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Seminar on the Establishment and Development
of the Automotive Industry in Developing Countries

Karlovy Vary, CSSR, 14 October - 1 November 1968

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QUALITY CONTROL ON FOUNDRY OPERATIONS FOR AUTOMOTIVE PARTS MANUFACTURE[1]

by

L.E. Komarov
Chief Metallurgist
Moscow Likhachev Automobile Plant
Union of Soviet Socialist Republics

Accompanied by Summary

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SUMMARY

1. The quality of cast parts is determined by the quality of the actual casting and treatment such as heat treatment, surface hardening, facing and machining.

2. To produce a cast of a desired quality, many technical factors must be considered, such as equipment, raw materials and operations of the whole cycle of casting.

3. Using modern methods and equipment to control foundry operations, it is possible to obtain high-quality castings of high accuracy and the strength that determines machinability.

4. Since production of castings in green sand moulds is the most commonly used method, pricipal attention is paid to this process.

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* This is a summary of a paper issued under the same title as ID/WG.13/1.

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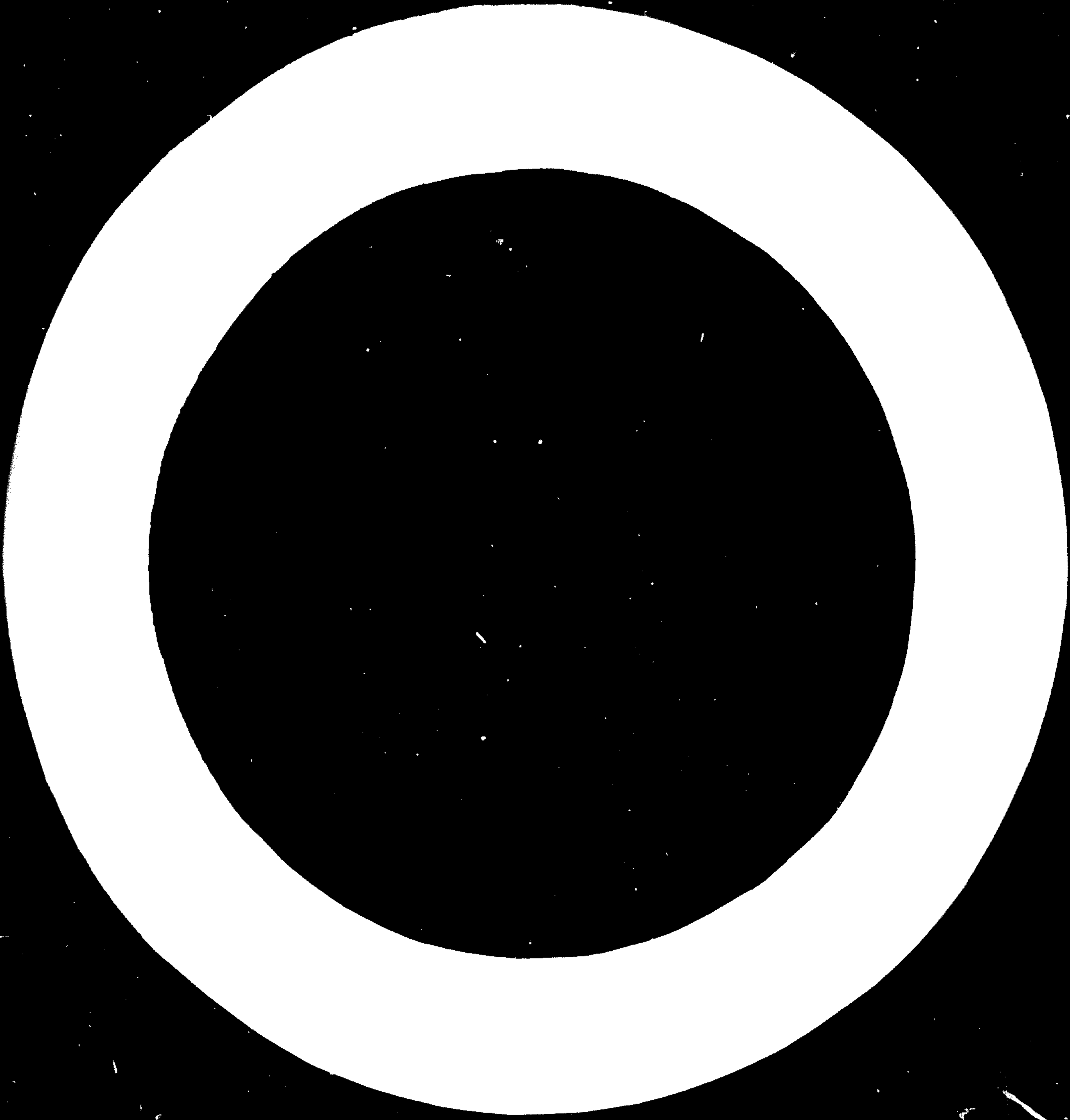

