost equal to the liquid nitriding process. The main differences between this process and gas nitriding are -

i) In nitrocarburising, a mixture of ammonia and endogas is used instead of pure ammonia,
and

ii) Parts are quenched in oil after nitrocarburising instead of furnace cooling adopted for gas nitriding.

The nitrocarburising differs from carbonitriding in that the carbonitriding is done in the austenitic stage whereas nitrocarburising is done in the ferritic stage, that is below 675°C. The actual temperature at which nitrocarburising is done is near 675°C. Due to the possibility of quenching after nitrocarburising, the process is suitable for low carbon low alloy steels, cast iron etc. The furnaces normally used for nitrocarburising are sealed quench furnaces with oil quenching facility. The main advantage of nitrocarburising over liquid nitriding is that no poisonous salts to be handled.

2.11 Local/Surface Hardening

Local or surface hardening means the hardening of certain portions or surfaces of components by localised heating. The different methods available for localised heating are -

i) Flame heating
ii) Induction heating
iii) Electron beam heating, and
iv) Laser heating

Of the above, the most popular methods are induction and flame heating. Details of the equipments used for these processes are given in Chapter III.

Induction or flame hardening is generally done for medium carbon steels and cast iron. The hardening process can be progressive, where the heating gradually progresses followed by quenching by jets or by single shot where the heating is done first followed by quenching by jets and/or immersion in the quenching medium. The most commonly used quenching medium is water. Polymer quenchant also can be used to reduce the quenching severity.

Flame or induction heating can be used for other heating applications such as tempering, annealing and normalising.

2.12 Heat Treatment of Ferrous Powder Metallurgy Parts

The heat treatment of powder metallurgy parts differ from that of steels mainly because the density of P/M parts is lower than that of steels. That means there are pores or voids in the P/M material, which affect the heat conductivity and hardenability. The relationships between density, case depth and case hardness are shown in Fig. 2.18.

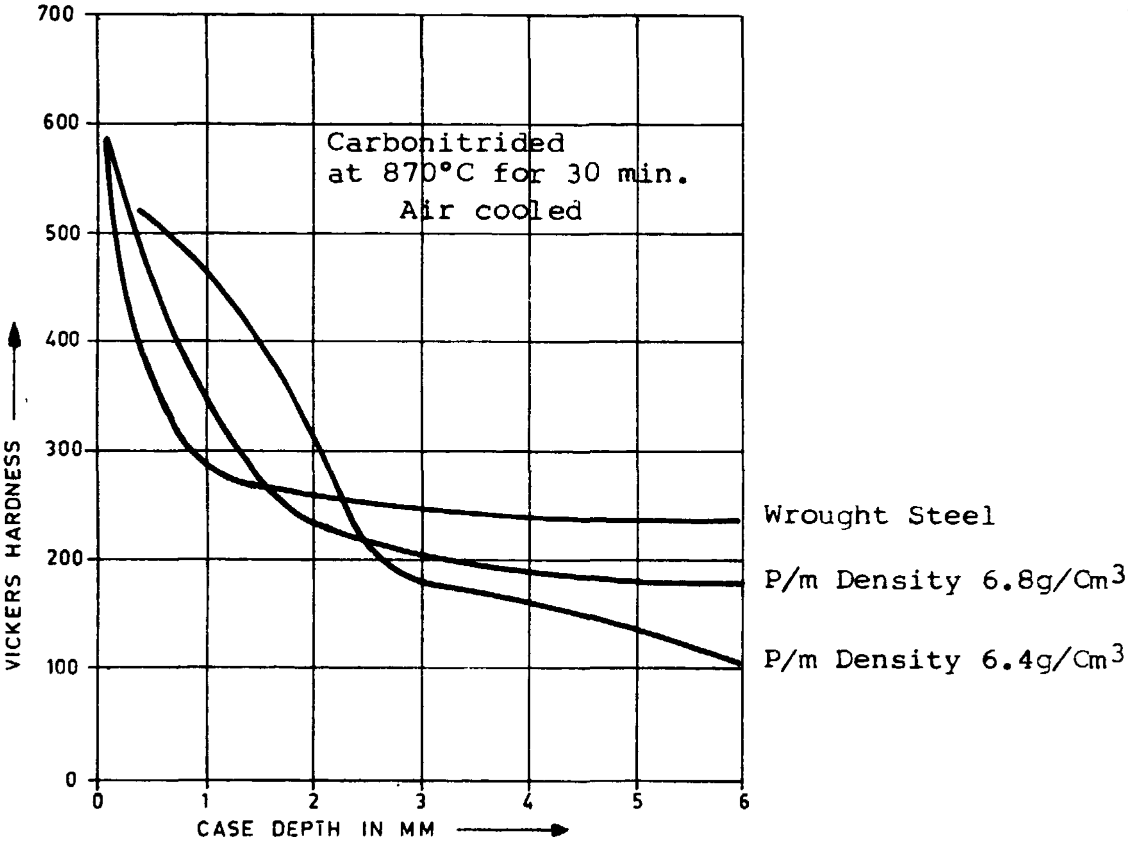


FIG. 2.18 EFFECT OF DENSITY ON CASE DEPTH AND CASE HARDNESS OF P/M PARTS

The common heat treatment processes carried out on P/M parts are case hardening and carbonitriding. The hardenability of P/M parts is reduced considerably at lower densities. (See Fig. 2.19).

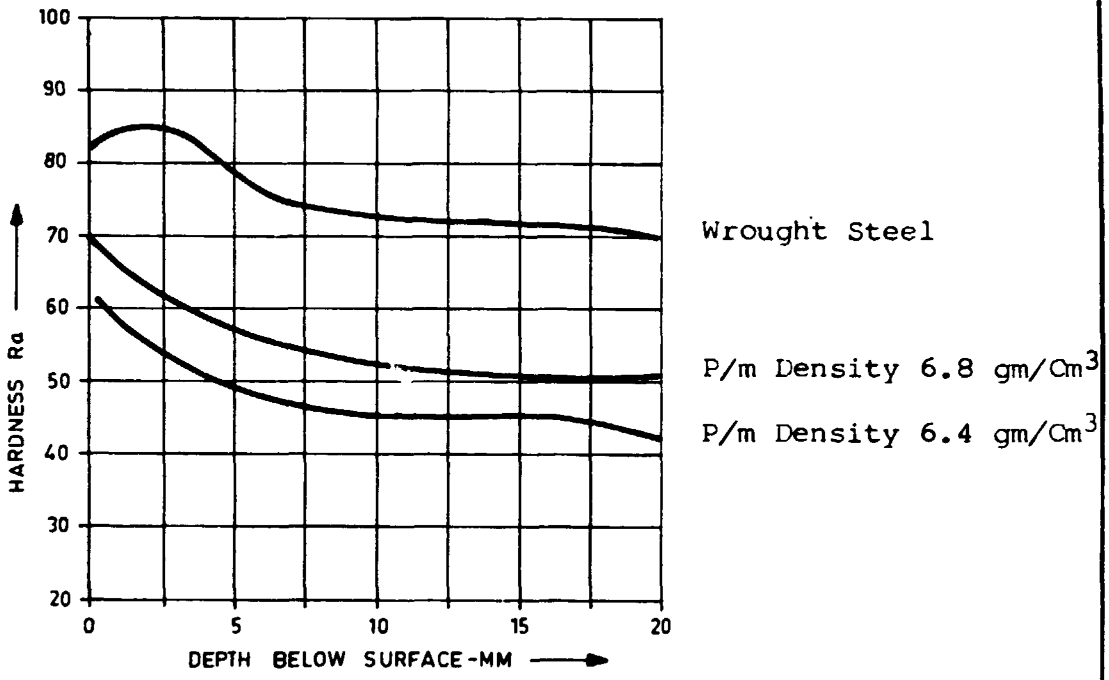


FIG. 2.19 VARIATION OF HARDENABILITY WITH DENSITY FOR P/M PARTS

Powder metallurgy parts are normally hardened in gaseous atmospheres only. Salt baths are not suitable because of the extreme difficulty to remove salts from the pores. The common furnaces with endogenerator or gaseous atmosphere control can be used for heat treating P/M parts.

The common quenching medium used for P/M parts is oil. Brine, water or salt are not suitable for quenching because they remain in the pores or voids and cause corrosion. With normal case hardening, P/M parts may not develop sufficient hardness due to the lower hardenability and the restriction of quenching medium. Hence P/M parts are generally carbonitrided, since the nitrogen increases the hardenability. Carbonitrided parts are tempered in air-circulated furnaces at 150 - 205° C.

For improving the hardenability, P/M parts are alloyed with copper or nickel.

Since the P/M parts have pores, the conventional hardness testing methods will show lower hardness values. To get the correct hardness, micro hardness has to be checked on the powder particle. As this is not convenient and practical, P/M parts are usually tested for hardness by the file test method.

2.13 Prevention of Decarburisation and Scaling

When steel is heated in air in ordinary furnaces to temperatures above 500°C, decarburisation and scaling takes place. This will reduce the surface hardness, cause material loss from the surface due to scaling and may also produce heavy distortion and/or cracking. Hence it is necessary to protect the surfaces of the parts during heat treatment operations involving high temperatures. The best way to protect the surfaces is to use vacuum furnaces, salt baths or atmosphere controlled furnaces. In the absence of the above parts can be heat treated packed in some material which will reduce the amount of scaling or decarburisation. The properties of packing media commonly used are given in Fig. 2.20.

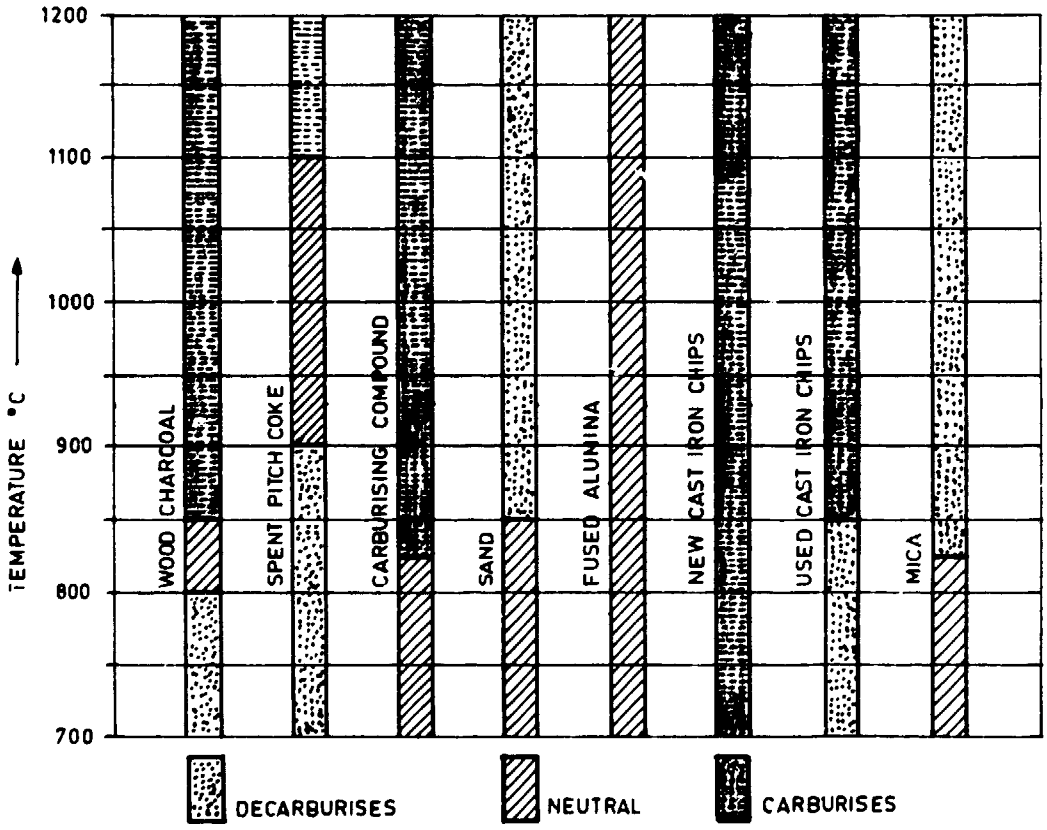


FIG. 2.20 **CARBURISING/DECARBURISING PROPERTIES OF PACKING MATERIALS**

CHAPTER III

Heat Treatment Equipments

3. HEAT TREATMENT EQUIPMENTS

Table of Contents

3.1 Types of Heating

The main types of heating applied to heat treatment furnaces are electric, gas and oil heatings. A comparison of the advantages and disadvantages of each of the above types of fuels is given in Table 3.1. For all precision heat treatments, electric heating is most suited. Oil or gas fired furnaces are used for works such as heating for forging, annealing etc., where the temperature control is not critical.

	Oil Fired Furnace	Gas Fired Furnace	Electrically Heated Furnace
1.	Difficult to control the temperature	Difficult to control the temperature	Easy to control the temperature precisely
2.	Furnace and surroundings not clean due to soot and oil spillage	Furnace and surroundings not clean due to soot	Furnace and surroundings will be very clean
3.	Storage area and equipments required for oil	Storage area and equipments required for gas	No storage area required
4.	Low capital cost	Low capital cost	High capital cost
5.	Maintenance cost very less	Maintenance cost very less	Maintenance cost high
6.	Can tolerate rough handling of the furnace	Can tolerate rough handling of the furnace	The furnace has to be operated very carefully.

TABLE 3.1 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF OIL FIRED GAS FIRED AND ELECTRIC FURNACES

3.2 Electric Heat Treatment Furnaces

3.2.1 Chamber Furnaces

The chamber furnace consists of a chamber heated by electrical resistance elements from the sides, top and or bottom.

Two kinds of materials are used for making the resistance elements. For furnaces whose operating temperature does not exceed 1200°C, the resistance element is fabricated in the coil or strip form from special nickel chromium or chromium-iron-aluminium alloy. For temperatures above 1200°C, the resistance element used is silicon carbide or molybdenum disilicide, in the form of rods. Due to the brittle nature of the elements, the operation and maintenance of furnaces with silicon carbide or molybdenum disilicide elements should be done carefully.

The specific resistance of nickel-chrom and chrom-iron-aluminium alloys do not change appreciably during heating. Hence they can be connected directly to the power supply. But in the case of silicon carbide and molybdenum disilicide elements, the specific resistance changes appreciably with temperature. Hence, these elements should be connected through transformers with facility for tap changing. The resistance of these elements also changes after repeated use and this process is called ageing. Hence, for replacement of elements it is not recommended to change only one or two of the group, as the resistance of the new ones will not match with the resistance of the old onces. In such cases it is recommended to replace the whole set of elements.

A diagram showing the principle of construction of chamber furnace is given in Fig. 3.1. The furnace can be in the horizontal position or in the vertical position. Furnaces operating below 600°C are provided with fans for the circulation of air to get uniformity of temperature. The advantages and disadvantages of chamber furnaces are given in Table 3.2.

Advantages	Disadvantages
1. Simple and easy to operate	1. No atmosphere control. Hence heavy decarburisation and scaling.
2. Low capital cost	2. Temperature inside the chamber will not be uniform
3. No furmes or effluent problem	3. Longer heating times due to poor heat transfer

TABLE 3.2 ADVANTAGES AND DISADVANTAGES OF CHAMBER FURNACES

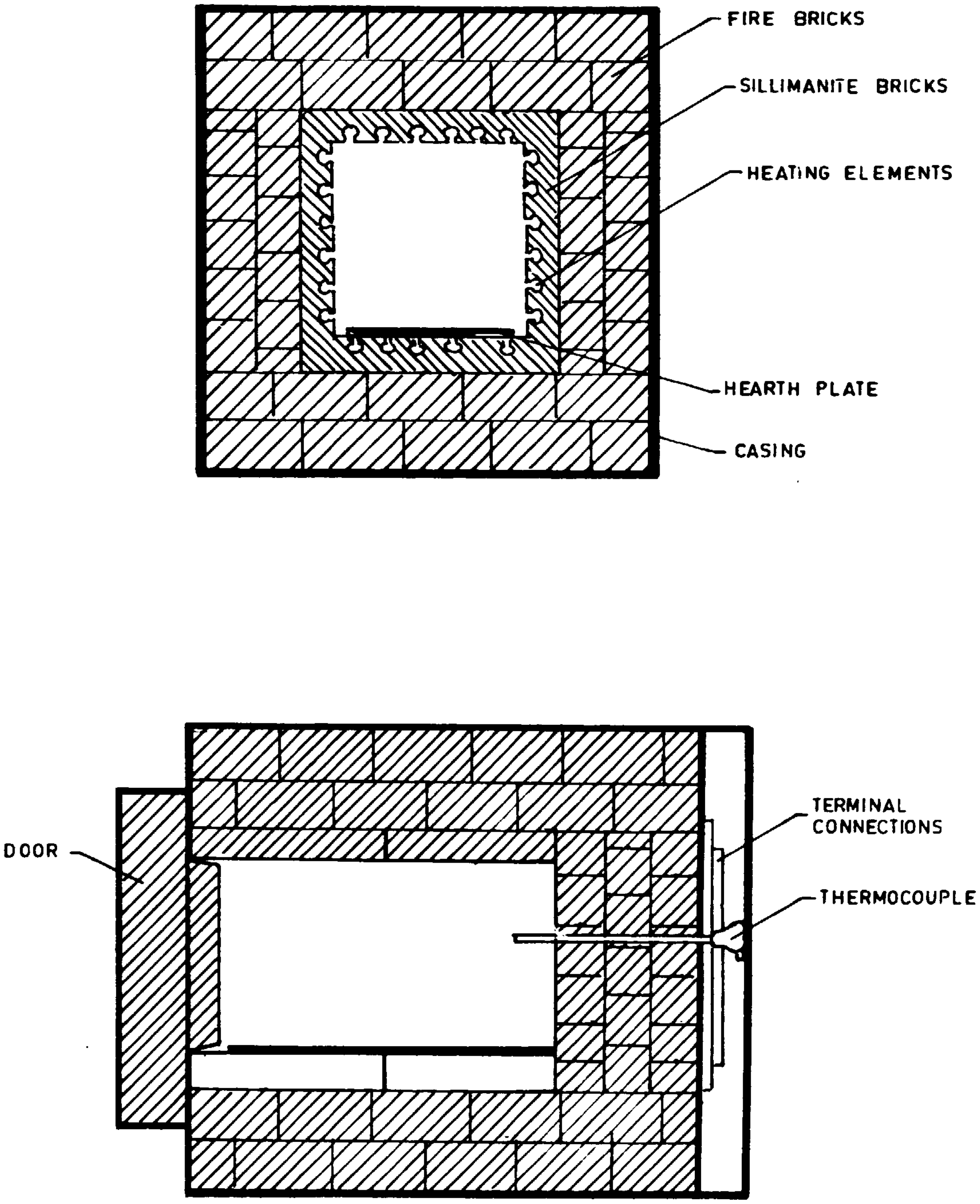


FIG.3.1 DIAGRAM SHOWING THE PRINCIPLE OF CONSTRUCTION OF CHAMBER FURNACES

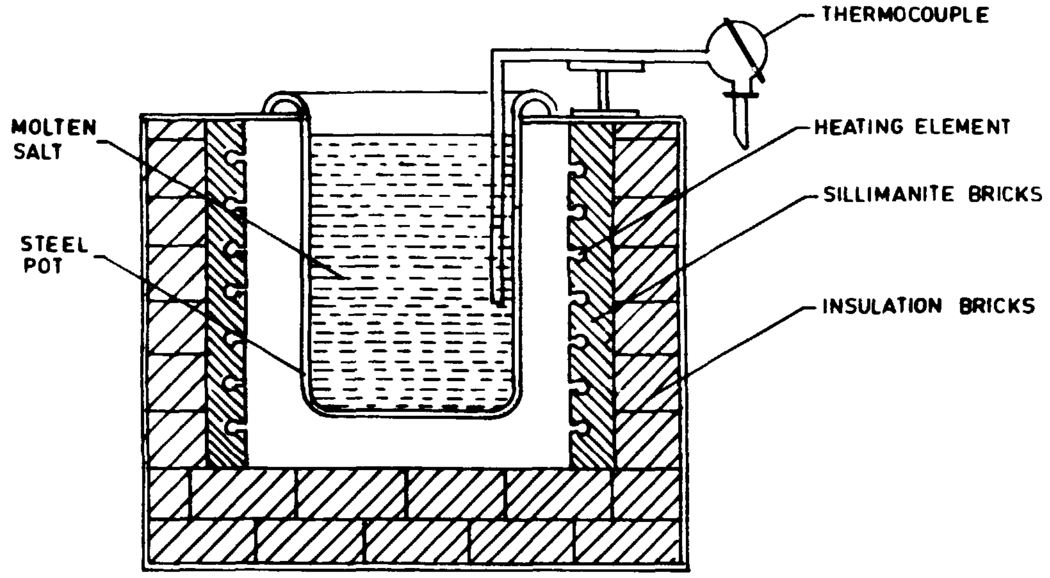
3.2.2 Salt Bath Furnaces

Salt bath furnaces are used for a wide variety of commercial heat treating operations such as hardening, tempering, liquid carburising, austempering, martempering etc. The furnaces can be externally or internally heated as illustrated in Fig.3.2. A comparison of the advantages and disadvantages of externally and internally heated salt baths is given in Table 3.3.

	Externally Heated Salt Bath Furnace	Internally Heated Salt Bath Furnace
1.	No transformer required	Transformer is required
2.	Easy to start. No special starting device required	Difficult to start, special starting devices required
3.	Temperature not uniform due to lack of stirring	Temperature uniform due to the stirring action of the current
4.	Cannot be used for temperatures above 1000°C	Can be used for temperature upto 1350°C by using ceramic pots
5.	In case of leakage of the pot, the heating elements get damaged	No such danger
6.	Usually confined to small size pots	Can be applied to any size of pot
7.	Needs stainless steel or aluminised steel pots	Low carbon or ceramic pots can be used

TABLE 3.3 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF THE INTERNALLY AND EXTERNALLY HEATED SALT BATH FURNACES

EXTERNALLY HEATED SALT BATH



INTERNALLY HEATED SALT BATH(UPTO 900°C)

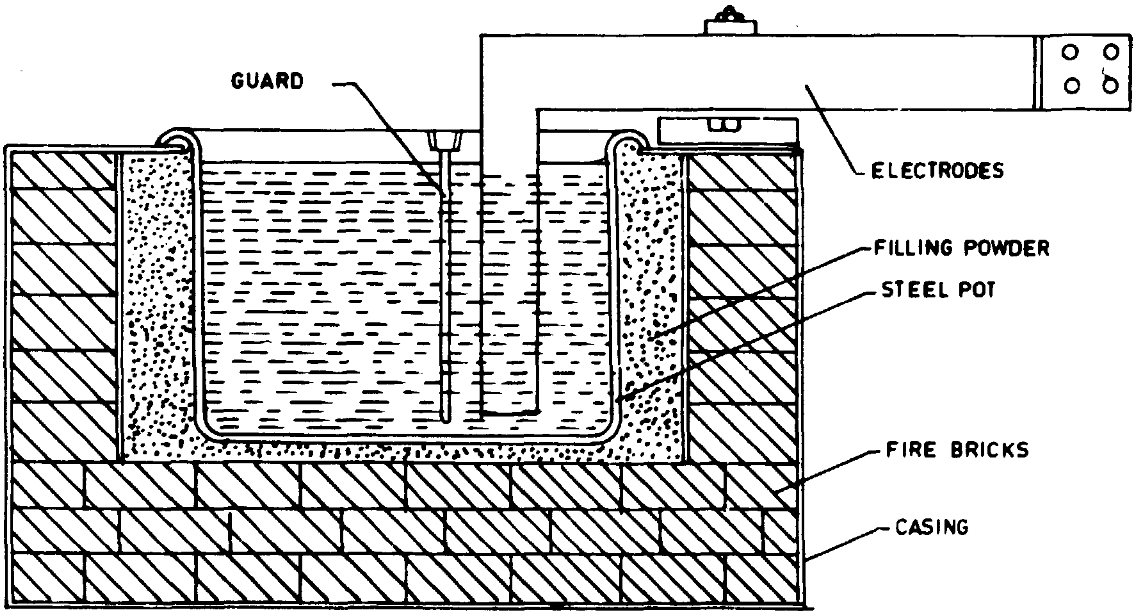


FIG. 3.2 DIAGRAM SHOWING THE PRINCIPLE OF CONSTRUCTION OF SALT BATH FURNACES

The composition of the salts used for melting in the salt bath varies depending upon the operating range of temperature. Separate salts are used for neutral hardening and for operations such as carburising, nitriding etc., where there is chemical reaction between the salt and the steel. The salts are available as proprietery salts from the manufacturers of heat treatment salts and hence the exact compositions are not known. However, the Table 3.4 gives the approximate composition of the neutral salts used for various temperature

Temperature range °C	Generally used for	Chemical Composition	Density gm/cm^3
160 - 540°C	Martempering quenching and Tempering	50 - 60% KNO_3 37 - 50% $NaNO_2$ 0 - 10% $NaNO_3$	1.8
260 - 593°C	Austempering and Tempering	45 - 57% $NaNO_3$ 45 - 57% KNO_3	1.8
704 - 900°C	Neutral Hardening of Tool Steels	40 - 60% NaCl 40 - 60% KCl	1.5
898 -1288°C	H.S.S Hardening	93 - 97% $BaCl_2$ 3 - 7% NaCl	3.0
550 - 760°C	H.S.S Quenching and Tempering	10 - 15% NaCl 25 - 30% KCl 40 - 45% $BaCl_2$ 15 - 20% $CaCl_2$	2.1

TABLE 3.4 COMPOSITIONS OF SALTS USED FOR DIFFERENT TEMPERATURE RANGES

The approximate weight of salts required for various sizes of furnaces are given in Table 3.5

Furnace Pot Size – mm	Weight of Salt Required in Kg.			
	Neutral Hardening	Neutral Quenching	H.S.S. Hardening	H.S.S. Quenching
200 dia x 300 dp	15	18	30	21
300 dia x 500 dp	54	65	108	76
400 dia x 800 dp	165	198	330	231
500 dia x 800 dp	228	274	456	319
500L x 500W x 900 Dp	360	432	-	-
700L x 700W x 900 Dp	848	-	-	-
800L x 600W x 600 Dp	-	1008	-	-
800L x 600W x 1300 Dp	-	1980	-	-
800L x 900W x 1000 Dp	-	2232	-	-

TABLE 3.5 WEIGHT OF SALTS REQUIRED FOR VARIOUS SIZES OF FURNACES

A comparison of the advantages and disadvantages of salt bath and chamber furnaces is given in Table 3.6

Salts being hygroscopic causes corrosion to the equipments used in the vicinity. Hence the equipments should be protected well against corrosion.

	CHAMBER FURNACE	SALT BATH FURNACE
1.	Decarburisation and scaling are caused due to lack of atmosphere control	No decarburisation or scaling
2.	Temperature inside the furnace not uniform	Good temperature uniformity
3.	Distortion after hardening is more	Distortion is less due to the bouyancy effect of the salt
4.	Longer heating times	Shorter heating times. Since the heat transfer between liquid salt and steel is faster than between air and steel
5.	Not suitable for Austempering and Martempering	Most suited for Austempering and Martempering
6.	Controlled depth hardening not possible	Controlled depth hardening is possible
7.	Easy to start and stop	Not easy to start and stop. The internally heated salt baths require special starting device
8.	Cleaning of parts after heat treatment is easy	Cleaning of parts after heat treatment is difficult due to salt
9.	No fumes	Furnaces operating at high temperature produce fumes
10.	No storage or handling of salt is required	Needs storage and handling of salts. Some of them are highly hygroscopic
11.	No effluent disposal problem	Some of the salts are poisonous, needs special neutralising treatment before disposing
12.	Low capital cost	Higher capital cost

TABLE 3.6 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF SALT BATH AND CHAMBER FURNACE

3.2.3 Fluidised Bed Furnaces

The principle of fluidised bed is to pass a gas through a dry solid of finely divided particles and to agitate them in such a way that the finely divided powder will act as though a liquid. The principle is shown diagramatically in Fig. 3.3.

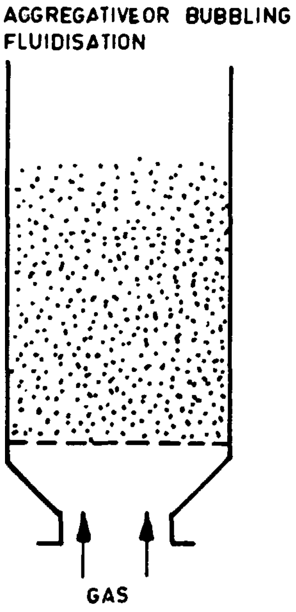


FIG. 3.3 DIAGRAM SHOWING THE PRINCIPLE OF FLUIDISED BED FURNACE

The fluidised bed furnace acts almost like a salt bath furnace. It has the advantages of salt bath furnace such as faster heating, closer control of temperature, less distortion of parts due to bouyancy etc. At the same time fluidised furnaces do not have the major disadvantages of salt bath furnace, such as fume, effluent disposal problems, difficulty in cleaning the parts after heat treatment etc. The fluided bed furnaces can be used upto 1050°C only and hence cannot be used for the hardening of high speed steels. Another drawback of this type of furnace is the higher consumption of gas. A diagram illustrating the construction of fluidised bed furnace is given in Fig.3.4.

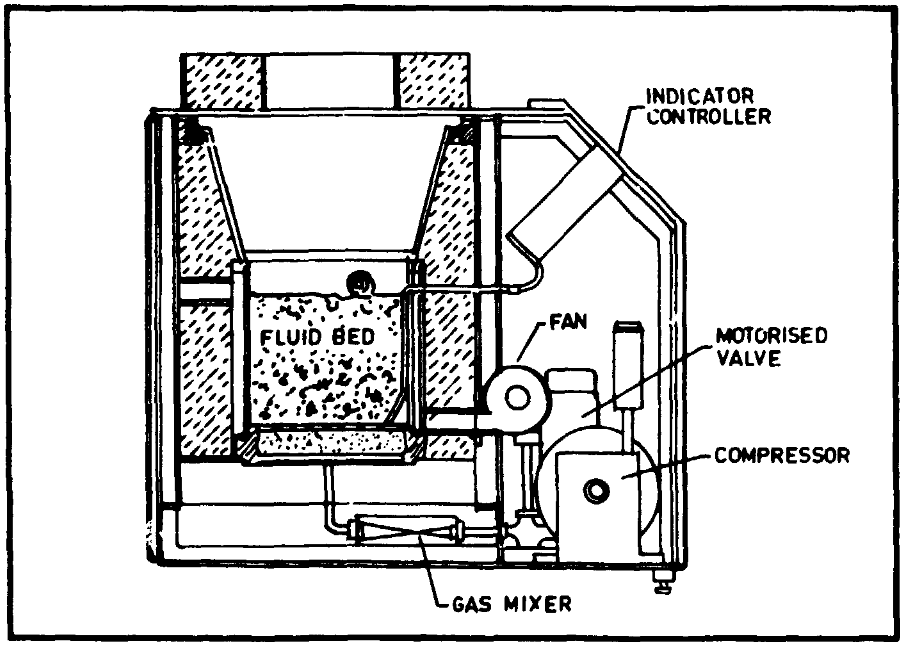


FIG. 3.4 DIAGRAM SHOWING THE CONSTRUCTION OF FLUIDISED BED FURNACE

Both gas or electricity can be used for heating.

3.2.4 Sealed Quench Furnace

The sealed quench furnace consists of two chambers, one for heating and the other for quenching and the chambers remain sealed during heating and quenching. Hence, the name sealed quench furnace. It is used mainly for neutral hardening, gas carburising, carbonitriding and nitempering.
Fig. 3.5 shows the construction of a typical sealed quench furnace.

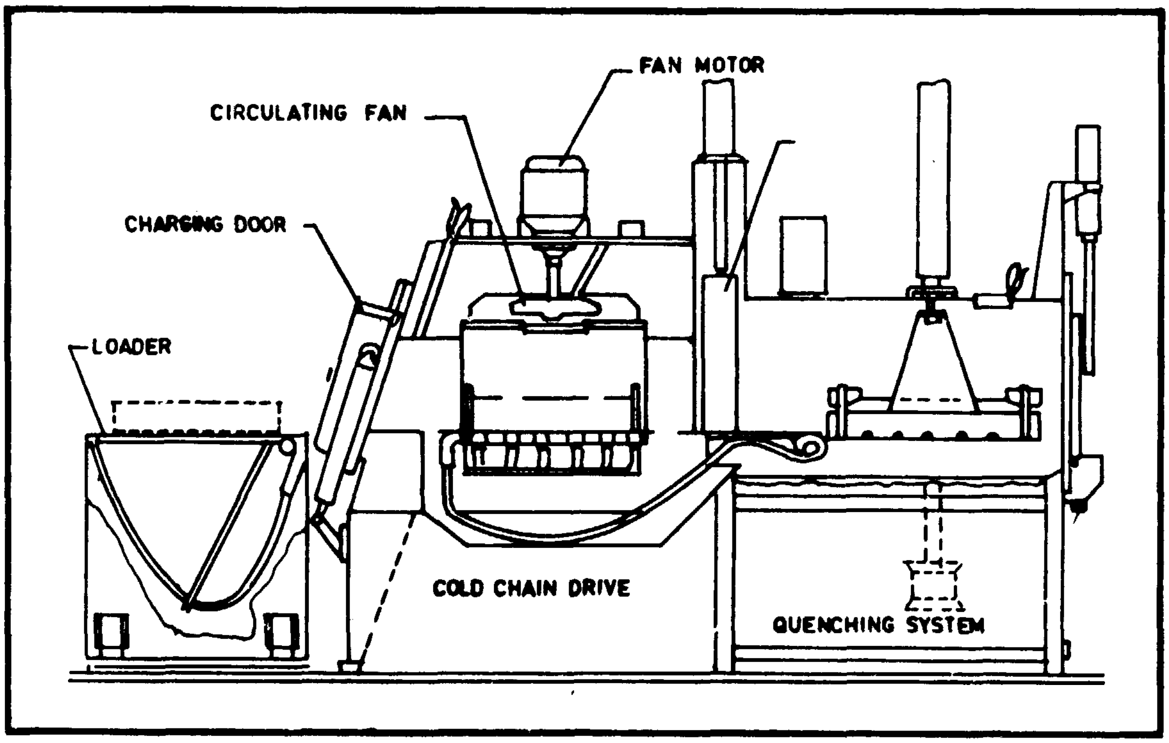


FIG. 3.5 DIAGRAM SHOWING THE CONSTRUCTION OF SEALED QUENCH FURNACE

The heating and quenching chambers are adjacent to one another in the same line, with a door forming the common wall. The heating chamber is provided with radiant tube heating elements and can be heated upto about 1100°C. The chamber is completely sealed when the doors are closed and provision exists for the introduction of suitable gaseous medium. A fan is provided in the chamber to obtain uniform temperature. The quenching chamber consists of an oil tank for oil quenching and a fan arrangement for cooling with inert gas or air. The quenching oil tank is provided with heating arrangements to maintain any desired quenching temperature. The parts are heated and quenched within the furnace, without contact with air which prevents completely any oxidation of the surface. A flame curtain prevents the entry of air when the door is opened.

The movement of the job from the heating chamber to the quenching chamber is automatic. All parameters such as heating time, quenching medium, its temperature, quenching duration etc. can be programmed. This makes it possible to get consistant results. A comparison of the advantages and disadvantages of sealed quench furnace with that of salt bath furnace is given in Table 3.7.

Sealed quench furnaces are mainly used for large batch production.

	SEALED QUENCH FURNACE	SALT BATH FURNACE
1.	Single furnace can do many operations such as carburising, hardening, carbonitriding, annealing, normalising and nitempering. Oil quenching, inert gas cooling and air cooling facilities are built-in.	Requires separate bath for carburising hardening, carbonitriding and nitriding. Full annealing cannot be done in salt bath. Quenching facilities to be provided separately.
2.	Parts after heat treatment will be clean. No elaborate cleaning equipment is required	Salt collects on parts. It is difficult to remove the salt completely from small holes etc.
3.	No salt fumes. The sorroundings will be clean	Salt fumes are produced which should be exhausted. Salt fumes condense on other machines and equipments and cause corrosion. Salt gets spilled over the surroundings making the area dirty.
4.	No waste disposal problem	Disposal of used salt is difficult. In the case of cyanide salt suitable neutralising set-up is necessary
5.	Starting the furnace is easy	Starting difficult with internally heated baths
6.	No regular replacement of wear parts	Needs regular replacement of electrodes, pots etc.
7.	Less human labour required as the quenching is done automatically	More manual labour required
8.	Requires gas storage installations	Only storage of salt is required
9.	Not possible to use for the hardening of H.S.S.	Suitable for the hardening of H.S.S.
10.	Longer heating times due to slower rate of heat transfer	Shorter heating times due to high rate of heat transfer

TABLE 3.7 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF SALT BATH AND AND SEALED QUENCH FURNACES

3.2.5 Vacuum Furnaces

The vacuum furnace, as the name implies, consists of a heating chamber which can be evacuated to a high degree of vacuum. The vacuum used is of the order of 0.0001 to 1 mm of Hg. There are two types of vacuum furnaces, based on the method of heating, called the cold wall type and the hot wall type. The principle of these two types are given in Fig.3.6.

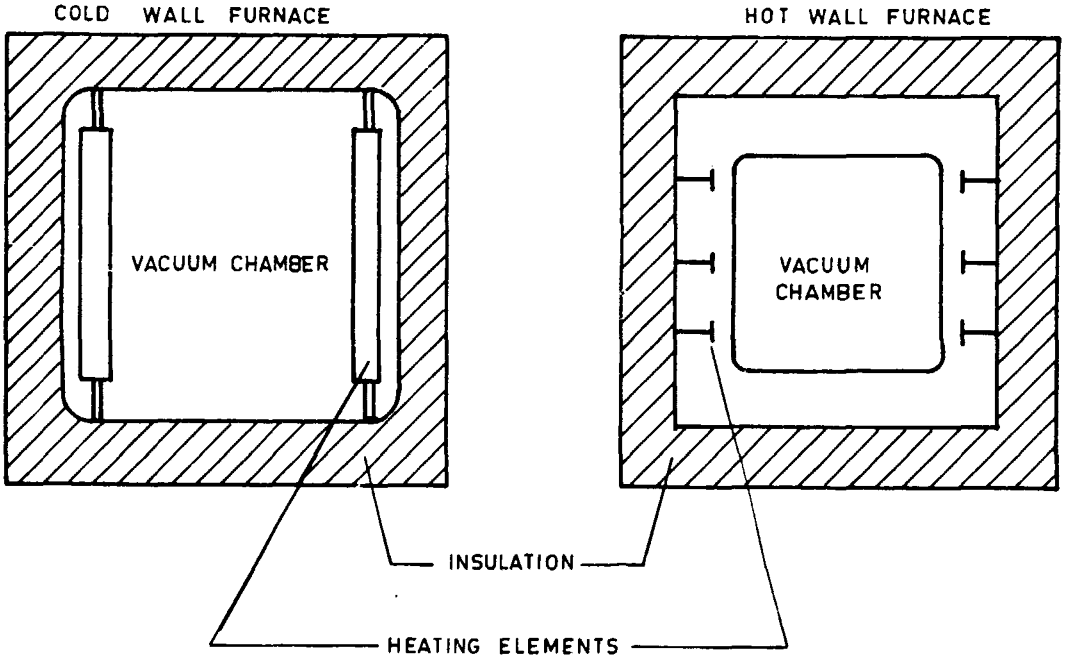
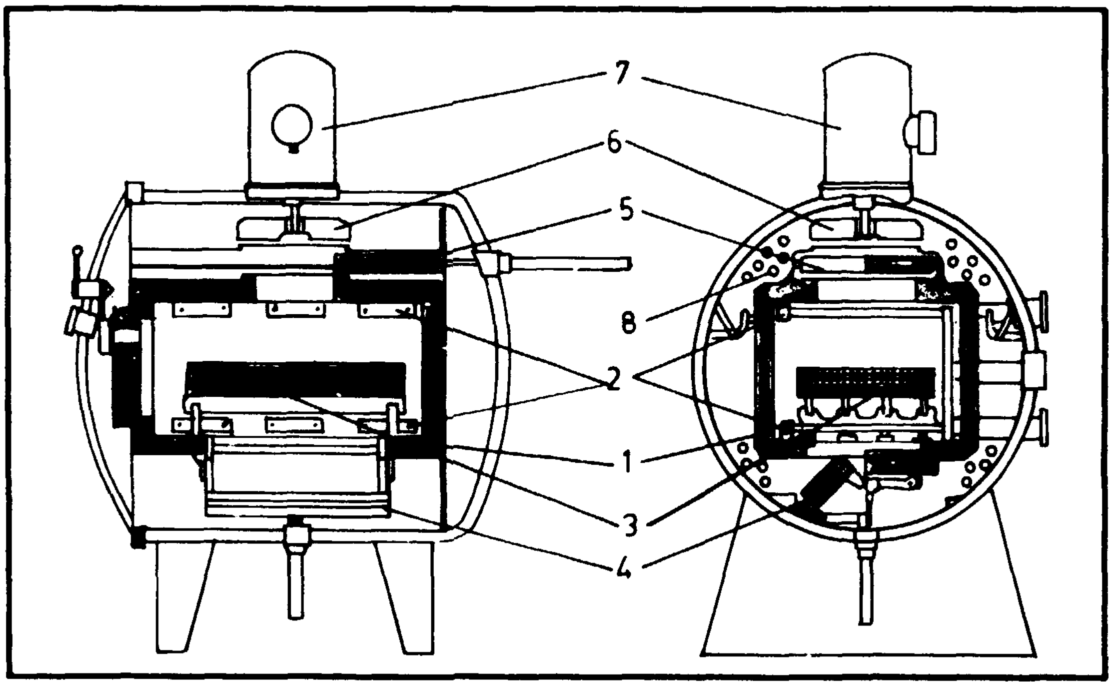


FIG. 3.6 PRINCIPLE OF HOT WALL AND COLD WALL VACUUM FURNACES

In the hot wall furnace, the vacuum chamber is heated externally whereas in the cold wall furnace the heating elements are inside the vacuum chamber. Because of the external heating, the shell of the vacuum chamber also gets heated, and makes it weak at high temperatures. Hence hot wall furnaces cannot be used for high temperatures (max. temperature 980°C). In the case of cold wall furnaces, the shell of the vacuum chamber does not get heated and hence such furnaces can be used for higher temperatures (upto 1350°C). Because of the limitation of temperature hot wall furnaces are not used any more.

The heating elements used in a vacuum furnace are graphite or refractory metals such as molybdenum. Due to the high melting point of these materials, the heating can be done very fast, making it possible to reach 1300°C in about 30 minutes time. Similarly these furnaces can be cooled also very fast. In the simple form of the furnace (Fig. 3.7) the heating and quenching are done inside the furnace. The quenching is done by circulating an inert gas at moderate pressures. With this method, sufficient quenching rate is achieved for the hardening of high alloy steels. When higher quenching rates are required, vacuum furnaces are provided with separate chamber for oil quenching. With this arrangement it is possible to do the hardening of all types of steels except water hardening steels. The same furnace can also be used for vacuum carburising, by injecting a pure hydro-carbon gas at low pressures.

A comparison of the advantages and disadvantages of vacuum furnaces and salt bath furnaces is given in Table. 3.8.



1. Heating Chamber	2. Heating Elements
3. Charge carrier	4. Bottom Bung
5. Top Bung	6. Fan
7. Fan Motor	8. Heat Exchanger

FIG 3.7 DIAGRAM SHOWING THE CONSTRUCTION OF VACUUM FURNACE

	VACUUM FURNACE	SALT BATH FURNACE
1.	The material after heat treatment will be free from any decarburisation, oxidation or scaling.	Neutral baths cause light decarburisation and colour change.
2.	No subsequent cleaning required as the jobs come out clean from the furnace.	Needs washing to remove salt. Even then salt cannot be completely cleaned, especially from small holes.
3.	No salt is required. No consumables spares such as pot, electrodes required.	Requires salt as a consumable item. Also needs regular replacement of pots and electrodes.
4.	No frequent shut down to change pots and electrodes.	Periodic shut downs required to change electrodes and pots.
5.	The furnace will attain 1300°C in about 30 minutes.	Requires about 3 hours to reach 1300°C.
6.	The furnace works on automatic cycle. Operator has to load and unload the jobs only.	Material has to be moved from bath to bath and to quenching tanks manually.
7.	No preheating is necessary.	Preheating is always required
8.	Clean atmosphere and surroundings.	Atmosphere and the surroundings not clean due to the presence of salt.
9.	More toughness for the hardened parts for the same value of hardness due to degassing.	Less tough.
10.	In many cases post heat treatment operations such as grinding can be avoided since the surface is absolutely free from decarburisation.	Due to decarburisation subsequent grinding operation is necessary.
11.	Different precise quenching rates possible.	Not possible to vary quenching rate.
12.	Starting and stopping easy. No emptying of molten salt.	Starting and stopping very difficult. H.S.S., hardening salt has to be baled out before putting off the furnace.

	VACUUM FURNACE	SALT BATH FURNACE
13.	No fumes.	Fumes are produced at high temperatures.
14.	No poisonous waste needing special treatment for disposal.	Salts containing Ba Cl2 and cyanide are to be neutralised before disposal.
15.	Vacuum brazing possible.	Vacuum brazing not possible.
16.	Longer soaking times are required since heat transfer in vacuum is very slow.	Shorter soaking times due to the salt medium directly transferring the heat.
17.	Degreasing is necessary before loading the parts into the furnace.	No degreasing required.
18.	Higher capital cost.	Low capital cost.

TABLE 3.8 COMPARISON OF THE ADVANTAGES AND DISADVANTAGES OF VACUUM FURNACES AND SALT BATHS

3.3 Temperature Measurement And Control Equipments

3.3.1 Thermocouples

Thermocouples are used for the measurement of the temperature of heat treatment furnaces. The construction of the thermocouple is based on the principle that when two junctions of a pair of dissimilar materials are maintained at different temperatures, a small EMF (in millivolts) is produced in the circuit. (See Fig. 3.8). The value of this EMF is proportional to the difference in temperature between the two junctions. Different types of pairs of dissimilar materials are used for the construction of thermocouples; but the most commonly used ones in heat treatment are given in Table 3.9.

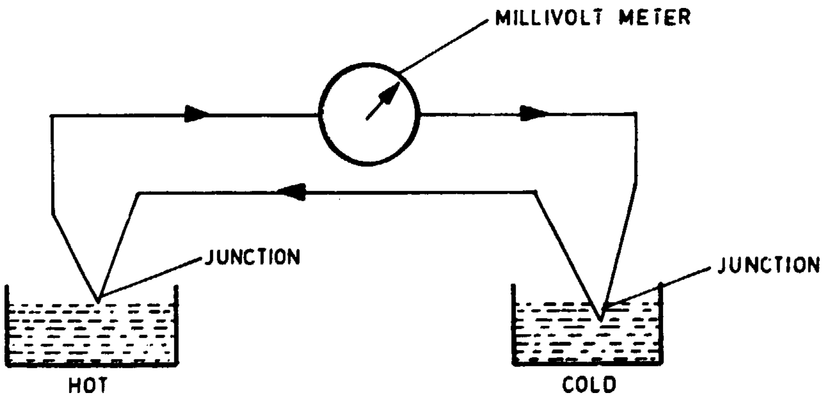


FIG. 3.8 PRINCIPLE OF THERMOCOUPLE

Type of Thermocouple Material	Measuring Range upto ....
Iron - Constantan	760°C
Chromel - Alumel	1260°C
Platninum Rhodium - Platinum	1400°C
Copper - Constantan	370°C (suitable for measuring sub-zero temperatures also)

TABLE 3.9 COMMONLY USED THERMOCOUPLE MATERIALS AND THEIR RANGES

Construction details of a typical thermocouple is given in Fig. 3.9.

3.3.2 Protective Sheaths

The thermocouple wires are protected from damage and against chemical reaction from the atmosphere of the furnaces, by using suitable covers or sheaths. The different materials used for the protective sheaths and their applications are given in Table 3.10.

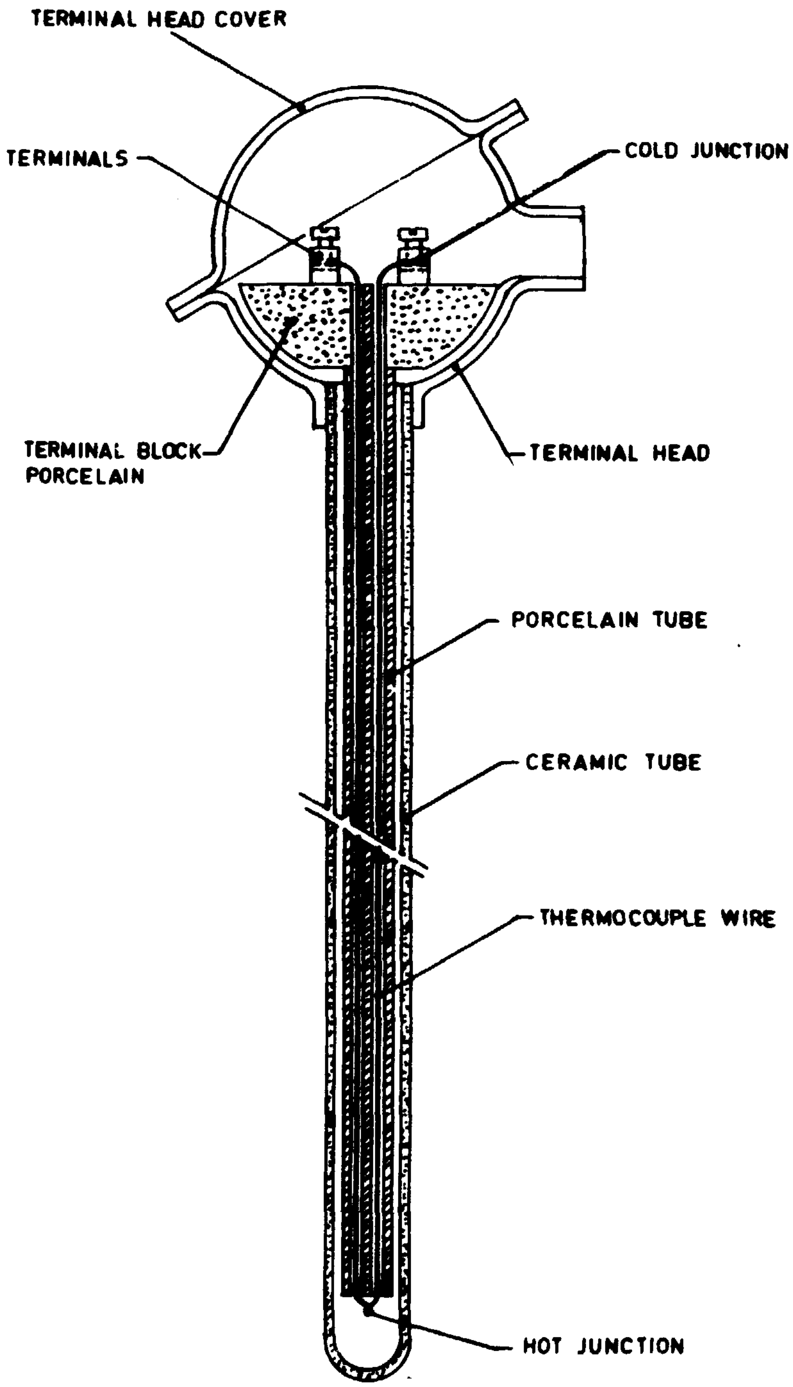


FIG. 3.9 CONSTRUCTION DETAILS OF A TYPICAL THERMOCOUPLE

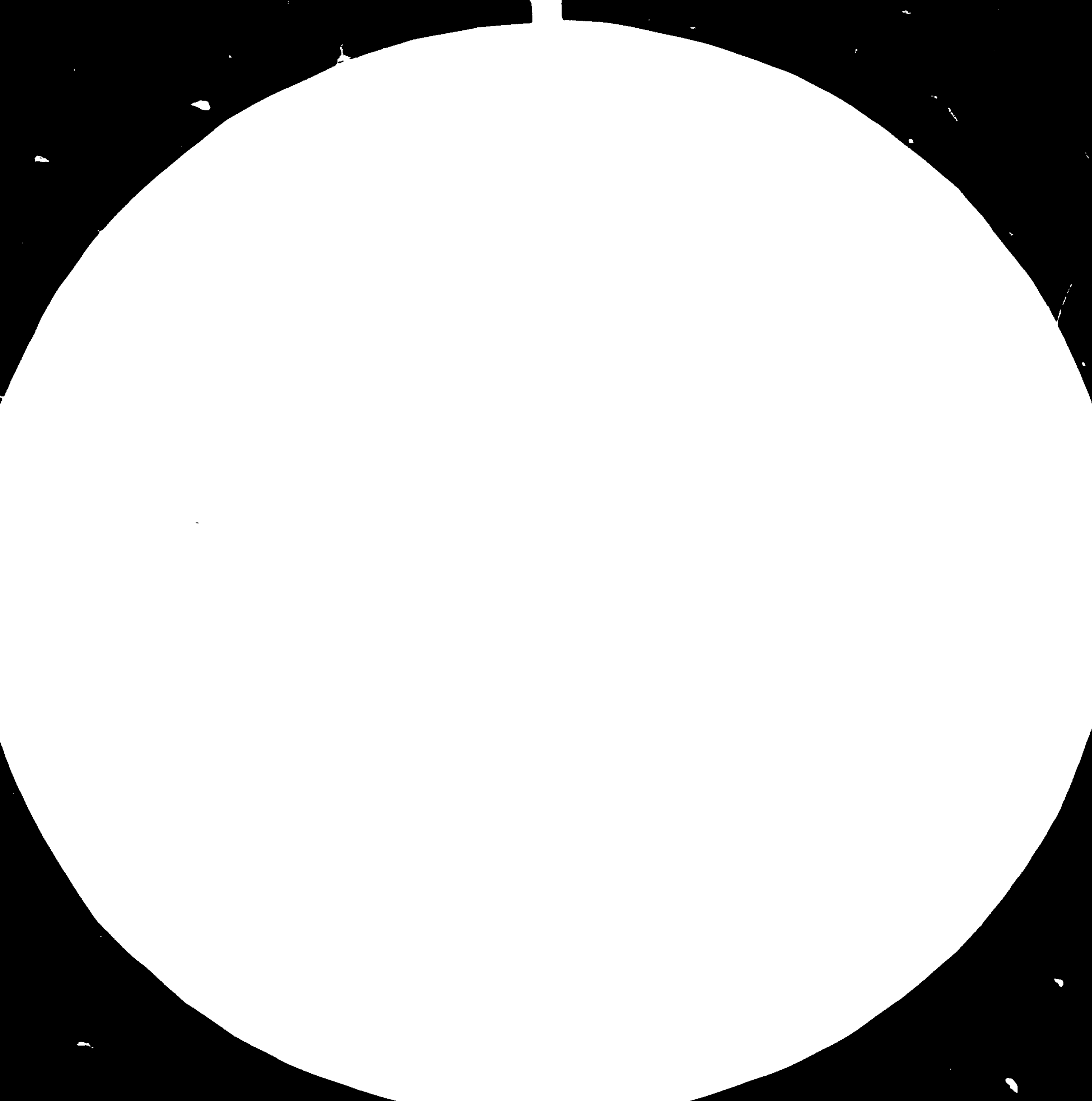
	Materials of Protective Sheath	Temperature range and applications
1.	Low alloy steel.	Can be used upto 680°C in non-corrosive environments. Used in ovens, ceramic dryers, glass tank flues etc.
2.	Cast Iron.	Can be used upto 700°C in oxidising conditions. Mainly used for measuring molten non-ferrous metals.
3.	Stainless Steel (AISI 310)	Can be used upto 1150°C under oxidising conditions. Good resistance to oxidation and corrosion.
4.	Inconel 600	Can be used upto 1150°C under oxidising conditions. Used in carburising, annealing and hardening furnaces, cyanide baths etc.
5.	Ceramic	Can be used upto 1510°C. Has poor mechanical shock resistance. Used in all types of furnaces except salt baths.

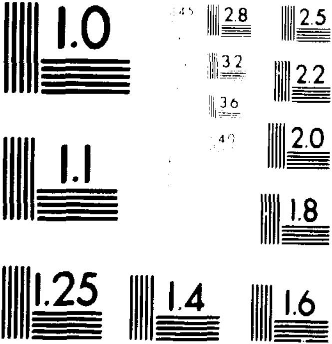
TABLE 3.10 PROTECTIVE SHEATHS AND THEIR APPLICATIONS

3.3.3 Compensating Cables

The cold junction of the thermocouple will be situated outside the furnace, but very near the outer wall of the furnace. Due to this the cold junction will be heated up slightly. Since the thermocouple develops e.m.f., proportional to the difference in temperature between the hot junction and cold junction, the temperature reading will be inaccurate when the cold junction gets heated up. To compensate for this difference, the compensating cable is used. Compensating cables are special wires used for connecting the thermocouple to the measuring instrument. It is made out of special wires which will produce a small e.m.f., proportional to the difference in temperature of the cold junction. This e.m.f., will be in the same direction and hence it will compensate for the loss in e.m.f., due to the heating up of the cold junction. Different compensating cables are used for different thermocouple types in order to match the e.m.f.. out put. That is, a compensating cable meant for Iron-Constantan thermocouple cannot be used for connecting chromel-alumel thermocouples and vice-versa etc. Compensating cables are identified by colour coding as given in Table 3.11.