5. Quality control begins with the verification of raw materials (cast iron, steel and iron scrap, metal chips, ferro-alloys, additions and fluxes) and basic and additional moulding materials (sand, fire-clay, bentonite, bonding materials, coal and others).

6. As the quality of materials is verified by suppliers, occasional checks in the consumer plant are made. If detailed information on quality control of raw materials is not available, it is necessary to perform quality-control tests at the plant.

7. The paper describes various methods and equipment for controlling foundry materials.

8. The second and third control steps are the verification of the molten metal and moulding and core sands preparation. The paper describes special methods and devices for examining the specific physical properties of tested materials, and the quality and dimensional accuracy of mould parts and cores.

9. Whenever heat treatment of castings is required, heating and chilling control is carried out. It is also frequently necessary to control the heat treatment atmosphere.

10. Final control steps determine the correlation between the quality of the real and required casting parts. Therefore, testing devices for control of strength, hardness, structure, soundness and dimensional accuracy of castings are described.

11. It is known that dimensional accuracy is determined for the accuracy and toughness of pattern-box equipment, accuracy of the preparation of the moulds and cores, and properties of moulds, core materials and cast alloys. These properties are revealed in an interaction between metal and mould while the metal is in the molten state and as it solidifies. Accordingly, control methods for the accuracy of the castings are described.

12. The paper gives data about the controls in each step of the foundry process in accordance with specific conditions of production.

Contents

I. GENERAL CONSIDERATIONS

1. It is well known that the quality of all cast components, including automobile parts, depends on the quality of the initial castings and of their subsequent processing (heat treatment, surface hardening and machining), and that the first and most important stage of all is to obtain a casting of the required quality.

2. The solution to this problem lies primarily in the selection and development of the technological processes, equipment and materials best suited to achieve the required results within the limits of the given parameters. The aim of the control of materials and operations during the whole cycle culminating in the production of castings is to keep within given limits any deviations from the rated value of the parameters of the technological process.

3. Quality control of casting production operations can therefore be most advantageously considered together with the conditions necessary to ensure the required quality in the production cycle. The aim of the present paper is to describe the best technological processes, the methods of ensuring that there is no deviation from those processes, and the methods of checking the main parameters of the production process. More specific and detailed information on individual questions can be found in the special literature. As sand-casting is the most usual method of producing castings, attention has been chiefly devoted to this operation in considering the production and quality control of castings.

II QUALITY CONTROL OF THE RAW MATERIALS

4. Measures to ensure the required quality of castings begin with quality control of the raw materials: those making up the charge (foundry pig-iron, steel and iron scrap, metal chips, ferro-alloys, alloying additives and fluxes) and those used to make the moulds (sand, clay, bentonite, silica flour, graphite, coal, binding materials, various types of strengthening materials, and other additives).

5. The required quality of these materials is usually guaranteed by the suppliers; periodic tests for quality are normally carried out by the user, but sometimes no checks are made at all. Where there is no full guarantee

of the consistently satisfactory quality of the materials supplied, the user must test them constantly.