Normally, the compensating cable wires are insulated with PVC and then covered with asbetos for protection against heat and then finally protected from mechanical damage with metallic braiding.





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

Thermocouple	Colour of the wires	
	+ve lead	-ve lead
Iron - Constantan	Red	Blue
Chromel - Alumel	Red	Green
Pt Rh - Pt	Red	White
Copper-Constantan	Red	Brown

TABLE 3.11 COLOUR CODING FOR COMPENSATING CABLES (DIN 43710)

3.3.4 Optical Pyrometers

Optical pyrometers are non-contact type instruments which indicate the temperature by sensing the heat or light radiated from the surface of the hot body. Since the radiation is very little at lower temperatures, optical pyrometers can be used for high temperature measurements only (minimum temperature about 850°C). As they do not involve physical contact with the hot body the upper limit is not critical. There are two types of optical pyrometers (i) Total radiation and (ii) Partial radiation or disappearing filament pyrometer.

3.3.4.1 Total Radiation Pyrometers

In this instrument the heat from the hot body is focussed on a thermo-element placed inside the pyrometer and the temperature of the thermo-element is measured using an ordinary millivoltmeter. The instrument is calibrated with suitable scale to read the temperature of the hot body directly. The instrument can be fixed on the furnace permanently and can be connected to an automatic temperature controller so that it can be used for controlling the furnace temperatures. Total radiation pyrometer is mainly used for the control of the temperature of H.S.S., hardening furnace. The accuracy of the readings obtained depends upon the condition of the surface of the bath. Fumes, scum or other foreign particles present on the surface affect the reading considerably. The pyrometer should be focussed on one side of the bath so that the jobs can be loaded in the bath without obstructing the field of view of the pyrometer.

3.3.4.2 Disappearing Filament Pyrometers (Partial Radiation Pyrometer)

Unlike the total radiation pyrometer, the partial radiation pyrometer can be used only for the occasional measurement of temperature. Human attention is required every time when a measurement is taken. The instrument has to be focussed on the hot body and the colour of the body is observed through the eye-piece. In the centre of the tube an electric resistance filament, normally in the shape of a hair pin, is placed which can be heated electrically through a potentiometer. The filament can be viewed simultaneously in the same field along with the surface of the hot body. The potentiometer is adjusted manually so that the colour of the hot body and the filament exactly matches. The potentiometer reading then corresponds to the temperature of the hot body. For convinience, the potentiometer is calibrated in degrees so that the temperature can be directly read. Disappearing filament pyrometers are used as a portable instrument for occasional measuring or checking of high temperatures of molten metal, salt etc. It cannot be used for continuous measurement or for automatic control of furnaces.

3.3.5 Infrared Pyrometers

The infrared pyrometers make use of the infrared radiations from the hot surface for temperature measurement. The instrument can be used as a portable or stationary equipment for temperature measurement. The applications and other details are same as for optical pyrometers.

3.3.6 Temperature Indicators

The temperature indicators are basically very sensitive millivoltmeters calibrated in degrees Centrigrade or Farhenneit instead of voltage. They are mainly moving coil type instruments. Each kind of thermocouple has different millivolt range and hence the temperature indicator for a particular kind of thermocouple cannot be used for other kinds. For example, a temperature indicator calibrated for Fe-Const thermocouple cannot be used along with chromel-alumel thermocouple and so on. The millivolts produced by various kinds of thermocouples at different temperatures are given in Fig.3.10. The kind of thermocouple to be used along with each indicator will be shown on the scale of the instrument.

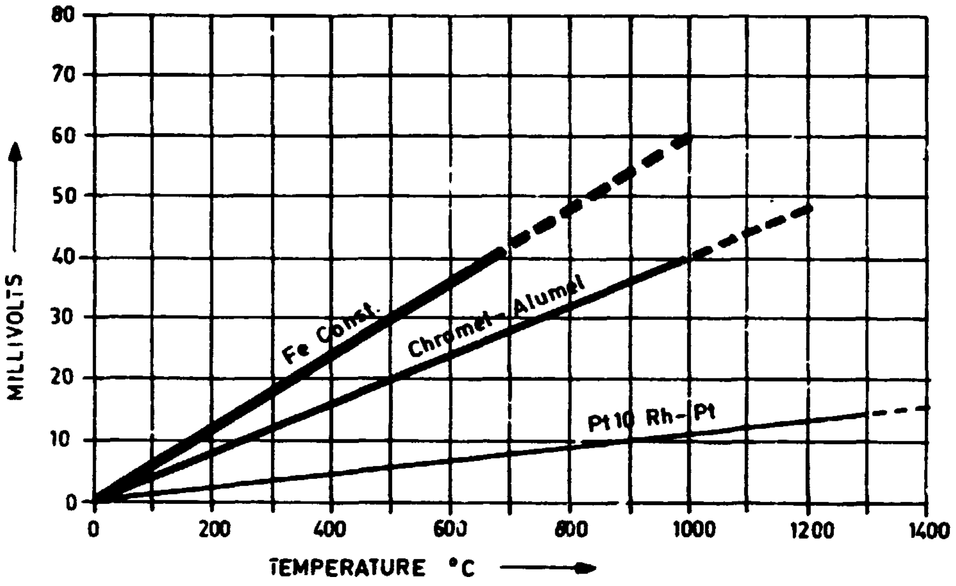


FIG. 3.10 EMF PRODUCED BY DIFFERENT THERMOCOUPLES

3.3.7 Temperature Controllers

The temperature controller consists of a temperature measuring instrument as described above and a mechanism to put on and off the furnace when the temperature is below or above the set temperature. The mechanism can be mechanical or electronic; the latter being very common now. The controllers commonly used serve both as a temperature indicator and as a temperature control instrument. As most of the controllers use a sensitive moving coil galvanometers for the measurement, they should be handled very carefully.

3.3.7.1 On-off Controllers

The on-off controller is the simplest type of controller. In this case furnace will be turned off when the temperature goes higher than the set value and will be turned on when the temperature drops below the set value. The actual temperature of the furnace will fluctuate little on either side of the set value in a sinusoidal form.

3.3.7.2 Proportionating Controllers
(PID Controllers)

With the normal on-off controller, the temperature of the furnace flcutates between two values slightly above and below the set temperature. This fluctuation is due to the thermal inertia of the charge and the lining materials of the furnace. Depending upon the power input and the amount of lining used, this fluctuation can be as high as 50°C. In order to avoid this, that is to maintain the furnace temperature within narrow limits, the proportionating controller is used. In the proportionating, the heat input is reduced gradually as the temperature approaches the set point; thus avoiding overshooting. In addition to closer control of temperature, the proportionating controller also saves energy. Proportionating controllers cannot be used in the ordinary furnaces as it needs facility to vary the heat input.

3.3.7.3 Programmable Controllers

In the programmable controller, instead of having a fixed set point, the set point is varied continuously to get any desired time-temperature cycle. For example, for annealing, stress-relieving etc., the desired rate of heating, soaking temperature and cooling rate can be obtained without changing the set point manually. The early type of programmable controllers make use of cams for programming the cycle, but now-a-days microprocessor based programmable controllers are available which obviates the necessity of preparing cams.

3.3.8 Temperature Recorders

Essentially a temperature recorder consist of a millivoltmeter to measure the temperature and a mechanism to record the reading. Recorders are available in single colour for recording the temperature of single thermocouple or in multicolour to record the temperatures of more than one thermocouple.

3.3.9 Calibration of Thermocouples and Temperature Measuring Instruments

The thermocouples and the temperature measuring instruments are susceptible to errors due to various reasons such as contamination, bad contact etc. Hence it is necessary that they are checked and calibrated periodically to ensure that the temperature measurement is accurate. In the case of operations where the temperature measurement accuracy is critical, the calibration has to be done every week. For radiation pyrometer it is necessary that the calibration is done every day. In all other cases the calibration can be done once in 1 - 2 months.

Though there are several methods available for checking the accuracy of temperature measurement, the simple and most commonly used method is the comparison method. In this method a standard thermocouple (usually Pt Rh - Pt) is inserted side by side with the actual thermocouple and the temperature measured with a very accurate instrument. If the error is small, correction can be made by adjusting the zero setting of the instrument. If the error is large, it is necessary to find out whether the thermocouple is defective or the measuring instrument. The accuracy of the measuring instrument can be checked independently with the help of a thermocouple test set. After locating the defective item, necessary action has to be taken to repair or replace the same.

3.3.10 Broken Thermocouple Safety Device

During the operation of the furnace it is likely that the thermocuple circuit breaks due to various reasons such as failure of the joint, breakage or damage of the cable, bad connection etc. In such cases no temperature will be indicated and hence the controller will be on continuously leading to excessive temperature and the resultant damage to the parts and the furnace. In order to prevent this every temperature controller will have a system called Broken Thermocouple Safety Device which puts off the furnace in case of breakage of thermocouple circuit, thereby protecting the furnace from damage due to breakage of thermocouple.

3.3.11 Thermal Fuse

The purpose of thermal fuse is to protect the furnace from excessive temperatures caused by the failure of the temperature control system. When the temperature goes above the maximum rated value for the furnace, the thermal fuse melts and the heating is cut-off.

The thermal fuse consists of two leads of heat resistant wire connected at the tip with a suitable metal or alloy whose melting point corresponds to the maximum temperature the furnace can withstand. It is inserted into the furnace in the same way as the thermocouple and is connected in series to the electrical control circuit of the furnace. When the temperature exceeds the maximum value, the tip melts and the heating circuit is cut-off ensuring the safety of the furnace. A sketch showing the construction of the thermal fuse is given in Fig.3.11. When replacing the thermal fuse care has to be taken to see that the melting point of the fuse corresponds to the maximum temperature of the furnace. It is not possible to use thermal fuses in salt bath furnaces.

FIG. 3.11 CONSTRUCTION OF THERMAL FUSE

3.4 Atmosphere Generating and Control Equipments

Atmosphere generators are used to supply suitable gas mixtures to the furnace to produce desired atmosphere conditions such as neutral, carburising etc.

3.4.1 Exothermic Generators

In the exothermic generator, hydrocarbon gases methane, propane, natural gas etc., are burnt with controlled amounts of air to produce a gas mixture containing nitrogen, carbon monoxide, hydrogen and carbondioxide. The burning is done in the presence of a nickel catalyst, in a refractory lined water jacketed combustion chamber at temperatures around 1200 - 1300°C.

Exothermic gas is used mainly for the bright annealing of steel. Because of its strong decarburising tendency it is not used for the hardening of steels.

3.4.2 Endothermic Generators

This type of atmosphere is produced by passing a carefully controlled mixture of fuel gas and air, over a heated catalyst forming a gas containing carbon monoxide, hydrogen and methane together with nitrogen. The reaction is so controlled to ensure absolute minimum amounts of carbondioxide and water vapour in the product gas. The reaction in this case is endothermic absorbing heat, and hence the name.

Endo-thermic gas is used for all types of neutral hardening, carburising etc. In the case of carburising, the endothermic gas is mixed with suitable proportions of carburising gas to produce different carbon potentials. A schematic flow diagram of an endothermic generator is shown in Fig. 3.12.

The reaction taking place in the generator is

$$2C_3H_8 + 3O_2 + 11.4N_2 = 6CO+8H_2+11.4N_2$$

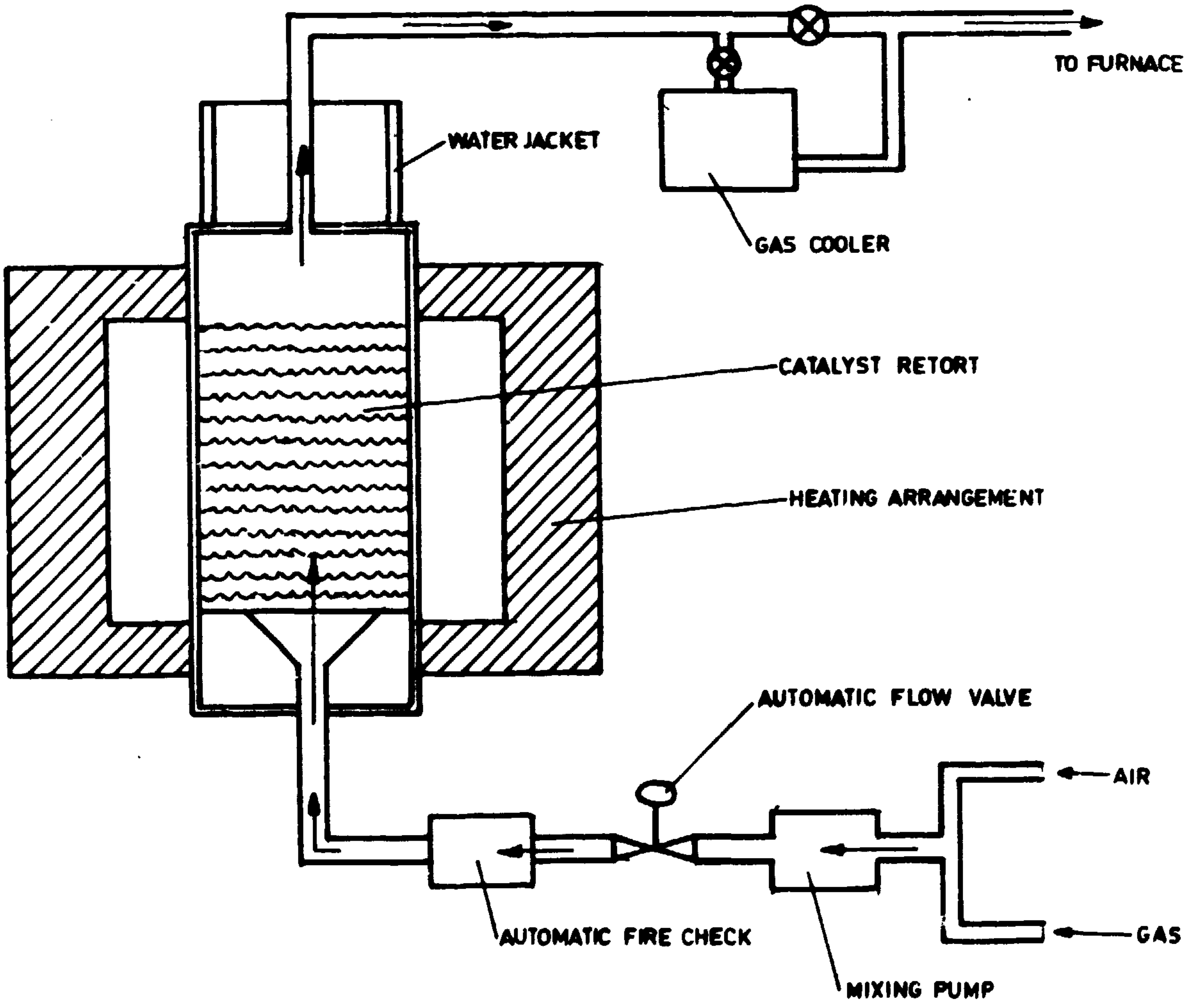


FIG. 3.12 SCHEMATIC FLOW DIAGRAM OF ENDOTHERMIC GAS GENERATOR

3.4.3 Control of Atmosphere Generators

Different methods are available for the control of the carbon potential of atmosphere generators. The commonly used methods are -

i) Dew point Analyser
ii) Infrared Analyser, and
iii) Oxygen Probe

3.4.3.1 Dew Point Analyser

Dew point is defined as the temperature, at a given pressure, at which a mixture of gases will begin to precipitate its moisture content. With the air gas mixture, the dew point will reflect the chemical balance of the mixture and in the case of protective atmospheres, the dew point is related to the carbon potential of the atmosphere. The relationship between dew point and carbon potential at different carburising temperatures is given in Fig. 3.13. By measuring the dew point the carbon potential can be controlled. There are different methods available for the measurement of dew point, such as Dew Cup, Fog Chamber, Chilled Mirror, Lithium Chloride etc.

Dew point analysers, though cheap and simple, are not very sensitive and accurate. Hence this method is not generally used for the automatic control of carbon potential.

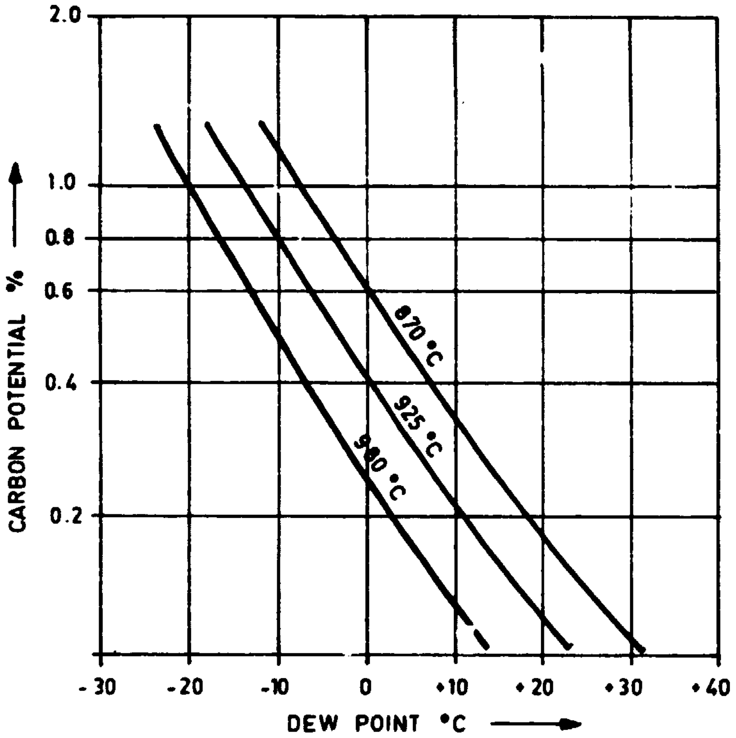


FIG. 3.13 RELATIONSHIP BETWEEN DEW POINT AND CARBON POTENTIAL

3.4.3.2 Infrared Analyser

Infrared analysers are based on the principle that any compound present in a gas mixture will absorb infrared energy in proportion to tis concentration in the mixture. In the case of carburising atmospheres the concentration of carbondioxide is used as an indicator of the carbon potential. The infrared analyser measures the concentration of carbondioxide in the gas mixture inside the furnace and it is used for the automatic control of the carbon potential.

Infrared analysers are very widely used for the control of carbon potential of carburising furnaces because of its good accuracy. However, these units are relatively expensive and complex and its maintenance and repair requires the skills of a trained electronic specialist.

3.4.3.3 Oxygen Probe

One of the most recently developed methods of measuring and controlling the carbon potential of gas carburising furnaces is the oxygen probe. The oxygen probe usually consists of two platinum electrodes separated by a solid electrolyte in the form of a gas tight zirconia tube closed at one end. The probe, which is usually enclosed in a ceramic sheath, is inserted into the furnace. The probe produces an e.m.f., in proportion to the partial pressure of oxygen in the atmosphere. This e.m.f., is used for controlling the carbon potential of the atmosphere inside the furnace.

3,5 Induction Heating Equipments

The principle of induction heating is that when a high frequency current passes through a coil placed adjacent to the material (magnetic materials only), the surface near the material gets heated due to electro-magnetic induction. (See Fig. 3.14).

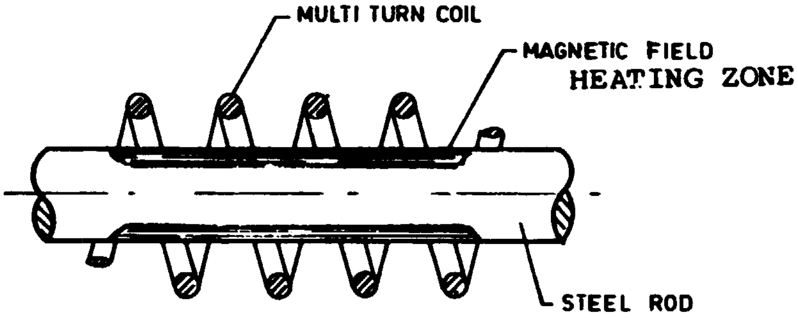


FIG. 3.14 PRINCIPLE OF INDUCTION HEATING

By suitable design of the coils, the heater can be used for the localised heating of external or internal surfaces.

The depth of heating depends upon the frequency. The higher the frequency the lower will be the depth of heating. The normal heating depths obtained for different frequency ranges are given in Table 3.12 alongwith the power requirement.

Depth of Hardening		Frequency KHZ	Power Requirement	
mm	inches		Watts/mm^2	KW/$Inch^2$
0.5 - 1.1	0.020-0.045	450	15 - 19	10 - 12
1.1 - 2.3	0.045-0.090	450	8 - 12	5 - 8
1.5 - 2.3	0.060-0.090	10	15 - 25	10 - 16
2.3 - 3.0	0.090-0.120	10	15 - 23	10 - 15
3.0 - 4.0	0.120-0.160	10	15 - 22	10 - 14
2.3 - 3.0	0.090-0.120	3	23 - 26	15 - 17
3.0 - 4.0	0.120-0.160	3	22 - 25	14 - 16
4.0 - 5.0	0.160-0.200	3	15 - 22	10 - 14

TABLE 3.12 DEPTH OF HARDENING AND POWER REQUIREMENTS AT DIFFERENT FREQUENCIES

There are different types of generators for producing high frequency current. The most commonly used ones are the motor generator, the solid state coverter and the vacuum tube generator. The first two types are used for frequency ranges upto 10 KHz whereas the vacuum tube generators are used for frequencies of 200 KHz and above. The efficiency of vacuum tube generator is low (about 50 % only) when compared to the motor generator and solid state coverter (efficiency 75 - 90 %).

3.6 Flame Hardening Equipments

Surface hardening of steel or cast iron using an oxy-acetylene flame is termed as flame hardening. Instead of acetylene, natural gas or LPG gas can be used along with oxygen for flame hardening. The main equipments required for flame hardening are -

i) a battery of gas cylinder,
ii) gas flow meters and regulating devices and,
iii) burners manufactured to suit the shape of the surface to be hardened, with built-in cooling jets.

For the hardening of large pieces, special handling equipments are required to effect the gradual movement of the burner in relation to the job.

The depth obtained in flame hardening is usually higher (about 3 - 5 mm) when compared to induction hardening. The heating will be slower than with induction hardening since the heat has to be conducted into the part whereas in induction hardening the heat is generated inside the part.

The control of heating is very difficult in the case of flame hardening, when compared to induction hardening.

3.7 Fixtures/Baskets

Fixtures/baskets are used for the following purposes:

i) to hold the job during heating and quenching.

ii) to support the job properly to reduce distortion during heat treatment.

The materials commonly used for making baskets and fixtures and their applications are given in Table 3.13.

	Material	Typical Applications
1.	Low Carbon Steel	Can be used for general purpose fixtures for hardening, tempering carburising etc. The life will be very less when used in furnaces without atmosphere control, such as muffle furnace. Mainly used for salt bath fixtures and baskets.
2.	Austenitic Stainless Steel	Can withstand high temperatures without oxidation or scaling. Mainly used for fixtures/baskets for chamber furnace, sealed quench furnace etc.

	Material	Typical Applications
3.	Inconel Alloys	Resistant to oxidation at higher temperatures. Also resistant to chemicals used in Heat Treatment. Very costly.
4.	Cast Iron - Plain and alloyed with Ni. and Cr.	Used for fixtures for gas carburising, gas nitriding etc. Any shape can be cast easily.
5.	Titanium	Titanium baskets and fixtures are used for liquid nitriding baths.

TABLE 3.13 MATERIALS USED FOR MAKING FIXTURES AND BASKETS

3.8 List of Heat Treatment Equipment Available in Factories Under S.O.E.I., Iraq

Specialised Institute, for Engineering Industries Doura, Baghdad

	Type of Furnace	Inside (working) Dimensions mm	Temperature Range	Heat-Treatment operation Possible
1.	Horizontal Twin Chamber Furnace Electrically Heated	400 Width 300 Height 1000 Depth for each chamber	Chamber 950°C max. Chamber 2 1350°Cmax	Hardening Annealing Normalising
2.	Horizontal Chamber Furnace Electrically Heated	500 Width 300 Height 800 Depth	1200°C max.	Annealing Normalising Stress relieving
3.	Vertical Air Circulated Furnace, Electrically Heated	600 Dia 1000 D	650°C max.	Pre-heating Tempering
4.	Immersed Electrode Salt Bath Furnace	310 Dia 500 D	1350°C max.	Hardening of H.S.S.

State Enterprise for Aluminium Semi-Products, Nasiriyah, Iraq

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
1.	Vertical Chamber Furnace, Electrically Heated	450 Dia 750 Deep	350°C max.	Pre-heating Tempering
2.	Salt Bath Furnace, Electrically Heated	350 Dia 700 Depth	1020°C max.	Hardening
3.	Vertical Chamber Furnace, Electrically Heated	450 Dia 750 Depth	350°C max.	Pre-heating Tempering
4.	Salt Bath Furnace, Electrically Heated	400 Dia 800 Depth	600 - 750°C	Ageing of Aluminium
5.	Salt Bath Furnace, Electrically Heated	350 Dia 700 Depth	600 - 900°C	
6.	Salt Bath Furnace, Electrically Heated	400 Dia 800 Depth	600 - 750°C	Ageing of Aluminium
7.	Salt Bath Nitriding Furnace	750 Dia 850 Depth	580°C	Nitriding
8.	Chamber Furnace	2000 Width 1700 Height 14200 Depth	100 - 250°C	Annealing of Aluminium

Industrial Complex - Diala, Iraq

	Type Furnace	Inside (Working) Dimensions	Temperature Range	Heat Treatment Operations Possible
1.	Horizontal Chamber Furnace Electrically Heated	390 Width 250 Height 630 Depth	Upto 1150°C	Hardening Annealing Carburising Enamelling
2.	Horizontal Chamber Furnace Electrically Heated	600 Width 450 Height 1350 Depth	Upto 1150°C	Hardening Annealing
3.	Vertical Air Circulated Furnace, Electrically Heated	300 Dia 580 Depth	Upto 600°C	Pre-heating Tempering
4.	Air circulated Furnace, Electrically Heated	600 Width 600 Height 600 Depth	Upto 500°C	Tempering Pre-heating
5.	Electrically Heated Salt Bath Furnace	350 Dia 1000 Depth	Upto 1000-1300°C	Hardening
6.	Electrically Heated Salt Bath Furnace	350 Dia 1000 Depth	1000 - 1300°C	Hardening

State Enterprise for Mechanical Industries
Iskandariyah, Iraq

	Type of Furnace	Inside (Working) Demensions mm	Tempe-rature Range	Heat Treatment Operations Possible
1.	Electrically Heated Chamber Furnace	450 Width 450 Height 950 Depth	950°C max.	Annealing Normalising Hardening Tempering
2.	Electrically Heated Chamber Furnace	750 Width 550 Height 1500 Depth	950°C max.	Annealing Normalising Hardening Tempering
3.	Electrically Heated Vertical Chamber Furnace	850 Width 500 Height 1700 Depth	950°C max.	Annealing Tempering Normalising Hardening
4.	Electrically Heated Vertical Chamber Furnace	500 Dia 650 Depth	650°C max.	Annealing Tempering
5.	Electrically Heated Conveyor Hearth Furnace	375 Width 270 Height 1425 Depth	700°C max.	Annealing Tempering
6.	Electrically Heated Conveyor Hearth Furnace	575 Width 270 Height 4215 Depth	700°C max.	Annealing Tempering
7.	Electrically Heated Conveyor Hearth Furnace	375 Width 270 Height 3255 Depth	870°C max.	Hardening Tempering Annealing Normalising
8.	Electrically Heated Vertical Chamber Furnace	600 Dia 2500 Depth	950°C max.	Normalising Hardening Annealing Tempering

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
9.	Electrically Heated Vertical Chamber Furnace	600 Dia 1200 Depth	950°C max.	Normalising Hardening Annealing Carburising Tempering
10.	Electrically Heated Salt Bath Furnace	350 Width 350 Height 800 Length	850°C max.	Hardening Annealing
11.	Electrically Heated Salt Bath Furnace	600 Width 450 Height 900 Length	600°C max.	Annealing Quenching
12.	Electrically Heated Chamber Furnace. Gas Carburising	900 Width 650 Height 1200 Length	1100°C max.	Carburising Hardening Carbonitriding Tempering Annealing
13.	Electrically Heated Chamber Furnace	900 Width 650 Height 1200 Depth	700°C max.	Annealing Tempering
14.	Electrically Heated Chamber Furnace	600 Width 800 Height 1400 Depth	950°C max.	Annealing Normalising Tempering Hardening
15.	Electrically Heated Chamber Furnace	1000 Width 850 Height 2200 Depth	860°C max.	Annealing Normalising Tempering Hardening
16.	Electrically Heated Chamber Furnace	400 Width 300 Height 600 Depth	1350°C max.	Annealing Normalising Tempering Hardening
17.	Electrically Heated Chamber Furnace	180 Width 200 Height 350 Depth	1500°C max.	Annealing Normalising Hardening Tempering

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
18.	Electrically Heated Vertical Furnace	600 Dia 800 Depth	950°C max.	Annealing Normalising Tempering Hardening
19.	Electrically Heated Salt Bath Furnace	300 Length 280 Width 400 Depth	1300°C max.	Hardening
20.	Electrically Heated Lead Bath	-	850°C	Quenching Annealing
21.	Electrically Heated Chamber Furnace	300 Width 260 Height 800 Depth	950°C max.	Annealing Normalising Hardening Carburising Tempering
22.	Electrically Heated Vertical Furnace	600 Dia 750 Depth	950°C max.	Annealing Normalising Hardening Carburising Tempering
23.	Oil Fired Furnace	2320 15900	950°C max.	Annealing of Castings
24.	Oil Fired Furnace	2320 15900	950°C max.	Annealing of Castings
25.	Oil Fired Furnace	1300 3480	950°C max.	Annealing of Castings

Taji Industrial Complex

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
1.	Electrically Heated Multi Purpose Chamber Furnace with Atmosphere Generator 'Endomat' and Carbon Potential Control unit 'Carbomat'	550 Width 500 Height 1150 Depth	750 to 1100°C	Carburising Nitriding Hardening
2.	Electrically Heated Chamber Furnace	550 Width 500 Height 1150 Depth	150 to 700°C	Annealing Tempering
3.	Single Zone Washing Machine	550 Width 500 Height 1150 Depth	Upto 70°C	Washing after Heat Treatment
4.	Double Chamber Vocuum Furnace VAC-K2Q	600 Width 500 Height 1200 Depth Max. Wt. of charge upto 1100°C-400Kg. upto 1300°C 250 Kg	500 - 1300°C	Carburising Hardening Nitriding Annealing Tempering
5.	Electrically Heated Single Chamber Tempering Furnace	600 Width 600 Height 1100 Depth	200 - 700°C	Annealing Tempering
6.	Electrically Heated Single Chamber Tempering Furnace	600 Width 600 Height 1100 Depth	200 - 700°C	Annealing Tempering
7.	Electrically Heated Double Chamber Furnace	500 Width 300 Height 700 Depth Each Chamber	950 and 1350°C max.	Hardening Annealing Tempering

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
8.	Gas Fired Heat Treatment Line with Hardening Furnace, Quenching Oil Tank and Tempering Furnace, Pusher Type automatic	7000 300 1600 for hardening Furnace 8000 1600 300 for tempering furnace	1100°C max. 700°C max.	Hardening Tempering
9.	Gas Fired Heat Treatment Line with Hardening Furnace, Quenching Oil Tank and Tempering Furnace. Pusher Type Automatic	7000 300 1600 for hardening furnace 8000 1600 300 for tempering furnace	1100°C max. 700°C max.	Hardening Tempering
10.	Electrically Heated Chamber Furnace	2000 Width 1000 Height 3200 Depth	850°C max.	Annealing Tempering
11.	Electrically Heated Chamber Furnace	3000 Width 1000 Height 3000 Depth	1100°C max.	Annealing Normalising Hardening Tempering
12.	Electrically Heated Chamber Furnace	400 Width 400 Height 800 Depth	1200°C max.	Annealing Normalising Hardening
13.	Electrically Heated Chamber Furnace	600 Width 400 Height 1000 Depth	1200°C max.	Annealing Normalising Hardening

Electrical Industries, Waziriah

	Type of Furnace	Inside (Working) Dimensions mm	Temperature Range	Heat Treatment Operations Possible
1.	Electrically Heated Chamber Furnace	800 Width 800 Height 1600 Depth	1200°C max.	Normalising Annealing Tempering Hardening
2.	Electrically Heated Chamber Furnace	800 Width 800 Height 1600 Depth	1200°C max.	Normalising Annealing Tempering Hardening
3.	Electrically Heated Vertical Chamber Furnace	700 Dia 800 Depth	600°C max.	Tempering
4.	Electrically Heated Carburising Furnace	300 Dia 600 Depth	950°C max.	Carburising
5.	Electrically Heated Chamber Furnace	600 Width 440 Height 1500 Depth	1200°C max.	Normalising Annealing
*6	Electrically Heated Chamber Furnace	600 Width 440 Height 1500 Depth	1200°C max.	Normalising Annealing
*7.	Electrically operated Vertical Chamber Furnace	400 Dia 500 Depth	650°C max.	Tempering
*8.	Electrically Heated Chamber Furnace		950°C max.	Normalising Hardening Annealing
*9.	Immersed Electrode Salt Bath Furnace	360 Width 240 Height 360 Depth	1300°C max.	Hardening
*10.	High Frequency Induction Hardening Equipment			Induction Hardening

* Not Working

CHAPTER IV

Steels & Cast Irons - Specifications & Heat Treatment Parameters

4. STEELS AND CAST IRONS - SPECIFICATIONS AND HEAT TREATMENT PARAMETERS

Table of Contents

4.1. Medium Carbon And Low Alloy Steels
(Constructional Steels)

4.1.1. Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.1.

DIN	B.S.	ASTM	GOST	JIS	CSN
C 35 Ck35	060A35	1035	35	S35C	12040
C45, Cf45 Ck45	080M46	1045	45	S45C	12050
C55, Cf53 Ck55, C60	070M55	1055-S6	55	S55C	12060
40Mn4	120M36	-	-	-	-
34Cr 4 41Cr 4	- 530M40	5132 5140-S7	35X 40X	SCr430 SCr440	14140
42CrMo4 50CrMo4	708M40	4140	-	SCM440	14331
36CrNiMo4 34CrNiMo6	-	-	45XHMA 40XHMA	-	-

4.1.2. Chemical Compositions

The chemical compositions of these steels are given in Table 4.2.

Steel		C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%
C35	Min	0.32	0.15	0.50	-	-	-	-	-
	Max	0.39	0.35	0.80	0.045	0.045	-	-	-
Ck35	Min	0.32	0.15	0.50	-	-	-	-	-
	Max	0.39	0.35	0.80	0.035	0.035	-	-	-
C45	Min	0.42	0.15	0.50	-	-	-	-	-
	Max	0.50	0.35	0.80	0.045	0.045	-	-	-
Ck45	Min	0.42	0.15	0.50	-	-	-	-	-
	Max	0.50	0.35	0.80	0.035	0.035	-	-	-
Cf45	Min	0.43	0.15	0.50	-	-	-	-	-
	Max	0.49	0.35	0.80	0.025	0.035	-	-	-
C55	Min	0.52	0.15	0.60	-	-	-	-	-
	Max	0.60	0.35	0.90	0.045	0.045	-	-	-
Ck55	Min	0.52	0.15	0.60	-	-	-	-	-
	Max	0.60	0.35	0.90	0.035	0.035	-	-	-
Cf53	Min	0.50	0.15	0.40	-	-	-	-	-
	Max	0.57	0.35	0.70	0.025	0.035	-	-	-
C60	Min	0.57	0.15	0.60	-	-	-	-	-
	Max	0.65	0.35	0.90	0.045	0.045	-	-	-
40Mn4	Min	0.36	0.25	0.80	-	-	-	-	-
	Max	0.44	0.50	1.10	0.035	0.035	-	-	-
34Cr4	Min	0.30	0.15	0.60	-	-	0.90	-	-
	Max	0.37	0.40	0.90	0.035	0.035	1.20	-	-
41Cr4	Min	0.38	0.15	0.50	-	-	0.90	-	-
	Max	0.45	0.40	0.80	0.035	0.035	1.20	-	-
42CrMo4	Min	0.38	0.15	0.50	-	-	0.90	0.15	-
	Max	0.45	0.40	0.80	0.035	0.035	1.20	0.30	-
50CrMo4	Min	0.40	0.15	0.50	-	-	0.90	0.15	-
	Max	0.54	0.40	0.80	0.035	0.035	1.20	0.30	-
36CrNiMo4	Min	0.32	0.15	0.50	-	-	0.90	0.15	0.90
	Max	0.40	0.40	0.80	0.035	0.035	1.20	0.30	1.20
34CrNiMo6	Min	0.30	0.15	0.40	-	-	1.40	0.15	1.40
	Max	0.38	0.40	0.70	0.035	0.035	1.70	0.30	1.70

TABLE 4.2. CHEMICAL COMPOSITIONS

4.1.3. Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.3.

Steel	Full Annealing Temperature °C	As annealed hardness HBN max	Normalising Temperature °C	Hardening Temperature °C	
				Water Quench	Oil Quench
C35,CK35	650-700	183	860-890	840-870	850-880
C45,CK45 Cf45	650-700	207	840-870	820-850	830-860
C55,CK55, C60,Cf53	650-700	241	830-860	800-835	810-845
40Mn4	650-700	217	850-880	820-850	830-860
34Cr4 41Cr4	680-720	217	840-880	820-850	830-860
42CrMo4 50CrMo4	680-720	237	840-880	820-850	830-860
36Cr NiMo4	650-700	217	850-880	820-850	-
34Cr NiMo6		235		-	830-860

TABLE 4.3 TEMPERATURES FOR HEAT TREATMENT OPERATIONS.

4.1.4. Hardenability Curves

The Jominy hardenability limits curves for these steels are given in Figs. 4.1 to 4.6.

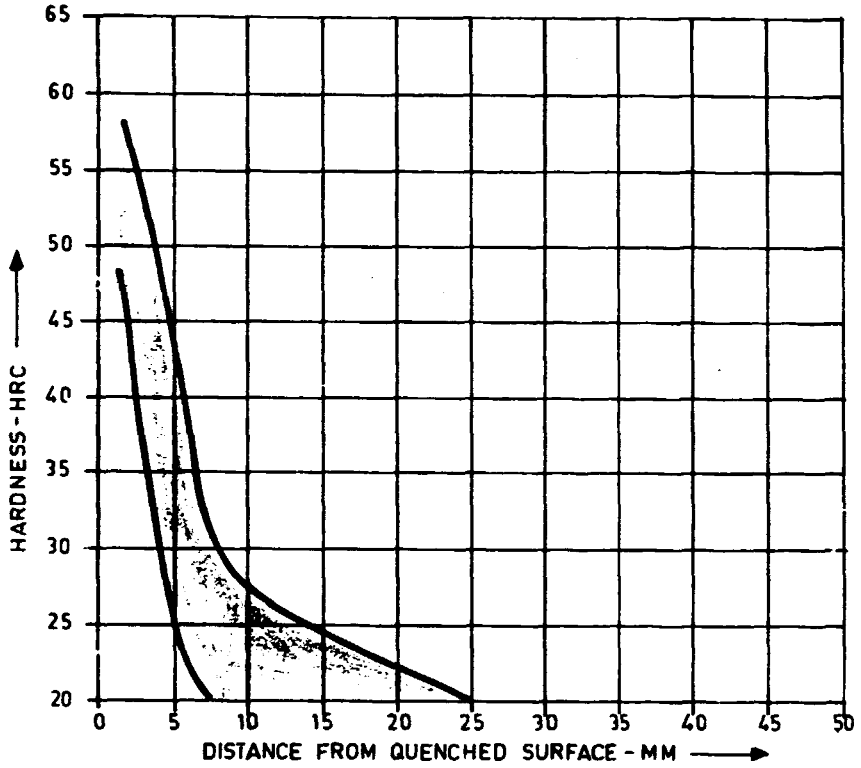


FIG.4.1 JOMINY HARDENABILITY LIMITS CURVES FOR C35 AND CK35

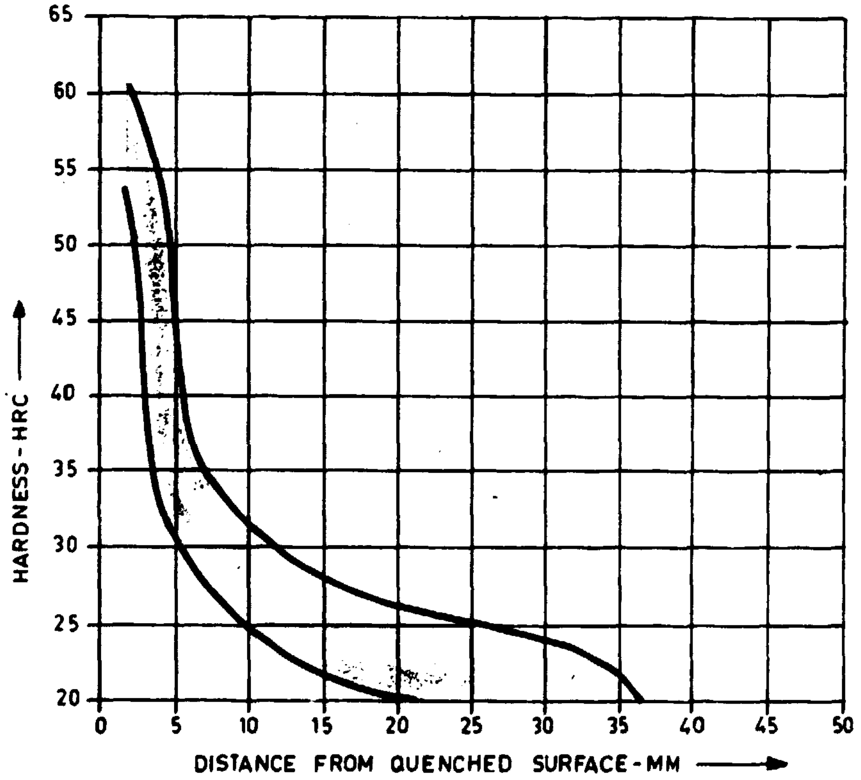


FIG.4.2 JOMINY HARDENABILITY LIMITS CURVES FOR C45 AND CK45

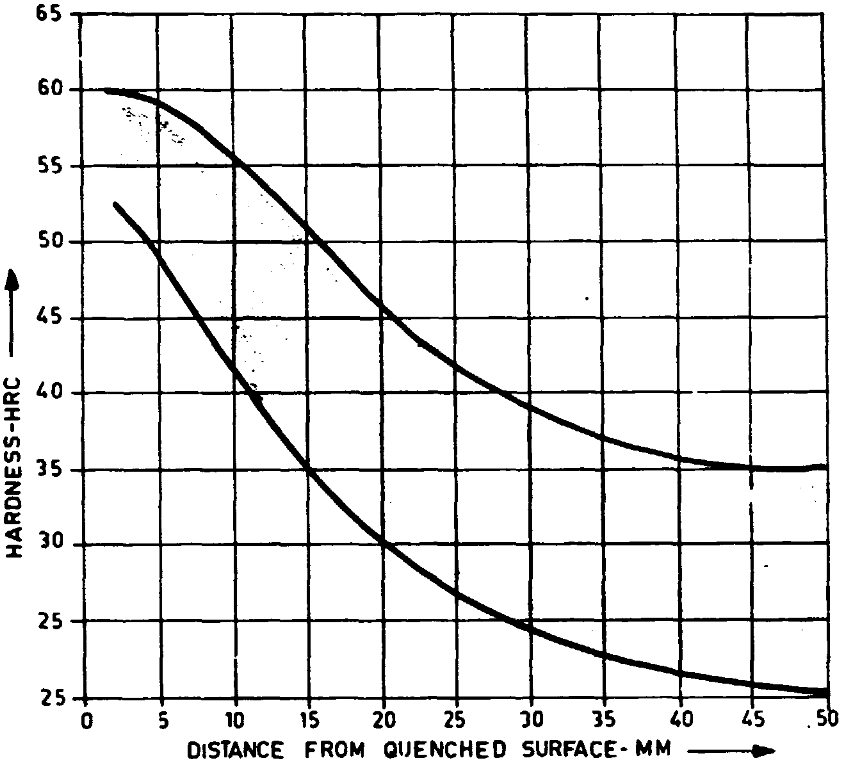


FIG.4.3 JOMINY HARDENABILITY LIMITS CURVES FOR 41 Cr 4

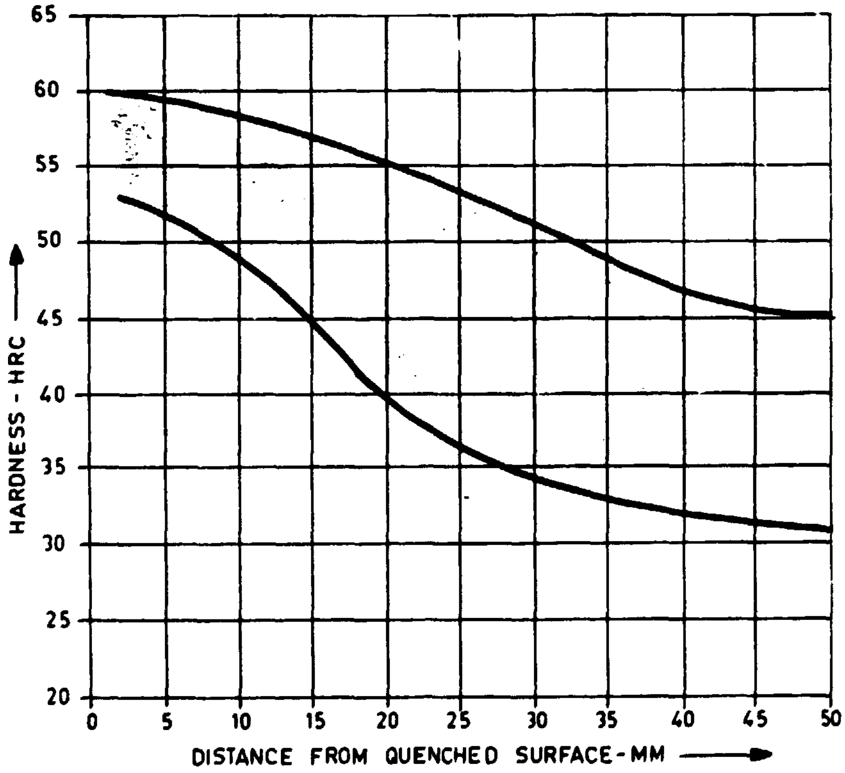


FIG.4.4 JOMINY HARDENABILITY LIMITS CURVES FOR 42 Cr Mo4

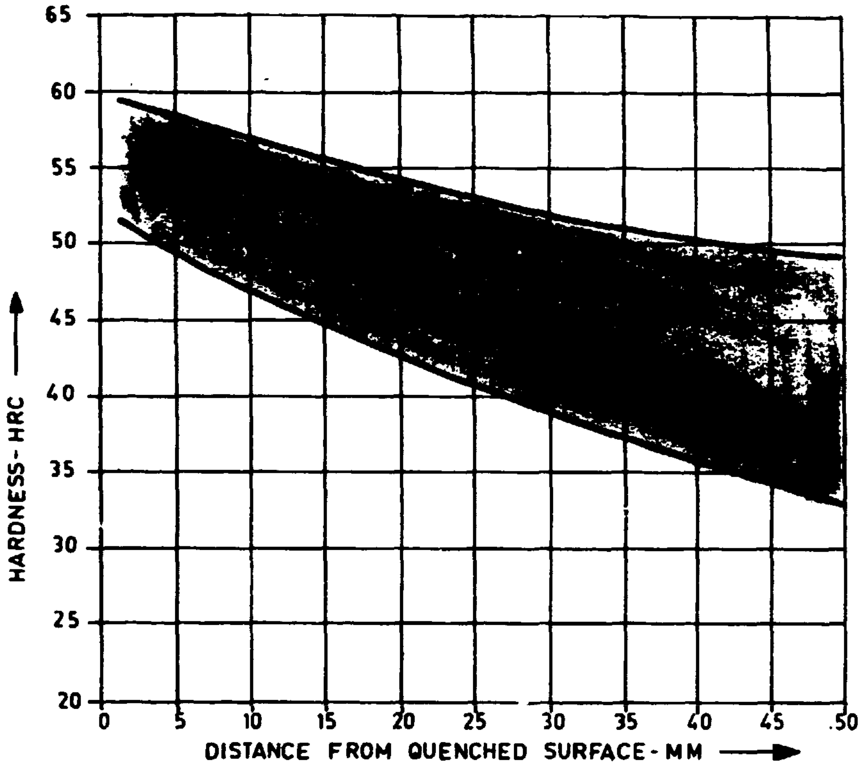


FIG.4.5 JOMINY HARDENABILITY LIMITS CURVES FOR 36 Cr Ni Mo4

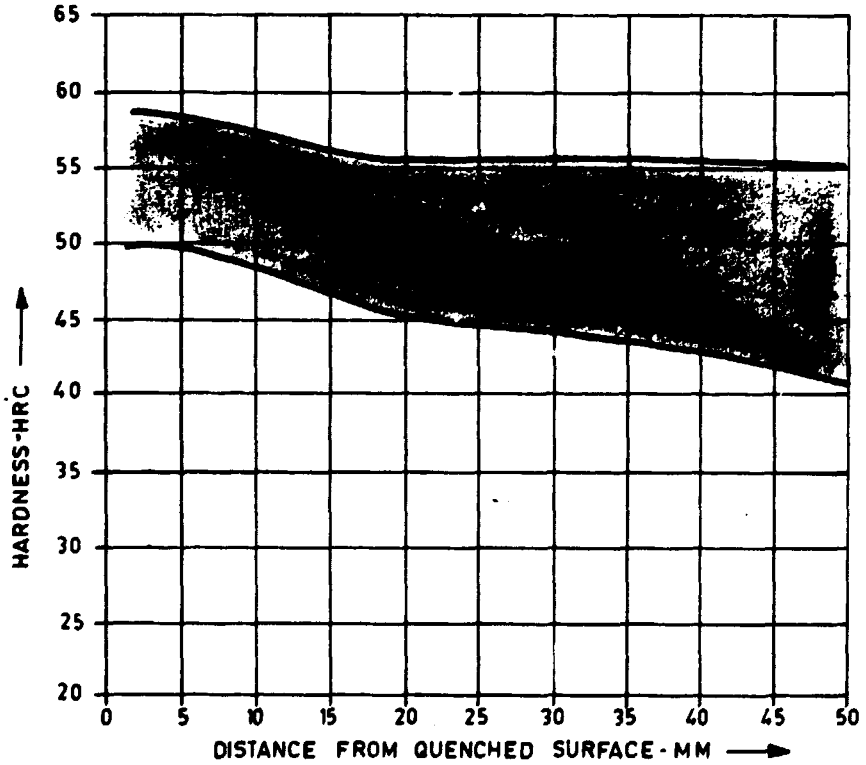


FIG.4.6 JOMINY HARDENABILITY LIMITS CURVES FOR 34 Cr Ni Mo 6

4.1.5. Tempering Response

The relationships between the tempering temperature and hardness are given in Figs. 4.7 to 4.11. The time for tempering should be about 60 mts for every 25 mm section thickness. After tempering the parts can be cooled in air if the tempering temperature is below 350°C and should be cooled in oil if the temperature exceeds this value, in order to avoid temper brittleness.

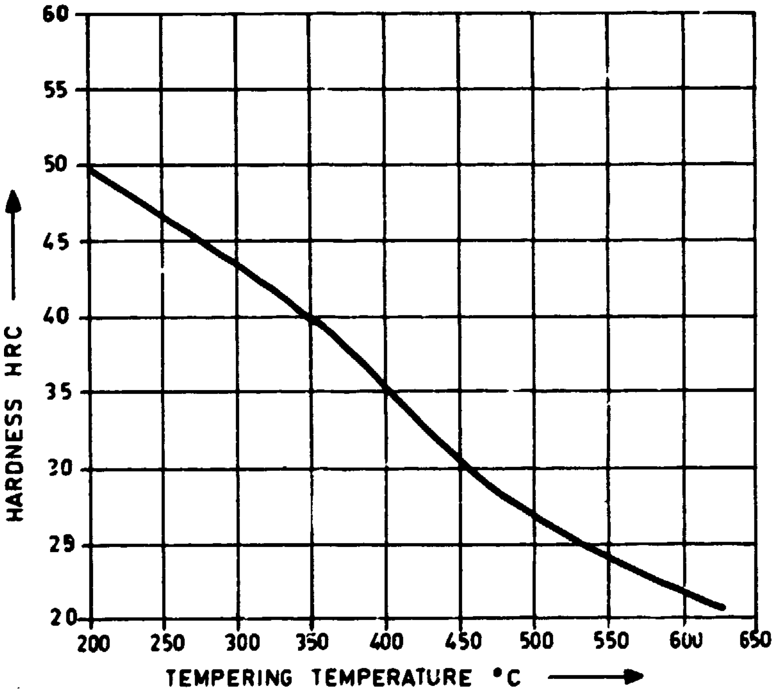


FIG. 4.7 TEMPERING RESPONSE OF C35 AND Ck35

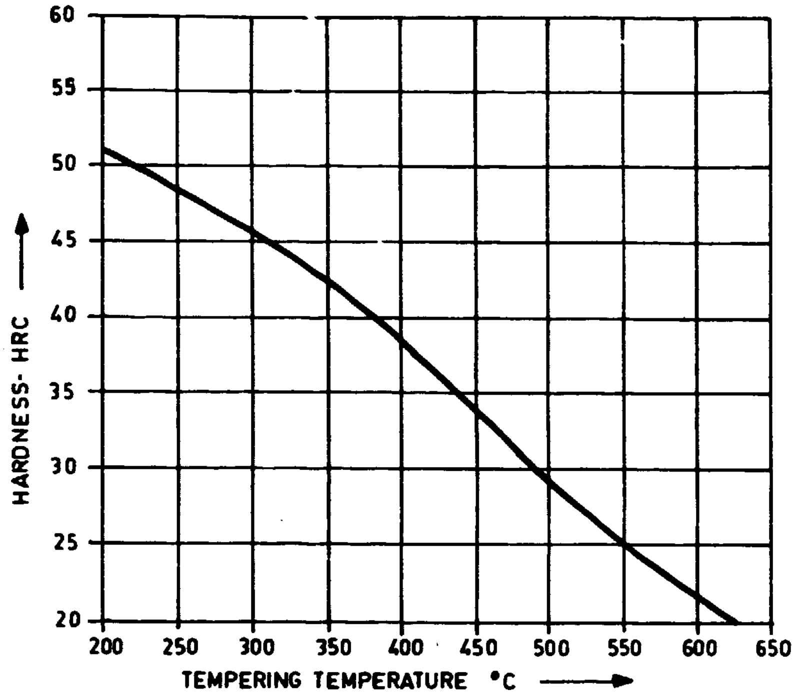


FIG.4.8 TEMPERING RESPONSE OF C45 AND CK45

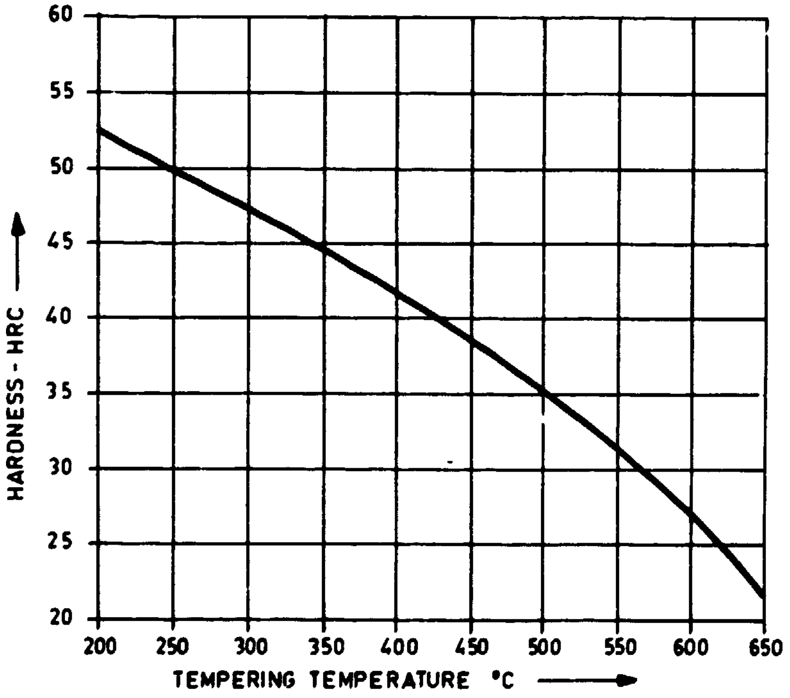
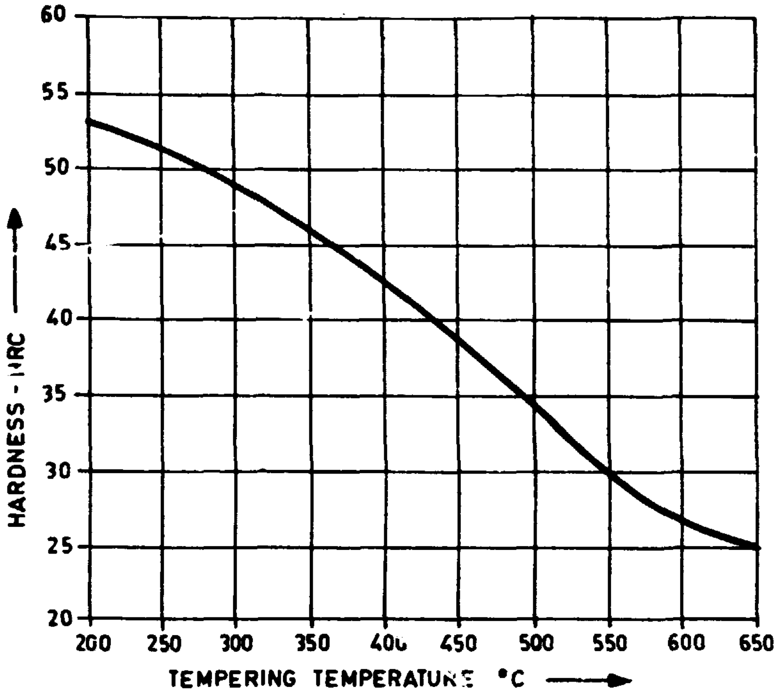
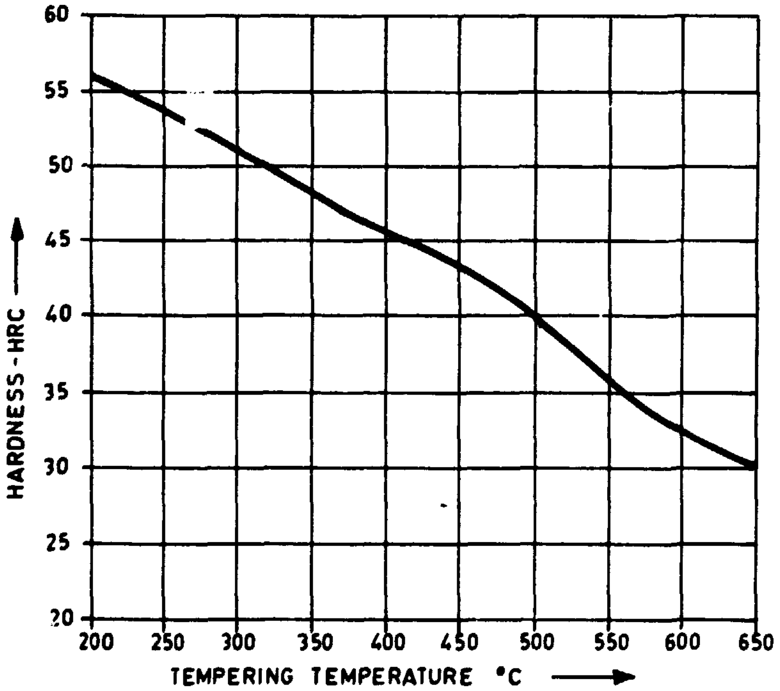


FIG.4.9 TEMPERING RESPONSE OF C55 AND CK55



41Cr4

FIG.4.10 TEMPERING RESPONSE OF 41 Cr 4



42CrMo4

FIG.4.11 TEMPERING RESPONSE OF 42 Cr Mo 4

4.1.6 Response To Liquid Nitriding (Tufftriding)

The case depths obtained and the hardness gradients after liquid nitriding are given in Figures 4.12 and 4.13.