6. The general requirements for satisfactory moulding materials may be summarized as follows: The basic moulding material - silica sand - must possess high resistance to heat and chemicals, contain the least possible quantity of impurities, and be of the specified grain size. The other materials added to mould mix must give it the necessary strength, plasticity and special technological properties when - and this is most important - they are added in minimal quantities.

Quality control of moulding materials

7. The most important characteristics of moulding sand are its chemical composition, granular composition, clay content, gas permeability, refractory qualities and carbonate content. Grain composition is determined from the relative weights of the piles of grains of the different gauges obtained by sieve analysis of a sample batch on a standard set of vibratory sieves. The clay content is determined by elutriation with an agitator according to Stock's sedimentation law.

8. Gas permeability is determined on a special apparatus that measures the ratio of filtration rate to pressure drop in a sample of given height rammed into a tube on a laboratory impact tester.

9. The chemical composition of moulding sand is determined by the ordinary methods of chemical analysis to measure its content of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O and Na_2O. Its refractory qualities are determined from the melting (softening) point of samples and from the temperature at which the grains slag (or start to sinter). Sands with a high clay content are tested for wet strength index under optimum moisture conditions. Clays and bentonites are tested for their binding capacity and colloidal qualities (degree of water absorption). The strength of moulding materials is determined by compressive strength testing of samples of given standard composition. Water absorption is determined as the amount of absorbed water per unit amount of dry material.

10. The Al_2O_3, TiO_2 and Fe_2O_3 content of refractory clay is determined by chemical analysis.

11. Silica flour is tested chemically to determine its silica content, carbonate impurities and loss in calcining. It is also periodically tested for fineness of division.

12. Coal dust intended for use in moulding sand is analysed for content of moisture, ash, sulphur and volatiles, and for fineness of division.

13. Graphite is tested for ash content and fineness of division.

14. Organic and inorganic binding materials are usually tested for their binding capacity and gassing. The binding capacity is determined by testing the tensile strength of a dried standard sample; gassing is defined in terms of the volume of gas given off by one gram of the material.

15. In particular cases, depending upon the requirements of the process, tests are also made of specific gravity and dry matter content (sulphite residues), viscosity (petroleum distillation wastes), amount of residue and acid number (vegetable oils, dextrin), ash content, solubility (dextrin), solvent content and pH value.

16. Sodium silicate solution is tested for liquor ratio and specific gravity.

17. Phenol and other thermo-setting resins that are widely used for shell moulds and cores produced in hot boxes are tested for curing-time, flowability, specific gravity, and melting point.

Quality control of the charge materials, fuel, fluxes and refractories

18. The quality of charge materials, like that of mould materials, is checked by the suppliers, who deliver them in given quantities with documents containing details of their composition and quantity. Thus foundry pig-iron is delivered in batches of 30-60 tons with certificates giving its weight and the results of its chemical analysis, usually for its content of C, Si, Mn, Cr, S and P. Thereafter its chemical composition need be tested only periodically by the user, and usually only for its content of Si and Mn. Every batch of foundry pig-iron with an unusually high content of other elements (the so-called natural alloys) must be tested for its content of Cr, Ni and Si.

19. Ferro-alloys, likewise, are delivered with accompanying documents giving the content of the basic element and of any others that may affect the quality of the cast metal. Thus FeSi is delivered with a certificate giving the content not only of the basic elements but also of aluminium, which may

make blow-holes. In the production of malleable iron, however, it is also essential to know the amount of Cr in the pig-iron, as this affects the annealing time of the iron. In this case, the user himself must make an analysis for chromium, unless it is economically advantageous to arrange with the supplier to do it. When additives contain chromium, molybdenum, vanadium, titanium, nickel, cobalt or (in steel melting) niobium, it is also essential to test for the content of these.

20. Efforts should be made to obtain iron or steel chips (whether in briquettes or not) from one or more constant suppliers. Typical sources of supply are the machine shops of the automobile factory itself, or of other firms that mass-produce metal goods.