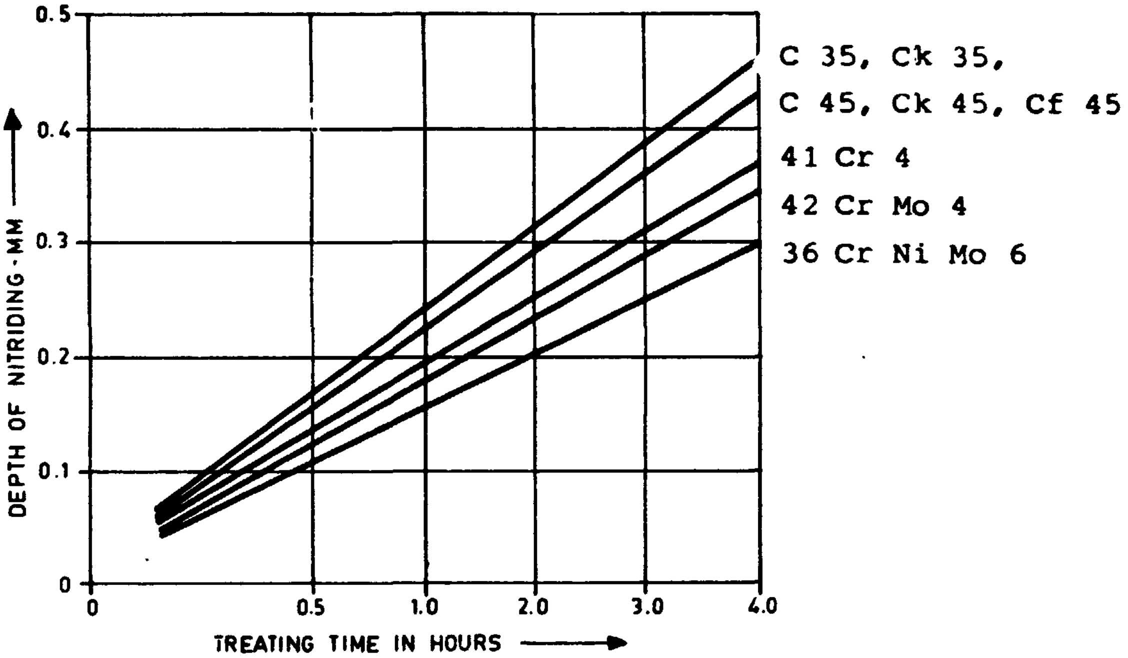


FIG.4.12 DEPTH OF NITRIDING VS NITRIDING TIME FOR LIQUID NITRIDING

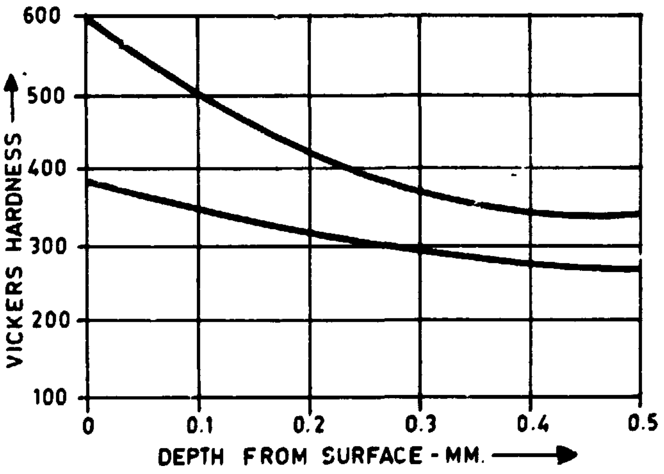


FIG.4.13 HARDNESS VS DEPTH FOR LIQUID NITRIDING

4.1.7. Response to Flame/Induction Hardening

The hardening responses to flame and induction hardening are given in Table 4.4.

Steel	As Quenched Hardness HRC	
	Oil Quench	Water Quench
C35, Ck35	-	35-50
C45, Ck45 Cf 45	52-58	55-60
C55, Cf53	58-62	60-63
41Cr4	55-60	62-64
42Cr Mo4	50-55	55-60
36Cr Ni Mo4	-	55-60

TABLE 4.4 AS QUENCHED HARDNESS AFTER FLAME OR INDUCTION HARDENING

For best results, induction or flame hardening is done in the normalised or quenched and tempered condition. After hardening the parts are to be tempered at 180°C or at highger temperatures depending upon the hardness requirement.

4.2 Case Hardening Steels

4.2.1. Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.5.

DIN	B.S.	ASTM	GOST	JIS	CSN
C10	040 A10	1010	10	S09CK	12010
C15	040 A15	1015	15	S15CK	12020
C22 Ck22	050 A20	1020	20	S22C	12024
16 Mn Cr5	-	5115.S7	18X	-	14220
20 Mn Cr5	-	5120-S7	18X T	SMnC21	-
15 Cr Ni6	-	4320-S7	12XH3A	SNC22	-
-	-	-	20X	-	-

TABLE 4.5 SPECIFICATION OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.2.2. Chemical Compositions

The chemical compositions of these steels are given in Table 4.6.

Steel		C%	Si%	Mn%	P%	S%	Cr%	Ni%
C10	Min	0.07	0.15	0.30	-	-	-	-
	Max	0.13	0.35	0.60	0.045	0.045	-	-
C15	Min	0.12	0.15	0.30	-	-	-	-
	Max	0.18	0.35	0.60	0.045	0.045	-	-
C22	Min	0.18	0.15	0.30	-	-	-	-
	Max	0.25	0.35	0.60	0.045	0.045	-	-
Ck22	Min	0.18	0.15	0.30	-	-	-	-
	Max	0.25	0.35	0.60	0.035	0.035	-	-
16MnCr5	Min	0.14	0.15	1.00	-	-	0.80	-
	Max	0.19	0.40	1.30	0.035	0.035	1.10	-
20MnCr5	Min	0.17	0.15	1.10	-	-	1.00	-
	Max	0.22	0.40	1.40	0.035	0.035	1.30	-
15CrNi6	Min	0.12	0.15	0.40	-	-	1.40	1.40
	Max	0.17	0.40	0.60	0.035	0.035	1.70	1.70
20X (GOST)	Min	0.17	0.17	0.50	-	-	0.70	-
	Max	0.23	0.37	0.80	0.035	0.035	1.00	-

TABLE 4.6 CHEMICAL COMPOSITIONS

4.2.3. Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.7.

Steel	Normalising Temperature °C	Soft Annealing Temperature °C	As Annealed Hardness HBN Max.	Carburising Temperature °C	Hardening Temperature °C	Quenching Medium	Tempering Temperature °C
C10	880-900	650-700	131	900-950	800-820	Water	150-180
C15	880-900	650-700	146	900-950	800-820	Water	150-180
C22	880-910	650-700	156	900-950	800-820	Water	150-180
Ck22	880-910	650-700	156	900-950	800-820	Water	150-180
16Mn Cr5	880-900	650-700	207	900-950	840-870	Oil	170-210
20Mn Cr5	880-900	650-700	217	900-950	840-870	Oil	170-210
15Cr Ni6	860-880	650-700	217	900-950	800-820	Oil	170-210
20X (GOST)	860-880	650-700	187	900-950	800-820	Oil	180-200

TABLE 4.7 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.2.4 Hardenability Curves

The Jominy hardenability limits curves for the alloy steels are given in Figs.4.14 to 4.16.

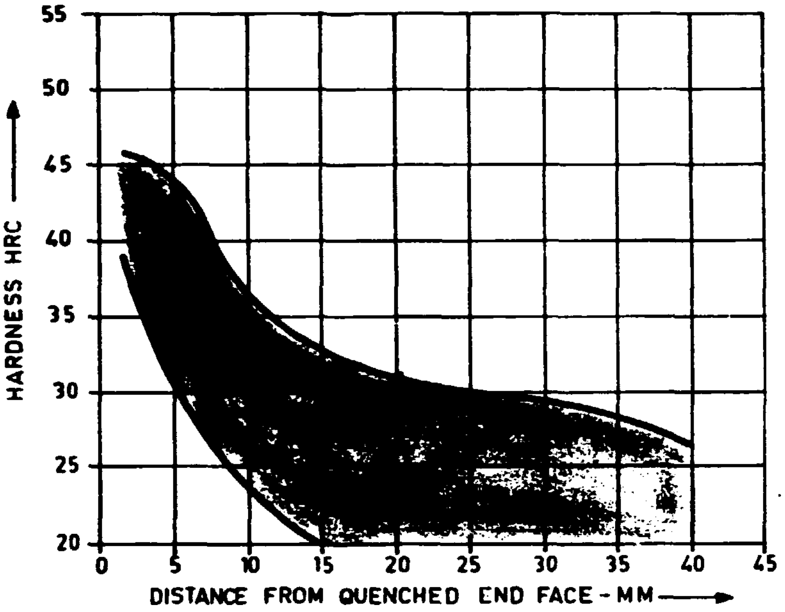


FIG.4.14 JOMINY HARDENABILITY LIMITS CURVES FOR 16 Mn Cr 5

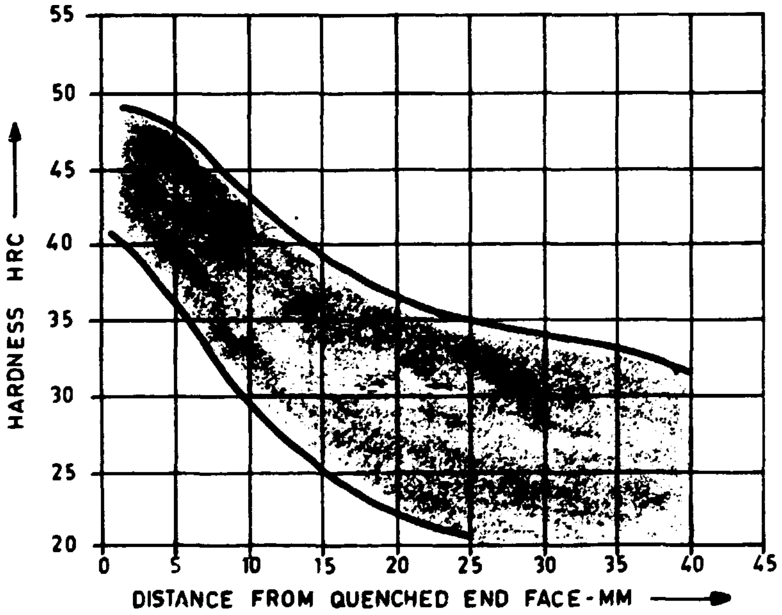


FIG.4.15 JOMINY HARDENABILITY LIMITS CURVES FOR 20 Mn Cr 5

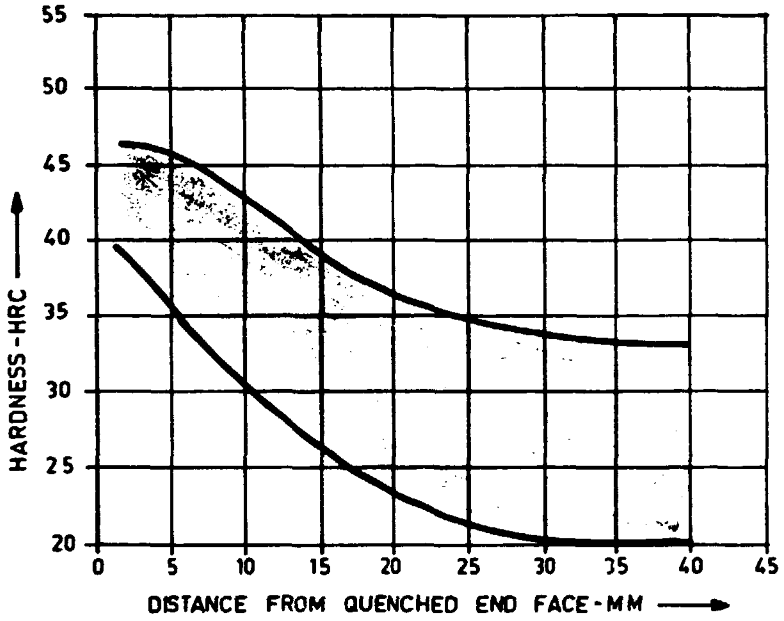


FIG.4.16 JOMINY HARDENABILITY LIMITS CURVES FOR 15 Cr Ni 6

4.3 Nitriding Steels

4.3.1. Specifications

DIN	ISO	BS	ASTM	GOST	JIS
34CrALMo5	3	905M31	D	-	-

4.3.2. Chemical Composition

		C %	Si %	Mn %	P %	S %	Al %	Cr %	Mo %
34CrAlMo5	Min	0.30	0.20	0.50	-	-	0.8	1.00	0.15
	Max	0.37	0.50	0.80	0.030	0.035	1.20	1.30	0.25

4.3.3. Heat Treatment Parameters

	Full Annealing Temp. °C	As Annealed Hardness HBN Max.	Hardening Temperature °C		Tempering Temperature °C
			Water	Oil	
34CrAlMo5	650-700	248	900-930	910-940	570-650

Hardness after Quenching and Tempering HBN	Stress relieving after machining temp. °C	Nitriding Temperature °C	Hardness after nitriding HV
238-295	550-570	500-520	950

4.4. Spring Steels

4.4.1. Specifications

Specifications of the steels included in this group are given in Table 4.8.

DIN	ISO	B.S.	ASTM	GOST	JIS
38Si7	-	-	-	-	-
-	-	-	-	65Г	-

TABLE 4.8 SPECIFICATION OF THE STEELS

4.4.2. Chemical Compositions

		C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %
38Si7	Min	0.35	1.5	0.50	-	-	-	-	-
	Max	0.42	1.8	0.80	0.045	0.045	-	-	-
65Г GOST	Min	0.62	0.17	0.90	-	-	-	-	-
	Max	0.70	0.37	1.20	0.035	0.035	0.25	0.25	0.20

TABLE 4.9 CHEMICAL COMPOSITIONS

4.4.3. Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.10.

Steel	Soft Annealing Temp. °C	As Annealed Hardness HBN max.	Normalising Temp. °C	Hardening Temp. °C	Quenching medium	Tempering Temp. °C
38Si7	640-680	217	830-860	830-860	Water	350-550
65Г	800-820	221	-	800-860	Oil	150-600

TABLE 4.10 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.5. Unalloyed Carbon Tool Steels

(Water Hardening)

4.5.1. Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.11.

DIN	ISO	BS	ASTM	GOST	JIS
C80W1	TC 80	BW1A	W1-8	Y8A	SKS
C105W1	TC 105	BW1B	W1-10	Y10A	SK3
75Cr1	-	-	-	-	-

TABLE 4.11 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.5.2. Chemical Compositions

The chemical composition of these steels are given in Table 4.12.

Steel		C%	Si%	Mn%	P%	S%	Cr%
C80W1	Min	0.75	0.10	0.10	-	-	-
	Max	0.85	0.25	0.25	0.020	0.020	-
C105W1	Min	1.00	0.10	0.10	-	-	-
	Max	1.10	0.25	0.25	0.020	0.020	-
75Cr1	Min	0.70	0.25	0.60	-	-	0.30
	Max	0.80	0.50	0.80	-	-	0.40

TABLE 4.12 CHEMICAL COMPOSITIONS

4.5.3. Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.13.

Steel	Annealing Temp. °C	As Annealed Hardness HBN Max.	Hardening Temp. °C	Quenching Medium	As Quenched hardness HRC	Hardness penetration mm	Tempering Temp. °C
C80W1	680-710	192	780-810	Water	64	2.5-3.5	180-300
C105W1	680-710	213	770-800	Water	65	2.0-3.0	180-300
75Cr1	700-720	200	770-800	Water	66	-	180-300

TABLE 4.13 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.5.4 Tempering Response

The relationships between the tempering temperature and hardness are given in Figs. 4.17 to 4.18.

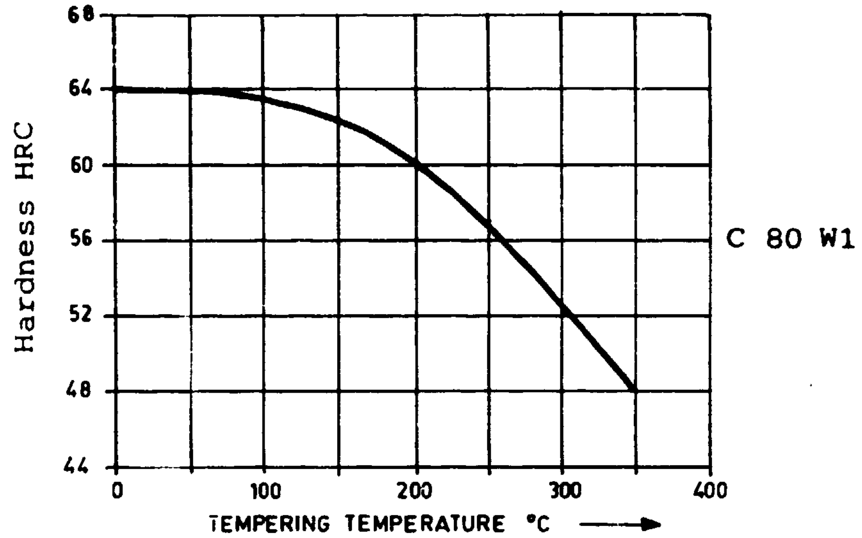


FIG.4.17 TEMPERING RESPONSE OF C 80 W1

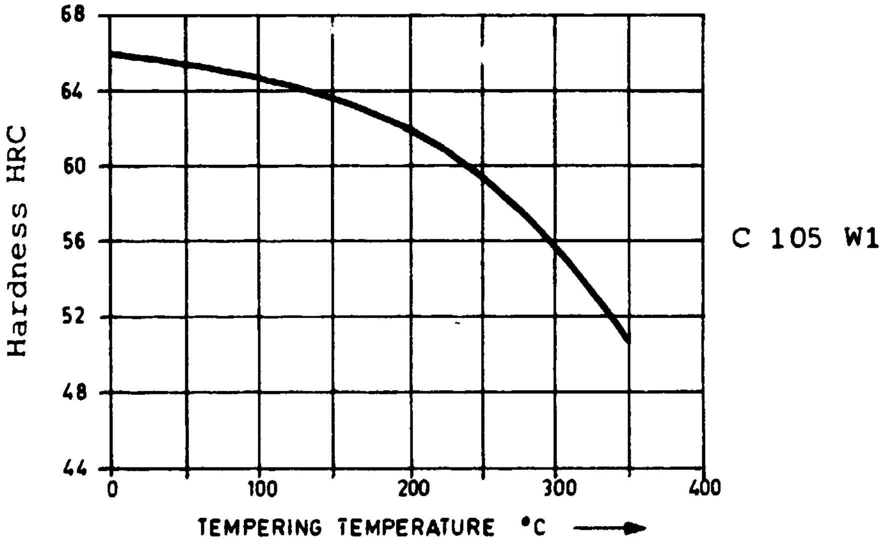


FIG.4.18 TEMPERING RESPONSE OF C 105 W1

4.6 Low Alloy Tool Steels
(Oil Hardening)

4.6.1. Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.14.

DIN	ISO	BS	ASTM	GOST	JIS
100Cr6	100Cr2	-	L3	15	-
105WCr6	105WCr1	-	01	XBГ	SKS 31
115CrV3	-	-	L2	-	-
60WCrV7	60WCrV2	-	S1	6XB2C	-
X19NiCrMo4	-	-	-	18X2H4MA	-
X45NiCrMo4	40NiCrMoV4	-	-	5XHM	-
56NiCrMoV7	55NiCrMoV	-	-	5XHM	-

TABLE 4.14 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.6.2. Chemical Compositions

The chemical compositions of these steels are given in Table 4.15.

Steel		C %	Si %	Mn %	Cr %	Mo %	Ni %	V %	W %
100Cr6	Min	0.95	0.15	0.25	1.35	-	-	-	-
	Max	1.10	0.35	0.45	1.65	-	-	-	-
105WCr6	Min	1.00	0.10	0.80	0.90	-	-	-	1.00
	Max	1.10	0.40	1.10	1.10	-	-	-	1.30
115CrV3	Min	1.10	0.15	0.20	0.50	-	-	0.07	-
	Max	1.25	0.30	0.40	0.80	-	-	0.12	-
60WCrV7	Min	0.55	0.50	0.15	0.90	-	-	0.10	1.80
	Max	0.65	0.70	0.45	1.20	-	-	0.20	2.10
X19NiCrMo4	Min	0.16	0.10	0.15	1.10	0.15	3.80	-	-
	Max	0.22	0.40	0.45	1.40	0.25	4.30	-	-
X45NiCrMo4	Min	0.40	0.10	0.15	1.20	0.15	3.80	-	-
	Max	0.50	0.40	0.45	1.50	0.35	4.30	-	-
56NiCrMoV7	Min	0.50	0.10	0.65	1.00	0.45	1.50	0.07	-
	Max	0.60	0.40	0.95	1.20	0.55	1.80	0.12	-

TABLE 4.15 CHEMICAL COMPOSITIONS

4.6.3. Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.16.

Steel	Annealing Temp. °C	As Annealed Hardness HBN Max.	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Range °C
100 Cr6	740-770	223	830-860	Oil	64	100-300
105 WCr6	720-750	229	800-830	Oil	65	100-400
115 CrV3	710-740	223	800-830	Water/ Oil	64	100-300
60WCrV7	720-750	229	860-900	Oil	60	100-500
X19Ni CrMo4 x	600-630	255	810-830	Oil	61	150-180
X45Ni CrMo4	610-630	262	840-870	Oil/air	56	100-500
56NiCrMoV7	680-710	248	840-870	Oil	56	400-650

x Carburising Steel

TABLE 4.16 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.6.4. Tempering Response

The relationships between the tempering temperature and hardness are given in Figs. 4.19 to 4.25.

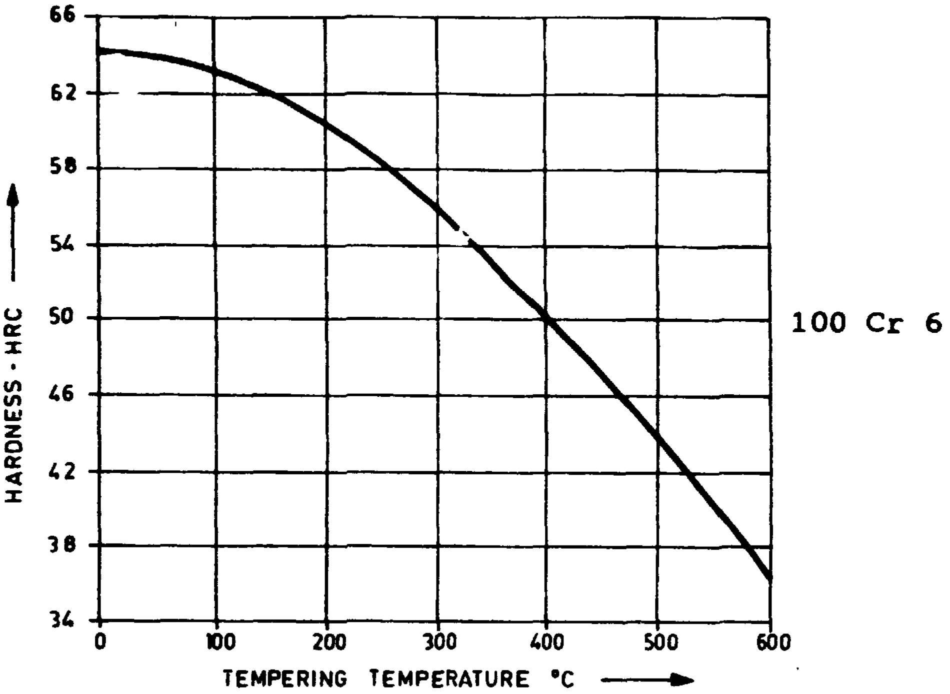


FIG.4.19 TEMPERING RESPONSE OF 100 Cr 6

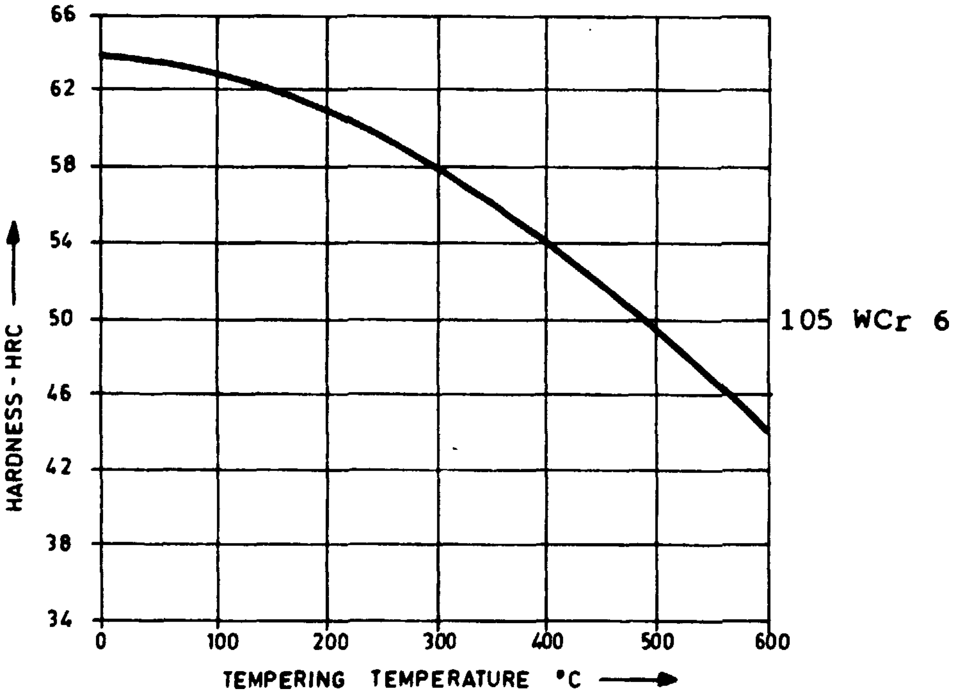


FIG.4.20 TEMPERING RESPONSE OF 105 WCr 6

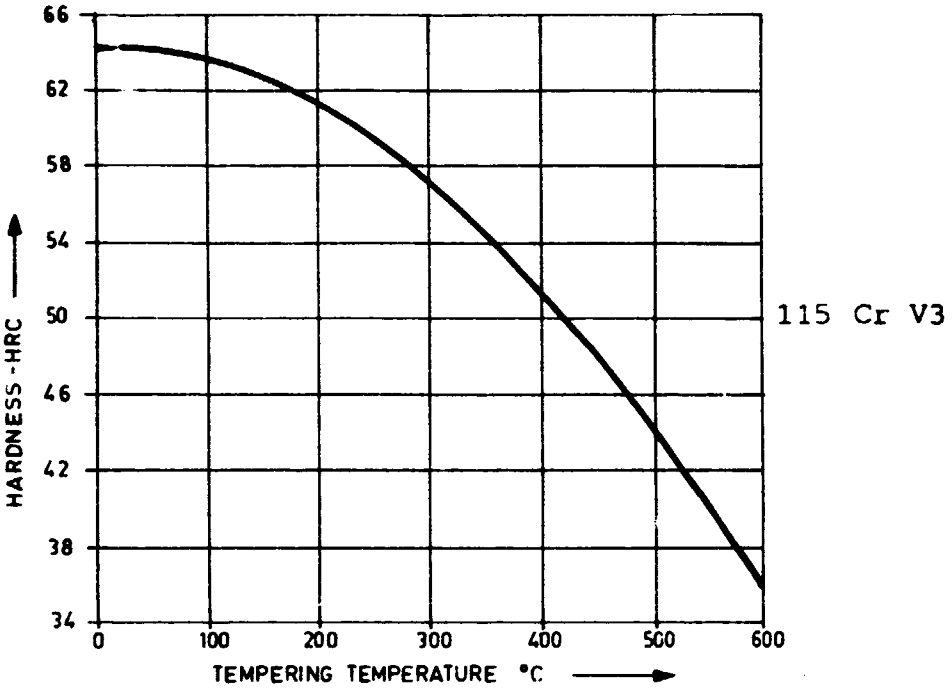


FIG.4.21 TEMPERING RESPONSE OF 115 CrV3

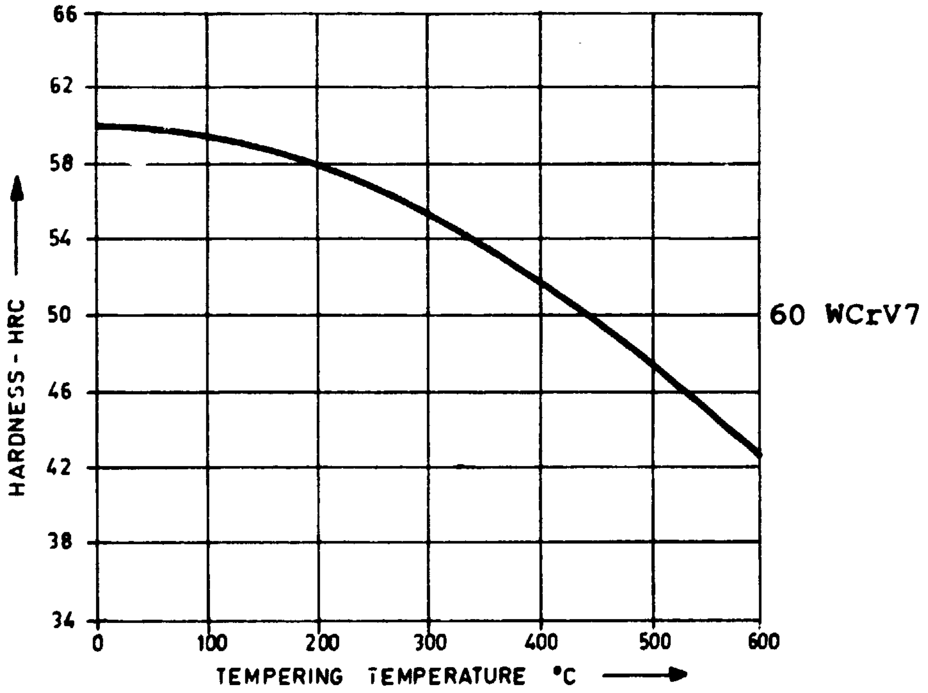


FIG.4.22 TEMPERING RESPONSE OF 60 WCrV7

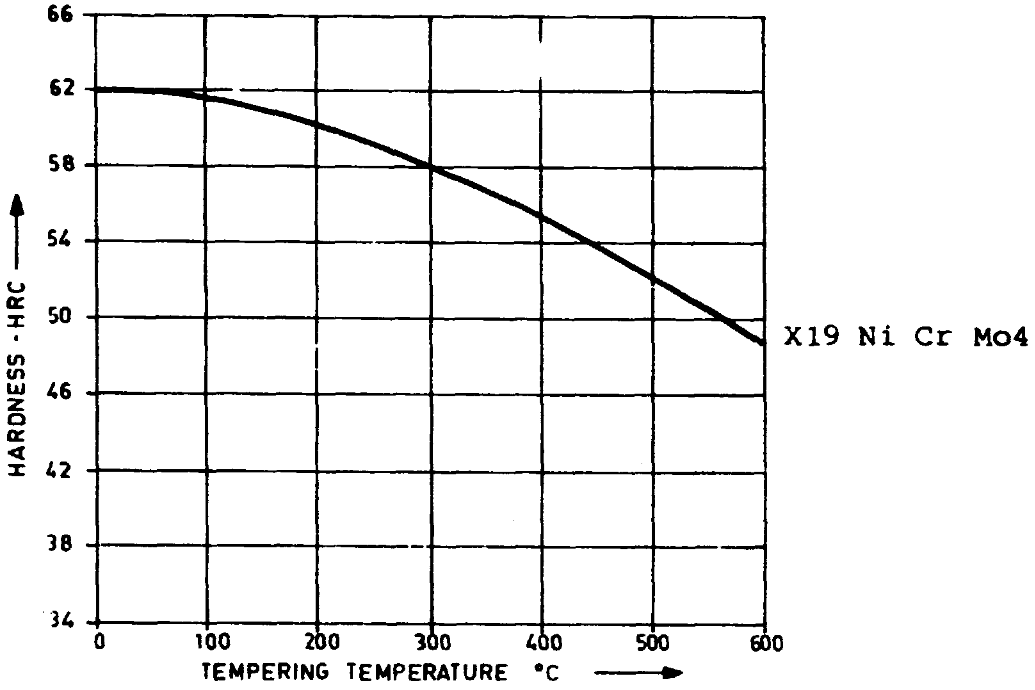


FIG.4.23 TEMPERING RESPONSE OF X19NiCr Mo4

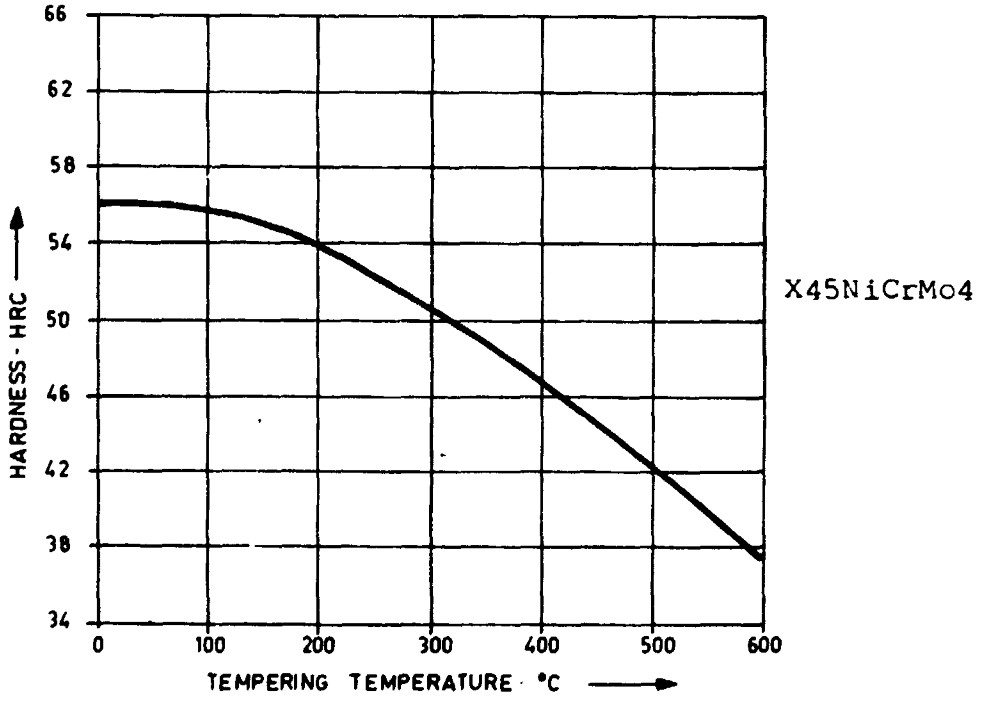


FIG. 4.24 TEMPERING RESPONSE OF X45CrNiMo4

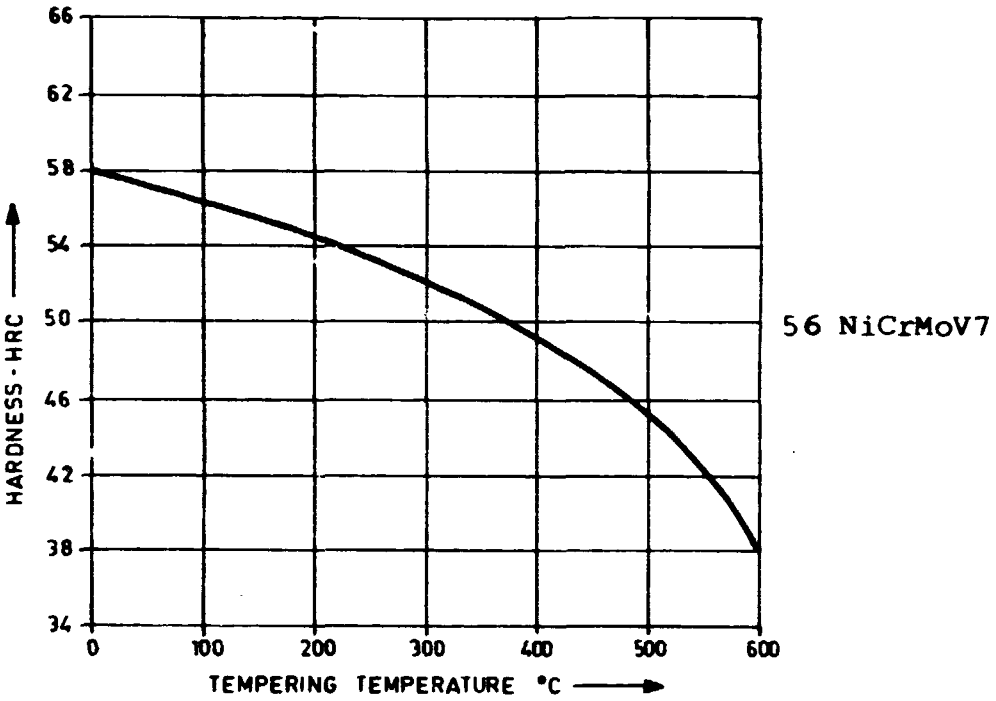


FIG. 4.25 TEMPERING RESPONSE OF 56 NiCr MoV7

4.7 High Carbon High Chromium Steels

4.7.1 Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.17.

DIN	ISO	B.S.	ASTM	GOST	JIS
X 155 Cr VMo 121	160 Cr MoV 12	BD2	D2	X 12 M	SKD11
X 210 Cr W 12	210 Cr W 12	-	-	X 12	SKD1

TABLE 4.17 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.7.2 Chemical Compositions

The chemical compositions of these steels are given in Table 4.18.

Steels		C %	Si %	Mn %	Cr %	Mo %	V %	W %
X 155 Cr VMo 121	Min.	1.50	0.10	0.15	11.00	0.60	0.90	-
	Max.	1.60	0.40	0.45	12.00	0.80	1.10	-
X 210 Cr W12	Min.	2.00	0.10	0.15	11.00	-	-	0.60
	Max.	2.25	0.40	0.45	12.00	-	-	0.80

TABLE 4.18 CHEMICAL COMPOSITIONS

4.7.3 Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.19

Steel	Soft Annealing Temperature °C	As Annealed Hardness HBN Max.	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Temperature °C
X 155 Cr. VMo 121	840-860	240	1020-1040	Oil/air	64	180-250
X 210 Cr W12	800-830	239	930-980	Oil/air	64	180-250

TABLE 4.19 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.7.4 Tempering Response

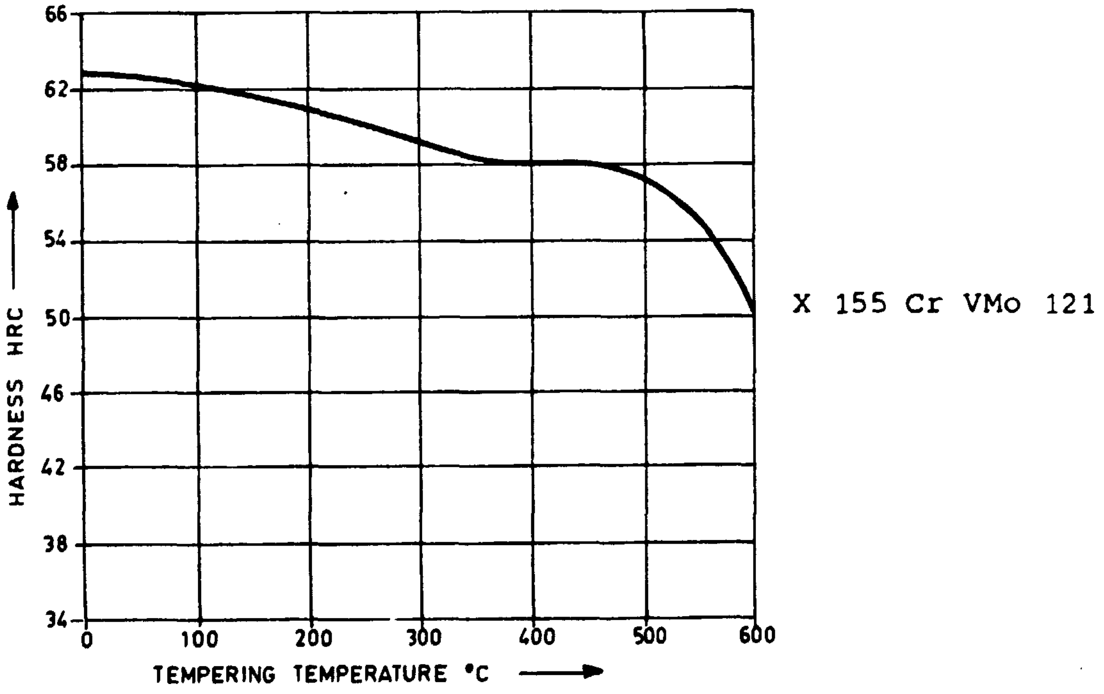
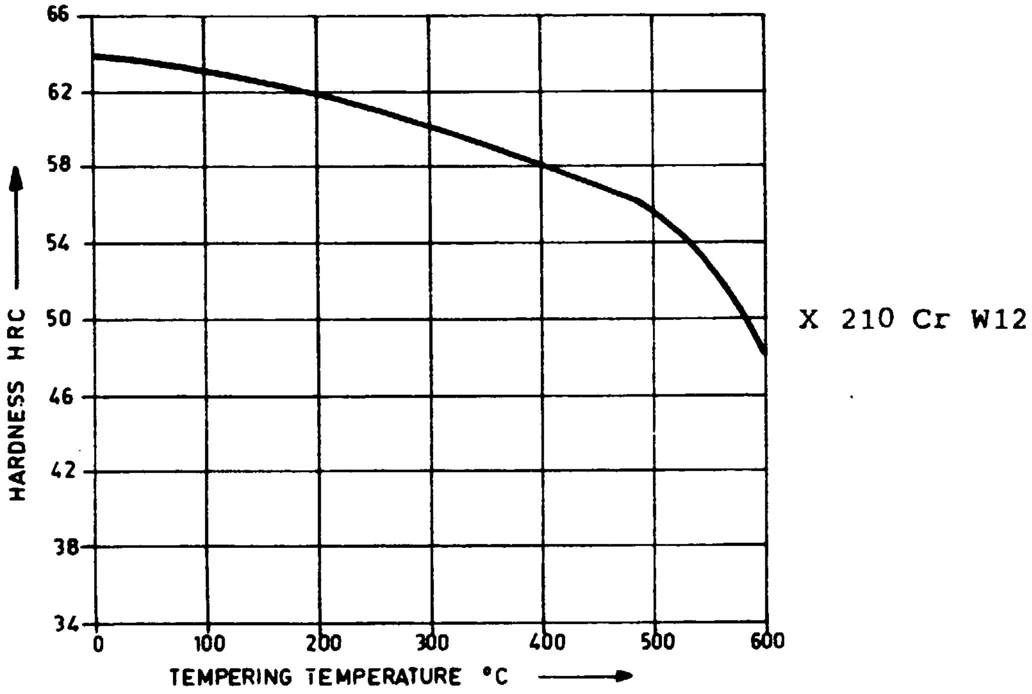


FIG. 4.26 TEMPERING RESPONSE OF X155CrVMo121



<u>FIG. 4.27</u> <u>TEMPERING RESPONSE OF X 210 Cr W12</u>

4.8 Hot Die Steels

4.8.1 Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.20.

DIN	ISO	B.S.	ASTM	GOST	JIS
X 32 Cr Mo V33	30 Cr Mo V3	BH 10	H 10	-	-
X 38 Cr Mo V51	35 Cr Mo V5	BH 11	H 11	-	SKD6
X 30W Cr V93	30W Cr V9	BH 21	H 21	3 X 2B8 Ø	SKD5

TABLE 4.20 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.8.2 Chemical Compositions

The chemical compositions of these steels are given in Table 4.21.

4.8.3 Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.22.

Steels		C %	Si %	Mn %	Cr %	Mo %	V %	W %
X 32 Cr MoV33	Min.	0.28	0.10	0.15	2.70	2.60	0.40	-
	Max.	0.35	0.40	0.45	3.20	3.00	0.70	-
X 38 Cr MoV51	Min.	0.36	0.90	0.30	4.80	1.10	0.25	-
	Max.	0.42	1.20	0.50	5.50	1.40	0.50	-
X 30W Cr V93	Min.	0.25	0.15	0.20	2.50	-	0.30	8.00
	Max.	0.35	0.30	0.40	2.80	-	0.40	9.00

TABLE 4.21 CHEMICAL COMPOSITIONS

Steel	Annealing Temperature °C	As Annealed Hardness HBN Max.	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Temperature °C
X 32 Cr Mo V33	760-780	229	1010-1050	Oil/air	51.0	500-670
X 38 Cr Mo V 51	760-780	229	1000-1040	Oil/air	55.0	550-650
X 30W Cr V 93	740-780	250	1100-1150	Oil/air	52.0	600-700

TABLE 4.22 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.8.4 Tempering Response

The relationships between the tempering temperature and hardness are given in Figures 4.28 to 4.30.

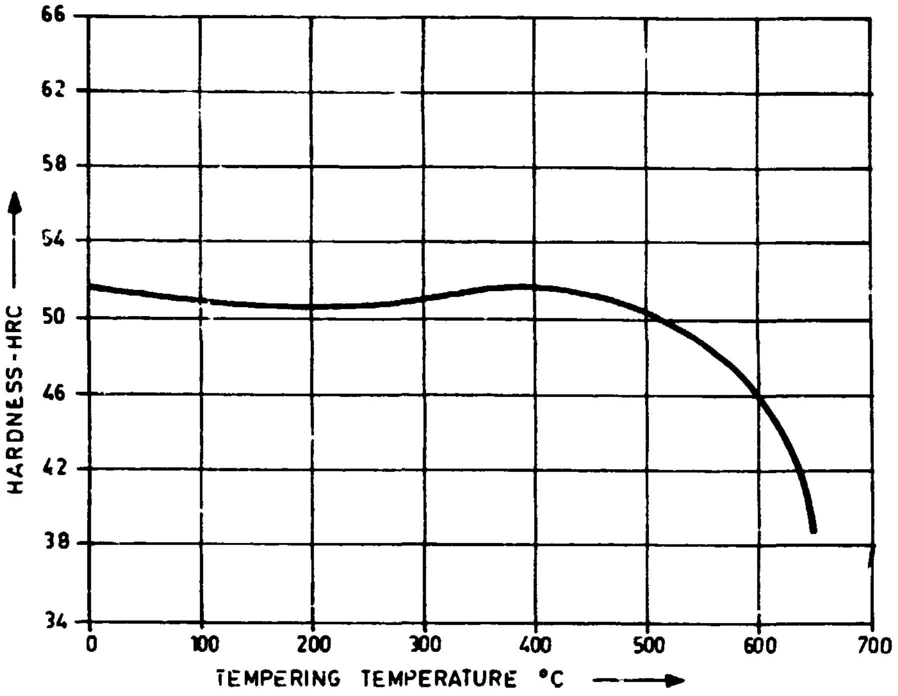


FIG.4.28 TEMPERING RESPONSE OF X 32 Cr Mo V33

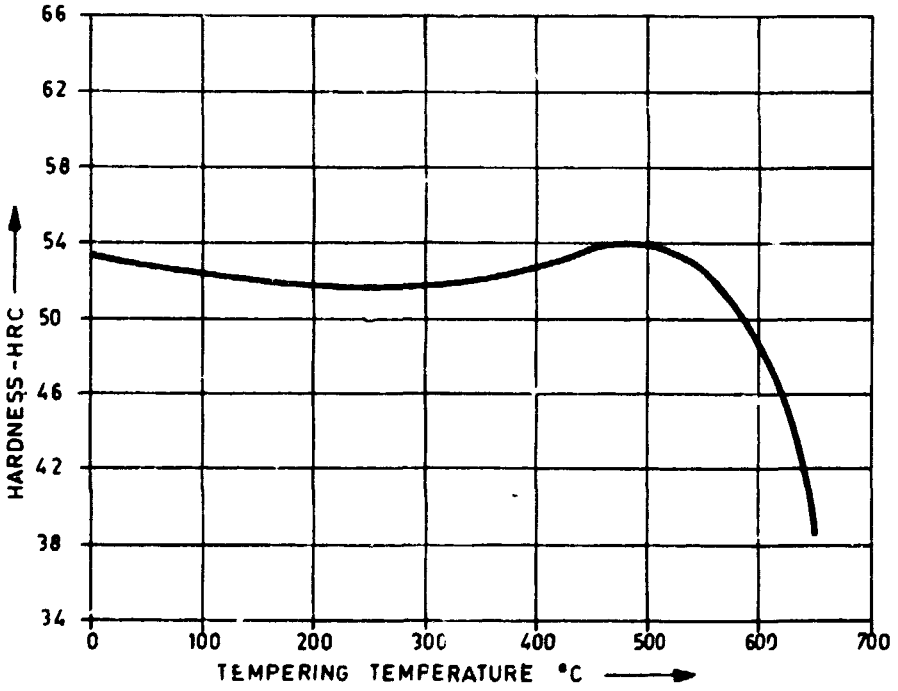


FIG.4.29 TEMPERING RESPONSE OF X38 Cr Mo V51

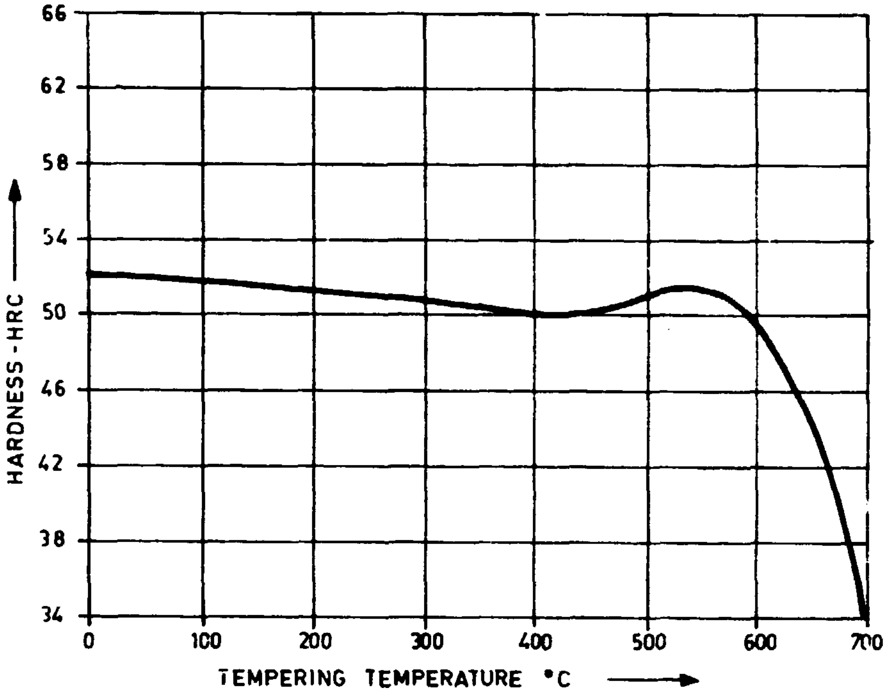


FIG.4.30 TEMPERING RESPONSE OF X 30 W Cr V 93

4.9 High Speed Steels

4.9.1 Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.23.

DIN	ISO	B.S.	ASTM	GOST	JIS
S-6-5-2	HS-6-5-2	BM2	M2	P6M5	SKH9
S-6-5-2-5	HS-6-5-2-5	-	-	-	SKH55
S-18-1-2-5	HS-18-1-1-5	B.T4	T4	P18K5 Ø 2 (P18)	SKH3
S-10-4-3-10	HS-10-4-3-10	BT42	-	-	SKH57

TABLE 4.23 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.9.2 Chemical Compositions

The chemical compositions of these steels are given in Table 4.24.

Steel		C %	Si %	Mn %	Cr %	Mo %	V %	W %	Co %
S-6-5-2	Min.	0.86	0.20	0.20	3.80	4.70	1.70	6.00	-
	Max.	0.94	0.35	0.35	4.50	5.20	2.00	6.70	-
S-6-5-2-5	Min.	0.88	-	-	3.80	4.70	1.70	6.00	4.50
	Max.	0.96	0.45	0.40	4.50	5.20	2.00	6.70	5.00
S-18-1-2-5	Min.	0.75	-	-	3.80	0.50	1.40	17.50	4.50
	Max.	0.83	0.45	0.40	4.50	0.80	1.70	18.50	5.00
S-10-4-3-10	Min.	1.20	-	-	3.80	3.20	3.00	9.00	9.50
	Max.	1.35	0.45	0.40	4.50	3.90	3.50	10.00	10.50

TABLE 4.24 CHEMICAL COMPOSITIONS

4.9.3 Heat Treatment Parameters

The temperatures for various heat treatment operations are given in Table 4.25.

Steel	Annealing Temperature °C	As Annealed Hardness HBN	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Temperature °C
S-6-5-2	770-820	240-300	1190-1230	Oil/air/ Salt Bath	64	540-560
S-6-5-2-5	790-820	240-300	1200-1240	"	64	550-570
S-18-1-2-5	820-850	240-300	1260-1300	"	64	560-580
S-10-4-3-10	800-830	240-300	1210-1250	"	66	550-570

TABLE 4.25 TEMPERATURES FOR HEAT TREATMENT OPERATIONS

4.9.4 Tempering Response

The relationships between the tempering temperature and hardness are given in Figs. 4.31 to 4.34.

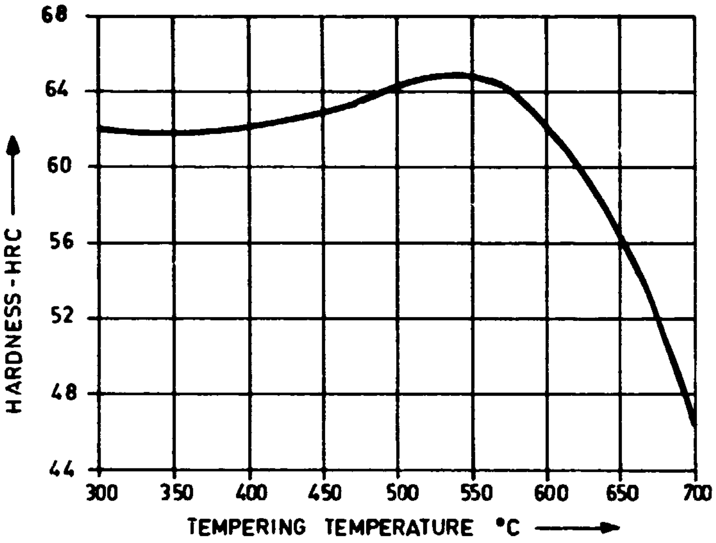


FIG.4.31 TEMPERING RESPONSE OF S-6-5-2

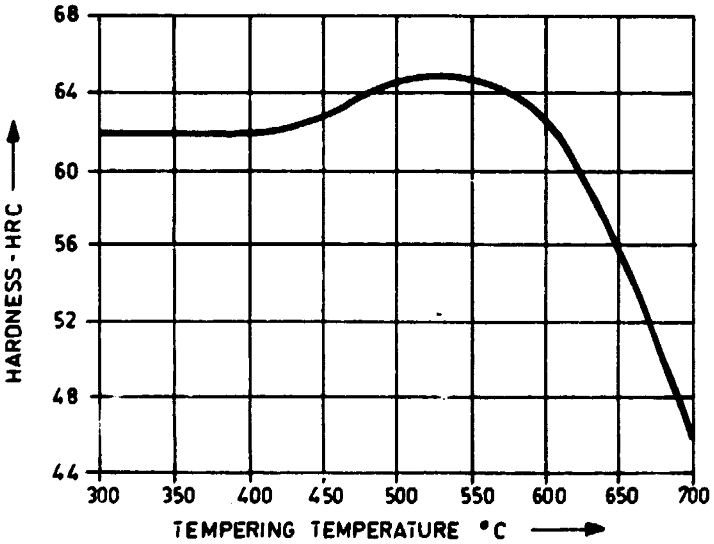


FIG.4.32 TEMPERING RESPONSE OF S-6-5-2-5

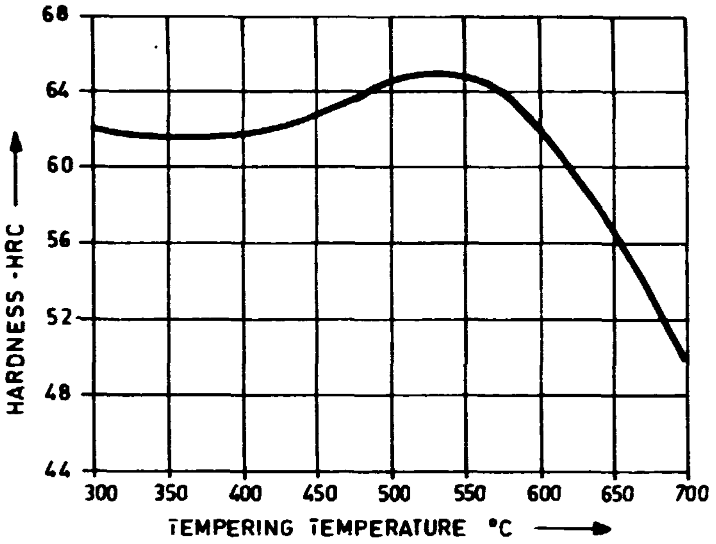


FIG.4.33 TEMPERING RESPONSE OF S-18-1-2-5

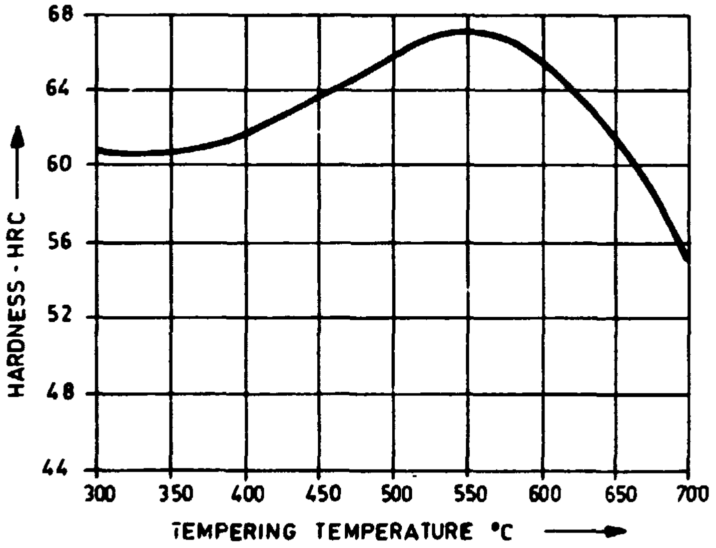


FIG.4.34 TEMPERING RESPONSE OF S-10-4-3-10

4.10 Stainless Steels

4.10.1 Specifications

Specifications of the steels included in this group and their nearest equivalents in other standards are given in Table 4.26.

DIN	ISO	B.S.	ASTM	GOST	JIS
X 5 Cr Ni 189	11	304 S15	304	08X18 H10	SUS-304
X10 Cr Ni Ti 189	15	321 S12	321	12X18 H10T	SUS-321
X10 Cr 13	3	410 S21	410	10 X 13	SUS-410
X20 Cr 13	-	420 S29	420	20 X 13	SUS-420J1

TABLE 4.26 SPECIFICATIONS OF THE STEELS AND THEIR NEAREST EQUIVALENTS

4.10.2 Chemical Compositions

The chemical compositions of these steels are given in Table 4.27.

Steels	C %	Si %	Mn %	Cr %	Ni %	Ti %
X 5 Cr Ni 189	$\leq$0.07	1.0	2.0	17-22	8.5-10	-
X 10 Cr Ni Ti 189	$\leq$0.10	1.0	2.0	17-19	9-11.5	$\geq$5x%C
X 10 Cr 13	0.08-0.12	1.0	1.0	12-14	-	-
X 20 Cr 13	0.17-0.22	1.0	1.0	12-14	-	-

TABLE 4.27 CHEMICAL COMPOSITIONS

4.10.3 Heat Treatment Parameters

The temperatures for heat treatment operations are given in Tables 4.23 and 4.29.

Steel	Annealing		Structure after the treatment
	Temperature °C	Cooling Medium	
X 5 Cr Ni 189	1000 - 1050	Water / air	Austenite
X10 Cr Ni Ti189	1020 - 1070	Water / air	Austenite

TABLE 4.28 HEAT TREATMENT TEMPERATURE FOR AUSTENITIC STAINLESS STEEL

Steel	Annealing Temperature °C	Cooling after Annealing	Hardening Temperature °C	Quenching Medium	Tempering Temperature °C	Hardness HRC
X 10 Cr 13	750-800	Furnace Cool	950-1000	Oil	700-750	31
X 20 Cr 13	750-800	Furnace	980-1030	Oil	650-750	47

TABLE 4.29 HEAT TREATMENT TEMPERATURE FOR MARTENSITIC STAINLESS STEEL

4.11 Grey Irons

4.11.1 Chemical Compositions

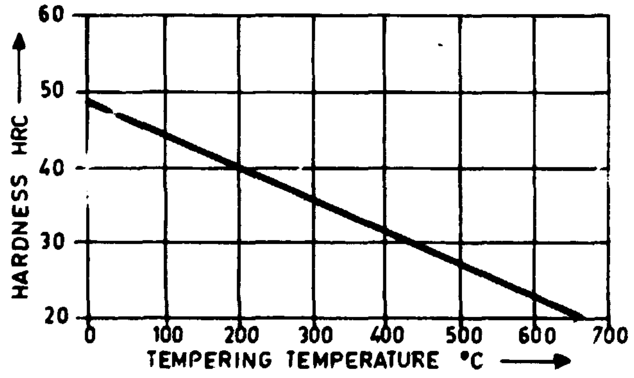
The compositions of the cast irons vary considerably from foundry to foundry. The typical composition of unalloyed grey iron will be as given below:

Total Carbon %	Si %	Mn %	P %	S %
3.00 - 3.70	1.80 - 2.80	0.50 - 1.00	0.07 - 0.15	0.15 max.

4.11.2 Heat Treatment Parameters

Ferritise Annealing Temperature °C	Full Annealing Temperature °C	Graphatise Annealing Temperature °C	Normalising Temperature °C	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC
705-760	790-900	900-955	885-925	815-870	oil	47

4.11.3 Tempering Response



4.12 Ductile Irons (S.G. Irons)

4.12.1 Chemical Compositions

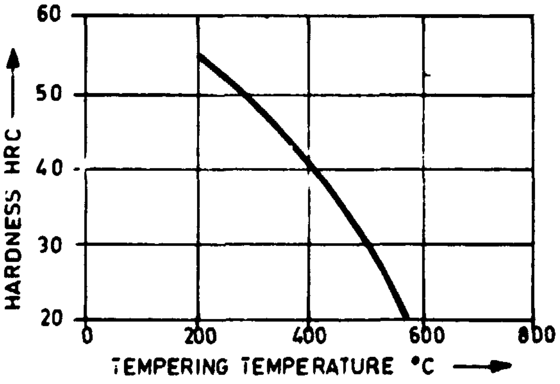
The typical composition of ductile iron is given below:

Total Carbon %	Si %	Mn %	Cr %	P %	S %	Mg %
3.50-3.80	2.00-2.80	0.3-1.00	0.08 max.	0.08 max.	0.02 max.	0.03-0.05

4.12.2 Heat Treatment Parameters

Annealing Temperature °C	Normalising Temperature °C	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Range °C
900-955	870-940	845 - 925	oil	55 - 57	180 - 500

4.12.3 Tempering Response



4.13 Malleable Iron

4.13.1 Chemical Compositions

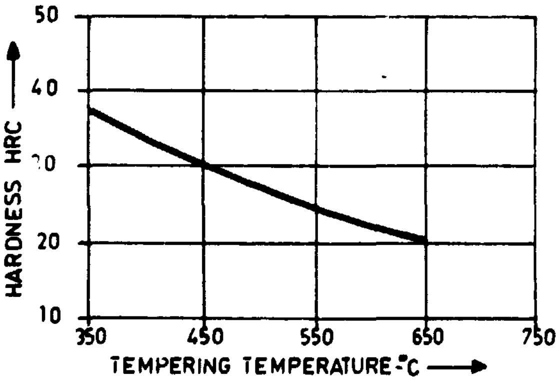
The typical composition of malleable iron is given below:

Total Carbon %	Si %	Mn %	P %	S %
2.00-2.70	1.00-1.75	0.25-1.25	0.05 max.	0.03-0.18

4.13.2 Heat Treatment Parameters

Annealing Temperature °C	Hardening Temperature °C	Quenching Medium	As Quenched Hardness HRC	Tempering Temperature °C
900-970°C	845-870	Oil	52-56	500-650

4.13.3 Tempering Response



CHAPTER V

Miscellaneous

5. MISCELLANEOUS

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5.1 Control of Distortion

Main causes for Distortion	Methods of reducing Distortion
Residual stress after machining	- Improved Machining conditions to reduce stress - Stress-relieving Thermal or Vibratory
Stress produced by metallurgical transformation	- Use the lower range of temperature and soaking time and less severe quenching enough to get the required hardness - Martempering - Austempering - Die or press quenching
Effects of mechanical stress and damage	- Careful handling especially when the pieces are hot - Proper support during heating eg. level furnace, hearth plate, loading in suitable fixtures etc. - Gradual heating to austenitising temperature (proper pre-heating)

Table 5.1 METHODS TO REDUCE DISTORTION

5.2 Failures in Heat Treatment - Analysis and Corrective Measures

5.2.1 Low Hardness

Probable Cause	Method of Identifying the cause	Corrective Action
Wrong Material	Check the material composition	Use correct material or modify the heat treatment parameters to suit the actual material used.
Heavy Decarburisation during hardening	Check the job for hardness after grinding off the decarburised layer	If ordinary muffle furnace is used for hardening, protect the pieces with suitable packing medium such as burnt cast iron chips, coke etc. If atmosphere controlled furnace is used, ensure that the atmosphere is neutral. If salt bath is used, correct the bath with suitable regenerator.
Low Hardening Temperature	Check whether the hardening temp.used is correct for the material. Check the temp.indicator/controller and thermocouple	Use correct hardening temperature recommended for the particular steel. Periodically check and calibrate the thermocouple and temp. controllers
Insufficient soaking time for hardening	Check the soaking time. Check whether the pieces are loaded in the furnace properly eg. not one piece over another	Use correct soaking times. The jobs should be loaded in the furnace properly. so that the heating can penetrate from all the sides.

Probable Cause	Method of Identifying the cause	Corrective Action
Quenching severity not enough	Check whether the correct quenching medium is used. Check for contamination of quenching medium Check the hardenability of the steel for the particular section thickness	Use correct quenching medium for the steel. Keep the quenching medium free from contamination Use steels of higher hardenability when heavy section thicknesses are involved.
High Tempering Temperature	Check the accuracy of the temperature indicator/controller and thermocouple of the tempering furnace	Periodically check and calibrate the thermocouples and temperature controllers
Material not machined enough before hardening to remove the decarburised layer completely	Remove the decarburised layer by grinding before checking the hardness	Machine the raw material sufficiently to remove the decarburised layer completely
Hardness testing not correct	Check whether the surface of the job is very rough. Test whether the hardness tester is giving correct values Check whether the testing method used is correct	Check the hardness on smooth surfaces only Check the accuracy of the hardness tester with test piece Use the correct testing method suitable for the piece
Delay in Quenching	Check the time lapse between heating and quenching	Rapid quenching is necessary especially for water hardening steels
Improper Carburising	Check the carburising conditions	Use proper carburising conditions

Table 5.2 REASONS FOR LOW HARDNESS AND CORRECTIVE ACTIONS

5.2.2 Non-Uniform Hardness

Probable Cause	Method of Identifying the cause	Corrective Action
Decarburised layer from the raw material not machined off completely	Grind off the decarburised layer and then check the hardness	Machine off the decarburised layer completely from all the surfaces requiring hardness
Non-homogeneous structure of material Mainly for cast iron	Check the material for porosity	Use sound and homogeneous material
Large variation in section thickness	Check the soaking time and also the hardenability of the steel	Use correct soaking time based on the largest section
Non-uniform heating	Uneven heating conditions inside the furnace	Correct the furnace to obtain uniform heating
Steam bubble formation while water quenching	Soft spots appear on the surface in typical dark and grey pattern	Shake the pieces well during water quenching. If permissible add little Nacl to the quenching water. Use polymer quenchant. Use higher hardenability steels
Non-Uniform cooling from hardening temperature (mainly for air cooling)	Check the method of cooling	Cool the pieces keeping them separate so that cooling can take place uniformly. When fan cooling is used rotate the work pieces

Table 5.3 REASONS FOR NON-UNIFORM HARDNESS AND CORRECTIVE ACTIONS

5.2.3 Cracks

Probable Cause	Method of identifying the cause	Corrective Action
Defective material Initial hair-line cracks before heat treatment. Heavy segregation banding or inclusion	Normally identified by the regular pattern observed. eg. Straight line crack in the direction of rolling, crack in the direction of forging etc.	Adopt visual, ultrasonic or other methods for inspecting the raw material
Quenching cracks due to - Too high quenching severity - Poor design of part - Insufficient pre-heating - Too high hardening temp. - Cooling in water after removing from the quenching medium - Re-hardening without intermediate tempering or annealing	The quenching cracks will be thick and dark. No pattern will be observed. The fracture surface will be dark in colour	Use proper quenching medium recommended for the steel. Guidelines for design given in 5.2.7 to be followed. Proper pre-heating and use of correct hardening temp. Jobs should be cooled down to room temperature in air after removing from the quenching medium. Before rehardening the parts should be annealed.

Probable Cause	Method of identifying the cause	Corrective Action
Stress Cracks produced due to - delay in tempering of high alloy or water hardening steels - No tempering	Very fine cracks normally visible after grinding. No colour difference. Hairline cracks	Tempering without delay
Cracks due to excessive retained austenite - Grinding Cracks	Fine cracks visible after grinding. The direction of the cracks will be at right angles to the direction of grinding	Grinding with a soft grinding wheel very slowly without allowing any heat to develop. Tempering once again at higher allowable temperature depending upon the hardness requirements Sub-zero treatment

Table 5.4 REASONS FOR CRACKS AND CORRECTIVE ACTIONS

5.2.4 Too Much Distortion

Probable Cause	Method of identifying the cause	Corrective Action
Overheating	Study of the microstructure. Check the temperature indicator/controller accuracy	Use the correct hardening temp. Check and calibrate the temperature indicator/controller periodically
Slender Job	Check the length to diameter ratio or the thickness in relation to the size of the part	- Suitable fixtures to be used for hardening to support/hold the piece - Stress relieving before hardening - Use minimum time and temperature just sufficient for the steel to develop the required hardness - Use martempering or austempering if possible - Press or die quench
Too high quenching severity	Wrong quenching medium. Contamination of the quenching medium	Make sure that the quenching medium is suited for the steel. Keep the quenching medium free from contamination, especially with water
Improper Quenching	Check the direction of movement of component during quenching	Use proper methods for quenching

Probable Cause	Method of identifying the cause	Corrective Action
High initial stresses	Check whether heavy machining is done before hardening	Stress relieve the parts before hardening
Faulty Design	Non-uniform material distribution	Use proper design parameters See para 5.2.7
Wrong material composition	Analyse the material composition	Use correct heat treatment parameters suitable for the actual material
Rehardening	Check the history of the part	Anneal before rehardening. Slow pre-heating for rehardening

Table 5.5 REASONS FOR TOO MUCH DISTORTION AND CORRECTIVE ACTIONS

5.2.5 Hardness Not Low After Annealing

Probable Cause	Method of identifying the cause	Corrective Action
Cooling rate not slow enough	Check the cooling rate	Reduce the cooling rate
The annealing temperature not sufficient to break the carbides (cast iron)	Check the temperature used for annealing	Use higher temperatures to break the carbides
Soaking time at annealing temperature not sufficient	Check the soaking time with the section thickness	Use sufficient soaking time corresponding to the section thickness

Table 5.6 REASONS FOR HARDNESS NOT LOW AFTER ANNEALING AND CORRECTIVE ACTIONS

5.2.6 Flaking of Carburised Skin

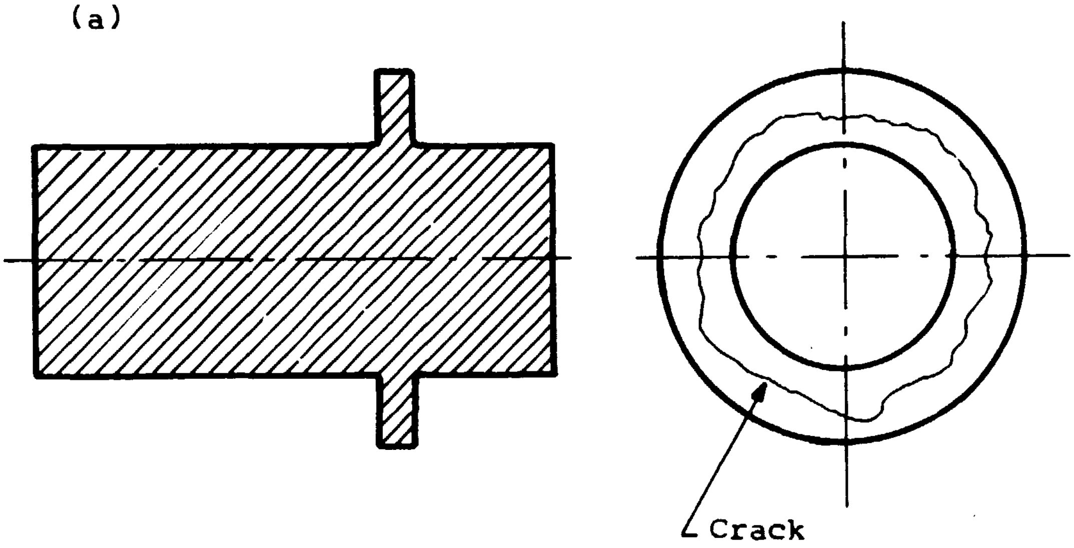
Probable Cause	Method of identifying the cause	Corrective Action
Too high carbon potential for carburising	Check the carbon potential	The carbon potential should be 0.8 to 1.1%
Too sharp transition from case to core	Check the microstructure to see the transition	The carburising conditions to be corrected.

Table 5.7 REASONS FOR FLAKING OR PEELING OF CARBURISED SKIN AND CORRECTIVE ACTIONS

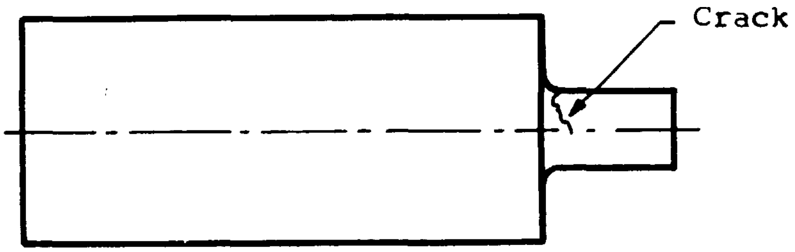
5.2.7 Guidelines for Design to Avoid Failures

Large and sudden variation in section thickness to be avoided as this will tend to produce quenching cracks. Examples:

(a)



(b)



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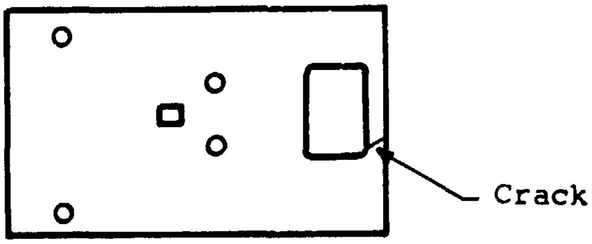
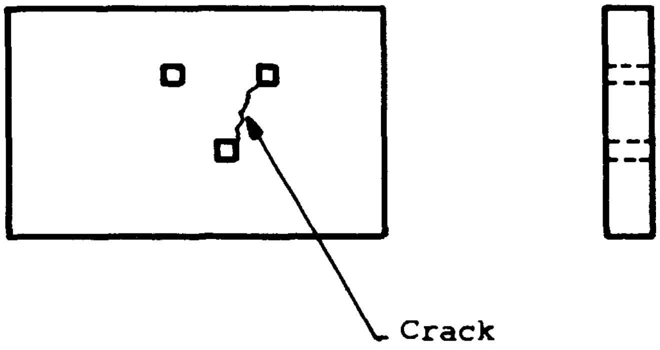
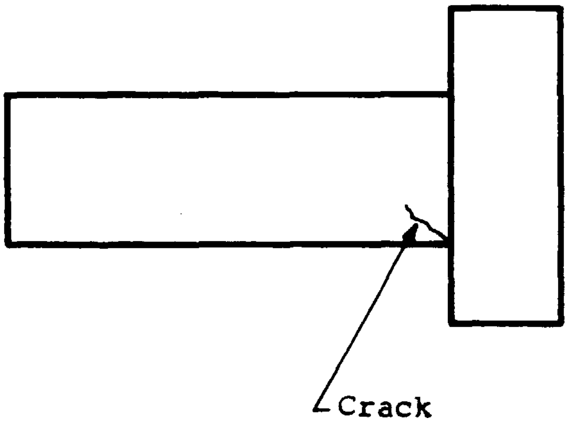


Sharp internal corners or sharp external section changes should be avoided. Examples

(a)

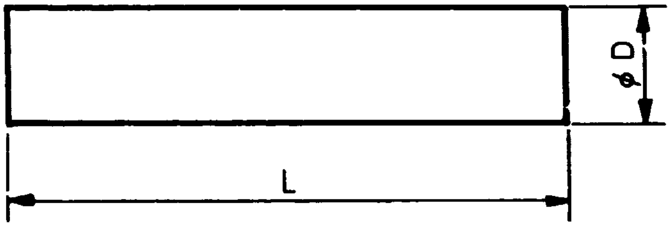


(b)



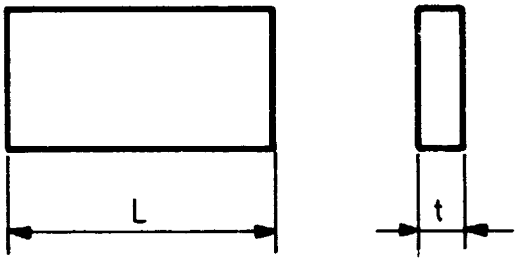
Avoid heat treatment for thin and very slender parts. The safe limit for length to diameter ratio is about 5 for small diameters (dia. 12 mm and below). Similarly the length to thickness ratio for small thicknesses (upto 20 mm) should be below 6. Examples are given in next page.

(a)



$\frac{L}{D} \leqq 5$

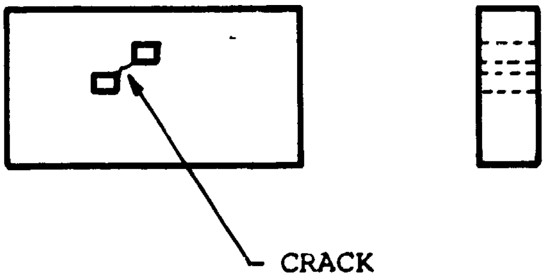
(b)

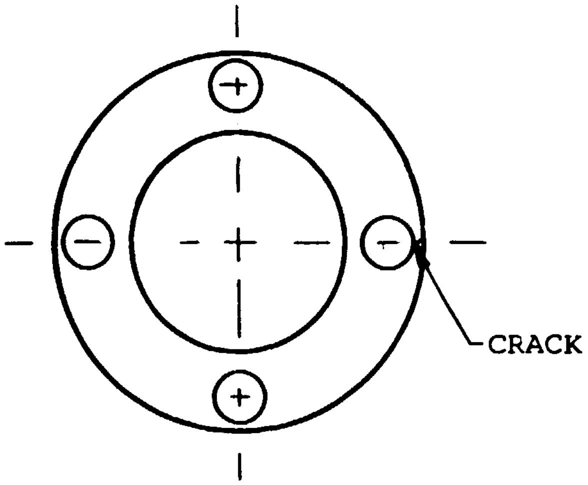


$\frac{L}{t} \leqq 6$

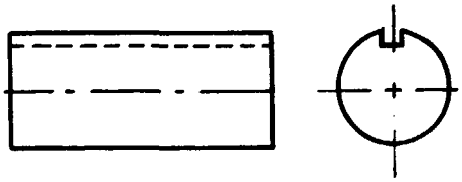
Avoid holes or slots too close to each other or too close to the edge. The safe thickness of material between holes should be equal to one thickness. Examples:

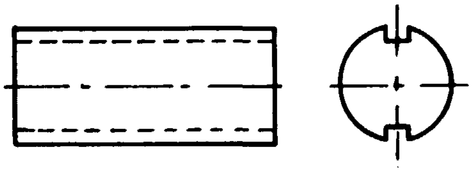
(a)



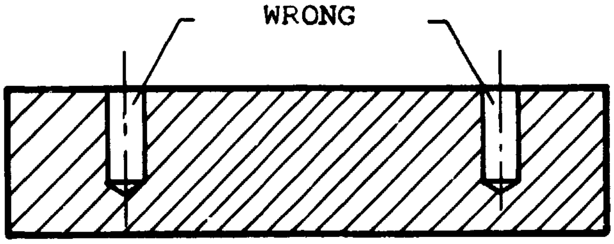


Avoid unsymmetrical grooves, keyways etc., which will cause non-uniform stress and result in heavy distortion. Wherever possible make the design symmetrical by providing additional grooves. Example:


WRONG


RIGHT

Avoid deep blind holes, which will prevent the circulation of quenching medium and hence give rise to cracks. Example:



In case the above guide-lines could not be followed due to any constraints, the alternative is to select a steel suitable for air hardening. For example with high carbon high chrome steel (air hardening steel) the above guidelines are not very critical.

5.3 Straightening

5.3.1 Straightening After Heat Treatment

Straightening after heat treatment can be done only if the hardness of the piece is less than 40 HRC or when the hardened layer is only on the surface and the core is soft i.e., case hardened, induction or flame hardened pieces with a soft core.

Straightening can be done using a press operated manually or by power. Small jobs can be straightened by hammering. Simple fixtures can be used for the quick pressing and checking of small pieces. Care should be taken to see that the pressing is uniform and it is not applied in sudden jerks. When the bend is heavy, the straightening should be done in stages i.e., the complete bend should not be removed in one pressing.

5.3.2 Straightening During Heat Treatment

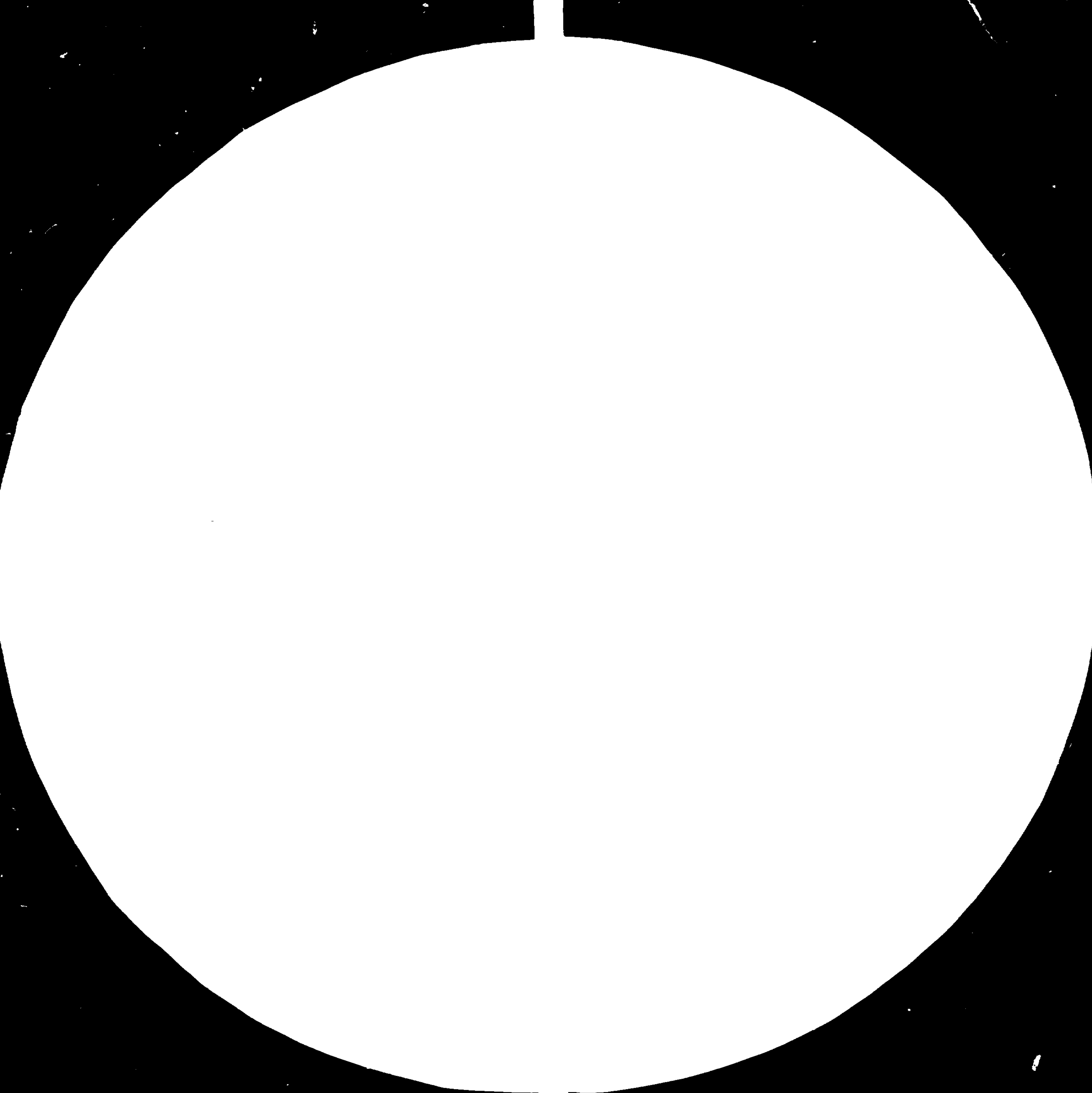
High speed steels are straightened during hardening before the pieces cool down to room temperature after quenching. The quenching is stopped at about 500 - 600°C (just when the red colour disappears) and the straightening is done quickly by hammering, pressing or rolling before the pieces get cooled to room temperature.

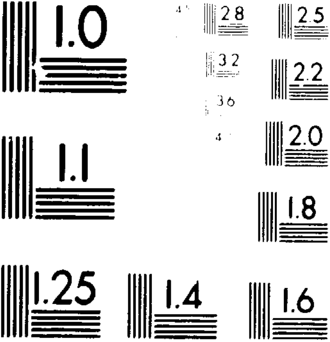
5.3.3 Straightening of H.S.S. Final

Long and slender high speed steel tools such as broaches are straightened finally by giving repeated blows with a small hammer. This method of straightening is a very slow process and takes long time.

5.4 Cleaning After Heat Treatment

The parts after heat treatment are cleaned to remove the scale, salt, oil, rust etc., adhering to the surface. The main processes employed for cleaning are (i) cleaning with hot water and (ii) blast cleaning with a suitable abrasive medium such as sand or steel grit/balls.




1.0
4.5
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

5.4.1 Wet Cleaning

Wet cleaning is used for removing the salt and oil from the surface of the jobs. Hot water is used to dissolve the salt. Two types of equipments are used for the wet cleaning. In the first method, the parts are dipped in a tank containing water heated to about 80°C and agitated with a fan. Small amounts (about 5%) of NaOH or a detergent liquid/powder is added to the water to remove the oiliness from the parts. The immersion time will be about 30 minutes. In the second method, parts are subjected to a high pressure spray of water. The equipment consists of a spray chamber with jets for spraying water from top and bottom, water tank with heaters and thermostat and a powerful pump. Normal water with 5% NaoH or detergent can be used for spraying also. The spraying time is about 15 - 20 minutes for ordinary jobs.

In both the above cases water will have to be changed occasionally when it gets contaminated with salt and oil. After the cleaning the surfaces of the parts should be immediately protected with oil or other rust preventives.

5.4.2 Blast Cleaning

Blast cleaning is mainly used for removing scale and rust from the surface of parts. The process consists of cleaning the surface with abrasive blast under pressure. The abrasives normally used are small chilled steel balls of about 0.5 to 1.0 mm diameter or chilled steel grits of fine mesh. For hardened components, chilled steel grit is more suitable than the chilled steel balls.

Two types of equipments are used for the blast cleaning. In one type compressed air is used for throwing the abrasive medium and in the other case the medium is thrown by centrifugal force and no compressed air is used.

The compressed air process is similar to spray painting. The abrasive blast comes through a nozzle along with compressed air. The parts to be cleaned are either held by hand underneath the jet or the jet is held in hand and directed over the parts. The complete blasting takes place inside a cabinet and hence this type of equipments are called blasting cabinets.

In the centrifugal method, the abrasive is fed in small quantities to the centre of a rotor which rotates at around 1000 r.p.m.

Due to the centrifugal force the abrasive gets thrown out radially, guided by the blades of the rotor. The parts to be cleaned are made to move slowly underneath the rotor on a revolving table. More than one rotor (the number depending upon the size of the rotating table) are used to cover the entire area of the table.

A comparison of the advantages and disadvantages of each method is given in Table 5.8.

During the blasting, in either method, lot of dust will be produced. Hence along with the equipment a suitable dust extraction and cleaning system should be used.

CENTRIFUGAL TYPE (AIRLESS)	COMPRESSED AIR TYPE
The cleaning is automatic. Only the parts are to be loaded and unloaded on the machine table.	The component or the nozzle is to be held/moved by hand inside the chamber during blasting.

CENTRIFUGAL TYPE (AIRLESS)	COMPRESSED AIR TYPE
No compressed air required for blasting	Compressed air is required for blasting
The rotor blades, rotor cage liners etc. wear fast and need regular replacement	Less wearing parts
The cleaning will be good only on plain surfaces and will not be effective on pockets or hidden areas	The cleaning can be done on hidden portions, pockets, tapped holes etc.
The cleaning takes place fast since many pieces can be loaded at a time	The cleaning takes more time as the cleaning has to be done on individual parts
Higher capital cost for equipment and needs more space	Lower capital cost and occupies lesser area

TABLE 5.8 COMPARISON OF CENTRIFUGAL AND COMPRESSED AIR TYPE SHOT BLASTING PROCESSES

5.5 Hardness Testing

5.5.1 Guidelines for Hardness Testing

The hardness testing method to be chosen will depend upon mainly the hardness range and the thickness of the piece to be checked. In the Rockwell 'C' method, the depth of impression equals (100-HRC) x 0.002 mm e.g., HRC 60 means (100-60) x 0.002 = 0.08 mm deep. The thickness of the piece for testing should be at least 10 times the depth of impression i.e., in this case for Rockwell 'C' 60 piece the minimum thickness should be 0.8 mm. The distance between two impressions should be at least 3 mm. When checking the hardness of case hardened parts by the Rockwell 'C' method, the case depth should be 0.5 mm minimum. For case depths between 0.3 and 0.5, Rockwell 'A' method can be used.

In the Vickers method, the depth of impression is about 1/7th of the diagonal. The length of the diagonal can be calculated from the formula given in Table 5.9. The thickness of the piece to be tested should be ten times the depth of indentation and the distance between the impressions should be at least three times the diagonal.

The identation depth in Brinell method is about 1/5th of the diameter of the impression. The distance between two adjacent impressions should be minimum one diameter of the impression. Brinell hardness upto 400 HB can be measured with a steel ball and upto 600 HB, a carbide ball should be used.

The hardness tester should be checked for accuracy with a standard test piece at least once in a day. The surfaces to be checked be smooth and free from any scale or dust.

5.5.2 Comparison of Vickers, Rockwell And Brinell Hardness Testing Methods And their Applications

Comparison of the types of indentors, loads, measuring methods and applications of the Brinell, Vickers and Rockwell methods of hardness testing is given in Table 5.9.

5.5.3 Corrected Values For Rockwell C Testing of Small Cylindrical Pieces

When testing cylindrical pieces, with diameters less than 10 mm, the corrections given in Table 5.10 should be used in order to arrive at the correct hardness.

Testing Method	Application	Type of indentor	Testing Load	Hardness value Calculated from	Mathematical Formula
Brinell	Soft to middle hard materials HB 950-4500 N/mm^2	Hardened steel ball D = 10 mm Ø D = 5 mm Ø D = 2.5mm Ø	3000 kg 750 kg 187.5kg	Diameter of the impression. (d)	$HB = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$ in N/mm^2
Vickers	Soft to Hard materials above HV 950 N/mm^2	Diamond Pyramid angle = 136°	can be varied from about 0.5-100kg	Diagonal of the impression. (d)	$HV = \frac{1.8544\ P}{d^2}$ in N/mm^2
Rockwell C	Middle hard to hard materials 20 - 70 HRC	Diamond cone included angle 120° Tip Radius r = 0.2 mm	150 kg	Depth of the impression	Directly read from the dial.
Rockwell 62.5	For thin or very hard materials (Tungsten carbide)	Diamond cone included angle 120° Tip Radius r = 0.2 mm	62.5 kg	Depth of the impression	Directly read from the dial
Rockwell A	For thin or very hard materials (Tungsten carbide)	Diamond cone included angle 120° Tip Radius 0.2 mm	60 kg	Depth of the impression	Directly read from the dial
Rockwell B	Soft to middle hard materials	Hardened steel ball D = 1/16 inches	100 kg	Depth of the impression	Directly read from the dial
Superficial Rockwell 15N	Middle to very hard materials 70-93 HR 15N	Diamond cone included angle 120° Tip Radius 0.2 mm	18 kg	Depth of the impression	Directly read from the dial

TABLE 5.9 COMPARISON OF VICKERS, ROCKWELL & BRINELL HARDNESS TESTING METHODS

HRC Reading obtained on work-piece diameters						Actual Hardness HRC
5 mm	6 mm	7 mm	8 mm	9 mm	10 mm	
29.5	30.5	31.5	32.0	32.5	33.0	35.0
30.5	31.5	32.5	33.0	33.5	34.0	36.0
31.5	33.0	33.5	34.0	34.5	35.0	37.0
33.0	34.0	34.5	35.0	35.5	36.0	38.0
34.0	35.0	35.5	36.5	36.5	37.0	39.0
35.0	36.0	37.0	37.5	37.5	38.0	40.0
36.0	37.0	38.0	38.5	39.0	39.0	41.0
37.5	38.0	39.0	39.5	40.0	40.0	42.0
38.5	39.5	40.0	40.5	41.0	41.5	43.0
39.5	40.5	41.0	41.5	42.0	42.5	44.0
40.5	41.5	42.0	42.5	43.0	43.5	45.0
42.0	42.5	43.5	43.5	44.0	44.5	46.0
43.0	43.5	44.5	45.0	45.0	45.5	47.0
44.0	45.0	45.5	46.0	46.0	46.5	48.0
45.0	46.0	46.5	47.0	47.5	47.5	49.0
46.5	47.0	47.5	48.0	48.5	48.5	50.0
47.5	48.0	48,5	49.0	49.5	49.5	51.0
48.5	49.0	49.5	50.0	50.5	51.0	52.0
49.5	50.5	51.0	51.0	51.5	52.0	53.0
51.0	52.0	52.0	52.5	52.5	53.0	54.0
52.0	52.5	53.0	53.5	53.5	54.0	55.0
53.0	53.5	54.0	54.5	54.5	55.0	56.0
54.0	54.5	55.0	56.0	56.0	56.0	57.0
55.5	56.0	56.0	56.5	57.0	57.0	58.0
56.5	57.5	57.5	57.5	58.0	58.0	59.0
57.5	58.0	58.5	58.5	59.0	59.0	60.0
58.5	59.0	59.5	60.0	60.0	60.5	61.0
59.5	60.0	60.5	61.0	61.0	61.5	62.0
61.0	61.5	61.5	62.0	62.0	62.5	63.0
62.0	62.5	62.5	63.0	63.0	63.5	64.0

TABLE 5.10 CORRECTED VALUES FOR ROCKWELL C TESTING OF SMALL CYLINDRICAL PARTS

5.5.4 Microhardness Testing

Microhardness testing machines are used for checking the hardness of very thin materials with very small loads in the range of few grams to a few kilograms. A Vickers diamond pyramid is used as the indentor and the diagonal of the impression is measured with a microscope. By this method it is also possible to check the hardness of different constituents of the microstructure such as carbides, pearlites etc.

5.5.5 Rebound or Scleroscope Testing

This test consists of dropping vertically a small hammer from a fixed height on to the polished surface of the metal under test, and noting by means of a scale, the height of rebound. The instrument used for this type of test is called the scleroscope. The total height of rebound is divided into 100 divisions and the number of division upto which the hammer has rebound gives the scleroscope number. This value can be converted to other hardness scales using the tables provided with the instruments. To get reliable hardness values, the surface to be tested should be horizontal and the rebound should be vertical. For vertical surfaces a pendulum type rebound is used.

Scleroscope is used mainly as a portable hardness tester for checking the hardness of large parts which cannot be loaded on a conventional hardness tester. Examples are large rolls, lathe bed guideways etc.

5.5.6 Ultrasonic and other Portable Hardness Tester

The scleroscope as mentioned above needs horizontal or vertical surfaces and also needs sufficient space above the surface. Hence this instrument cannot be used on inclined surfaces, holes or small areas. In order to overcome the above limitation hardness testers are developed using ultrasonic and other similar principles, which give the hardness of the material just when the surface is touched with the probe. The probe is very small and needs only a small area for checking. Also the job can be in any position inclined, vertical or horizontal. The main limitation of this method is that the surface to be tested should be ground or machined smooth.

5.5.7 The File Test

The file test, properly applied, can be very valuable. Usually 15 - 20 cm. Second-cut bastard or triangular files are chosen. The piece to be tested is firmly gripped and the file applied and moved steadily forward under uniform load. Skill is required in the test, but this is quickly attained. The method enables large areas of a piece or many pieces to be examined quickly for hardness. Soft surfaces or soft spots are readily detected. Worn files give misleading results. The file test is the method generally adopted for checking powder metallurgy parts after hardening.

5.6 Cast Depth Measurement

5.6.1 Visual Checking of Fracture

In this method a test piece made out of the same material as the actual parts is loaded in the furnace for carburising along with the actual parts. For easy fracturing the test piece may be prepared as per the drawing given in Fig. 5.1. After the carburising, the test piece is hardened in the normal way and fractured. The fractured surface will have different appearance for the case and the core. The depth of case can be measured with a scale or by using a low magnification microscope with graduated eye piece. In the case of fine grained alloy case hardening steels, the distinction between case and core may not be very clear. In such cases, the fractured surface is ground, polished with emery paper and etched with acid. The case will etch dark and the core will be light. For very accurate results and for studying the transition from case to core, the fractured surface is polished and etched like other microscopic specimens and then observed under the microscope.

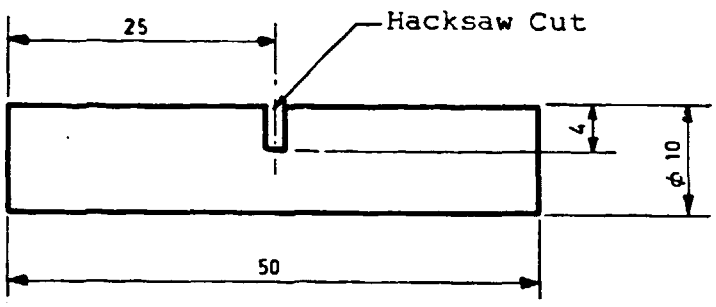


Fig. 5.1 TEST PIECE FOR CHECKING CASE DEPTH

5.6.2 Non-destructive Tests

The non-destructive tests make use of the difference in magnetic properties of case and core. Two types of equipments are available for the measurement of case depth; one using the principle of eddy current and the other using coercive force measurement. In the eddy current method the magnetic properties of the piece are compared with those of an identical piece with known case depth. The main disadvantage of this process is that it is not an absolute method and needs a lot of standard specimens. In the other method the probe is placed on the piece and the cc-ercive force value is measured. Then the case depth is read from a calibration curve previously prepared by destructive checks of samples with shallow and deep cases. Because the coercive force is an absolute value, it is not necessary to compare with standard pieces. When compared with the eddy current device, the coercive force meter can handle deeper cases upto 20 mm and the reading is not affected by minor composition changes.

5.7 Crack Checking

5.7.1 Visual Checking

Large cracks, especially quenching cracks will be visible to the naked eye when inspected after cleaning the pieces. The quenching cracks will have a dark appearance which makes it easy to detect. Fine cracks such as stress cracks will not be easily visible, but can be seen by using a magnifying glass.

5.7.2 Ultrasonic Testing

Ultrasonic waves are mechanical vibrations set up in the part being inspected by an ultrasonic transducer or crystal. The transeducer is used to transmit ultrasonic waves and to detect or receive these waves In the ultrasonic testing of steel, a short burst of ultrasonic energy known as the initial pulse is transmitted into the piece using a probe through some coupling medium such as water or oil. The ultrasonic wave travels in essentially a straight line and is reflected from the back surface of the piece, which forms an echo. If there is any imperfection or crack in the steel, part of the wave gets reflected at this imperfection and an additional echo is observed before the back surface echo. From the size and location of this echo, the nature and location of the crack can be predicted. Ultrasonic testing is not very effective for testing fine surface cracks.

5.7.3 Dye Penetrant Testing

The dye-penetrant method is the simplest and most effective method of checking surface cracks. The process requires a dye with very low surface tension, a solvent such as acetone for cleaning and a suitable absorbant powder supsension for developing. The surface to be tested is cleaned first with the solvent to remove the oiliness. After that the surface is sprayed with the dye and it is allowed to remain on the surface for about 10 minutes. The dye is then wiped off and the surface is cleaned with the solvent to remove any trace of dye present on the surface. Now the developer is sprayed over the surface, and the cracks show up as dark red line against the white back-ground of the developer. The main dis-advantage of this method is that it requires a clean and smooth surface.

5.7.4 Magnetic Flux Testing

In this method, the part to be checked is magnetised with a suitable electric coil. After magnetising a spray of special liquid is applied on the surface. The surface is then inspected with ultraviolet light. Cracks will show up as luminous lines. This method can be used mainly for inspecting small components which can be magnetised easily.

5.8 Safety Precautions

The operators should wear asbetos hand-gloves, face shields, overalls and safety shoes to protect the body from the heat of the furnace.

The floors of the heat treatment shops should be clean and not slippery.

Inflammable materials should not be stored near the furnace.

All jobs before dipping into the salt bath should be thoroughly pre-heated.

The salts used for carburising contain cyanide which is very poisonous. Hence these salts should be stored and handled carefully.

Salts containing cyanide (carbursing salts) should not be mixed with salts containing nitrite and nitrate (quenching and austempering salts)

During gas nitriding, the furnace should be purged completely with Nitrogen or Ammonia before the temperature is raised above 150°C.

5.9 Effluent Disposal

5.9.1 Salt Bath Fumes

Salt bath furnaces operating at high temperatures produce fumes. These fumes are extracted using suitable exhaust fans and let out to the atmosphere through tall chimneys. But the salt fumes being heavy, do not go up in the air, instead settles down on the surrounding areas causing heavy corrosion and damage to vegetation etc. Hence it is recommended that the fumes are made to condense inside special chambers and only the clean air is let outside.

5.9.2 Waste Salts

Waste salts from neutral baths are not poisonous and hence they can be disposed off without any treatment. But waste salts from carburising and nitriding baths contain cyanide and hence they should be neutralised before they are disposed off. The cyanide containing waste salts are first dissolved in large quantities of water and stored in special tanks. The neutralisation is carried out by adding ferrous sulphate or oxidising agents such as chlorine or sodium hypo chlorite. The amount of chemical required for the neutralisation will depend upon the amount of cyanide present in the waste. After adding the neutralising chemical the solution is allowed to stand for 24 hours to complete the reaction. After that a sample of the solution is taken and tested for excess of treatment chemical (FeSO$_4$ or Chlorine) which ensures that the neutralisation is complete. The waste may be then let off to the drains.

Another method of neutralising cyanide is by electrochemical oxidation. In this process the cyanide is electrolytically decomposed to harmless products. With this method neutralisation is more effective than the other methods. No chemical is used, but only electricity is used, which makes this process less expensive for operation. The main disadvantage of this process is that the oxidation takes very long time, about 200 hours.

5.10 First Aid Instructions

5.10.1 First Aid for Burns from Salts Containing Cyanide

i) Flood the affected area with a large volume of water

ii) Soak the affected area in sodium bicarbonate solution for a prolonged period

iii) Apply sterile dressing

iv) If a crust develops or has formed on the burned area before the above treatment can be applied, it should not be removed. Cover with a sterile dressing.

5.10.2 First Aid for Cyanide Poisoning

i) If the patient has swallowed cyanide and is conscious, give one tumbler full of the antidote. (The antidote consists of 150 gm B.P. Ferrous Sulphase crystals and 3 gm B.P. Citric Acid Crystals dissolved in one litre cold water and 60 gm of anhydrous sodium carbonate dissolved in a litre of water. Both these solutions are mixed in equal proportions.)

ii) Give nothing by mouth to an unconcious patient

iii) Remove the clothing splashed with molten cyanide or cyanide solution

iv) Keep the patient warm and do not in any circumstances allow the patients to walk about.

5.10.3 First Aid for Barium Salt Poisoning

If it is suspected that the worker has swallowed any salt containing Barium:

i) Give a strong solution of salt and water or mustard and water

ii) Cive the antidote (a heaped tablespoonful of Glauber's salt dissolved in a glass of water) and repeat if necessary.

CHAPTER VI

Conversion Tables

6. Conversion Tables

6.1 Hardness Conversion Tables*

Tensile Strength N/mm^2	Vickers Hardness HV	Brinell Hardness HB	Rockwell Hardness			
			HRA	HRB	HRC	HR 15N
255	80	76.0				
270	85	80.7		41.0		
285	90	85.5		48.0		
305	95	90.2		52.0		
320	100	95.0		56.2		
335	105	99.8				
350	110	105		62.3		
370	115	109				
385	120	114		66.7		
400	125	119				
415	130	124		71.2		
430	135	128				
450	140	133		75.0		
465	145	138				
480	150	143		78.7		
495	155	147				
510	160	152		81.7		
530	165	156				
545	170	162		85.0		
560	175	166				
575	180	171		87.1		
595	185	176				
610	190	181		89.5		

* As per DIN 50150

Tensile Strength N/mm²	Vickers Hardness HV	Brinell Hardness HB	Rockwell Hardness HRA	HRB	HRC	HR 15 N
625	195	185				
640	200	190		91.5		
660	205	195		92.5		
675	210	199		93.5		
690	215	204		94.0		
705	220	209		95.0		
720	225	214		96.0		
740	230	219		96.7		
755	235	223				
770	240	228		98.1	20.3	69.6
785	245	233			21.3	70.1
800	250	238		99.5	22.2	70.6
820	255	242			23.1	71.1
835	260	247			24.0	71.6
850	265	252			24.8	72.1
865	270	257	63.1		25.6	72.6
880	275	261	63.5		26.4	73.0
900	280	266	63.8		27.1	73.4
915	285	271	64.2		27.8	73.6
930	290	276	64.5		28.5	74.2
950	295	280	64.8		29.2	74.6
965	300	285	65.2		29.8	74.9
995	310	295	65.8		31.0	75.6
1030	320	304	66.4		32.2	76.2
1060	330	314	67.0		33.3	76.8

Tensile strength N/mm^2	Vickers hardness HV	Brinell hardness HB	Rockwell Hardness		
			HRA	HRC	HR15N
1095	340	323	67.6	34.4	77.4
1125	350	333	68.1	35.5	78.0
1155	360	342	68.7	36.6	78.6
1190	370	352	69.2	37.7	79.2
1220	380	361	69.8	38.8	79.8
1255	390	371	70.3	39.8	80.3
1290	400	380	70.8	40.8	80.8
1320	410	390	71.4	41.8	81.4
1350	420	399	71.8	42.7	81.8
1385	430	409	72.3	43.6	82.3
1420	440	418	72.8	44.5	82.8
1455	450	428	73.3	45.3	83.2
1485	460	437	73.6	46.1	83.6
1520	470	447	74.1	46.9	83.9
1555	480	(456)	74.5	47.7	84.3
1595	490	(466)	74.9	48.4	84.7
1630	500	(475)	75.3	49.1	85.0
1665	510	(485)	75.7	49.8	85.4
1700	520	(494)	76.1	50.5	85.7
1740	530	(504)	76.4	51.1	86.0
1775	540	(513)	76.7	51.7	86.3
1810	550	(523)	77.0	52.3	86.6
1845	560	(532)	77.4	53.0	86.9
1880	570	(542)	77.8	53.6	87.2
1920	580	(551)	78.0	54.7	87.5

Tensile strength N/mm^2	Vickers Hardness HV	Brinell Hardness HB*	Rockwell Hardness		
			HRA	HRC	HR15N
1955	590	(561)	78.4	54.7	87.8
1995	600	(570)	78.6	55.2	88.0
2030	610	(580)	78.9	55.7	88.2
2070	620	(589)	79.2	56.3	88.5
2105	630	(599)	79.5	56.8	88.8
2145	640	(608)	79.8	57.3	89.0
2180	650	(618)	80.0	57.8	89.2
	660		80.3	58.3	89.5
	670		80.6	58.8	89.7
	680		80.8	59.2	89.8
	690		81.1	59.7	90.1
	700		81.3	60.1	90.3
	720		81.8	61.0	90.7
	740		82.2	61.8	91.0
	760		82.6	62.5	91.2
	780		83.0	63.3	91.5
	800		83.4	64.0	91.8
	820		83.8	64.7	92.1
	840		84.1	65.3	92.3
	860		84.4	65.9	92.5
	880		84.7	66.4	92.7
	900		85.0	67.0	92.9
	920		85.3	67.5	93.0
	940		85.6	68.0	93.2

* Converted from: HB = 0.95 HV

6.2 Temperature Conversion Table

°C	°F	°C	°F	°C	°F
0	32	250	482	500	932
10	50	260	500	510	950
20	68	270	518	520	968
30	86	280	536	530	986
40	104	290	554	540	1004
50	122	300	572	550	1022
60	140	310	590	560	1040
70	158	320	608	570	1058
80	176	330	626	580	1076
90	194	340	644	590	1094
100	212	350	662	600	1112
110	230	360	680	610	1130
120	248	370	698	620	1148
130	266	380	716	630	1166
140	284	390	734	640	1184
150	302	400	752	650	1202
160	320	410	770	660	1220
170	338	420	788	670	1238
180	356	430	806	680	1256
190	374	440	824	690	1274
200	392	450	842	700	1292
210	410	460	860	710	1310
220	428	470	878	720	1328
230	446	480	896	730	1346
240	464	490	914	740	1364

°C	°F	°C	°F	°C	°F
750	1382	970	1778	1190	2174
760	1400	980	1796	1200	2192
770	1418	990	1814	1210	2210
780	1436	1000	1832	1220	2228
790	1454	1010	1850	1230	2246
800	1472	1020	1868	1240	2264
810	1490	1030	1886	1250	2282
820	1508	1040	1904	1260	2300
830	1526	1050	1922	1270	2318
840	1544	1060	1940	1280	2336
850	1562	1070	1958	1290	2354
860	1580	1080	1976	1300	2372
870	1598	1090	1994	1310	2390
880	1616	1100	2012	1320	2408
890	1634	1110	2030	1330	2426
900	1652	1120	2048	1340	2444
910	1670	1130	2066	1350	2462
920	1688	1140	2084	1360	2480
930	1706	1150	2102	1370	2498
940	1724	1160	2120	1380	2516
950	1742	1170	2138	1390	2534
960	1760	1180	2156	1400	2552

Conversion Formula : $°C = (°F - 32) \times \frac{5}{8}$

$°F = \frac{9}{5} °C + 32$

CHAPTER VII

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