21. The nature of the machined metal is then known and remains unchanged for a long time, so that it may be necessary to make only periodic chemical analyses of delivered chips.

22. Steel scrap is usually analysed only for its Cr and [illegible] content when intended for melting pig-iron but for all basic elements when intended for steel melting. Cast-iron scrap, unless of a known composition, is analysed for its content of C, Si, Mn, P and S. Steel and cast-iron scrap is also tested to ensure that the size and thickness of the pieces comply with the supply specifications established in accordance with the particular conditions of production. Fluxes for iron and steel melting must also be tested.

23. Thus limestone loaded into cupola furnaces to cause the coke ash and sand to slag must contain not more than 0.5 per cent MgO, as this would hinder slag formation. It must not contain calcite impurities, because this substance may explode at high temperature, nor, if possible, gypsum, which contains sulphur. Limestone is also tested for its content of ferric oxide, silicic acid and particles of clay, sand and dust, and for its lump size, hardness and density.

24. Only washed fluorspar should be used. It should be tested for its CaF_2, SiO_2, S and Al_2O_3 content and for hardness and specific gravity in accordance with the purchase specifications.

25. Unslaked lime (quicklime), which is used for slag formation in furnaces with a basic lining, must be analysed for its content of CaO, MgO, moisture, S, SiO_2, P_2O_5 and $Fe_2O_3+Al_2O_3$, its dust content, calcining losses, lump size

and storage time. The last test is most important because of the strong tendency of quicklime to decompose through water absorption; this may increase the gas content of the metal.

26. The quality of the fuel (i.e. foundry coke) has a considerable influence on metal melting in a cupola furnace and on the quality of the product. It must therefore be tested constantly.

27. Foundry coke is chemically analysed for its content of C, H_2, O_2+H_2, S, ash and water. Coke must also be tested for lump size, strength (shown by the percentage of the initial amount of coke left on a 40-mm sieve after tumbling in a drum tester), resistance to dumping (shown by the percentage remaining on a 60-mm sieve after the sample batch has been thrice dumped on a cast-iron plate from a height of 2 metres), porosity and calorific value.

28. In testing all materials before releasing them for use in production, particular attention must be paid to their purity. As a general rule, materials containing impurities must be rejected.

29. Since molten metal reacts with the lining of the melting plant, the refractories must also be tested. These are tested for their chemical composition (fireclay and silica-fireclay bricks are tested for their content of NiO_2, Al_2O_3, CaO and Fe_2O_3; dinas bricks for their content of SiO_2, Al_2O_3 and CaO; and magnesite bricks for their content of MgO, SiO_2, CaO, Al_2O_3 and Fe_2O_3), for their melting point, and for refractory qualities. Their outward appearance must also be carefully inspected.

30. All these recommendations are based on the experience of various undertakings in the automobile industry. The main object of testing the quantity and purity of the basic charge materials is to provide a constant guarantee of their quality (condition) before they enter the technological process of producing castings. Thus almost all the charge ingredients, fluxes and refractories are tested for their chemical composition. The two main methods used are spectroscopic analysis and chemical analysis.

31. Spectroscopic analysis is a modern physical method for determining the chemical composition of a substance. In essence it consists of vapourizing and also exciting the substance: i.e. imparting additional energy to the atoms of which it is composed. The atoms are then allowed to return of their own accord to their normal state, and in doing so they radiate the energy

imparted to them during excitation in the form of light of various wavelengths. The atoms of each element radiate waves of a given wavelength; and the intensity of the radiation depends on the number of atoms causing it: i.e. on the content of the particular element in the specimen. The radiated light is directed into the spectroscopic apparatus through an extremely narrow slit, (only some hundredths of a millimeter wide), where it is broken down into its component wavelengths. As a result a "bright-line spectrum" is formed at the output of the instrument. The spectra thus obtained from the specimens analysed are then compared with previously-prepared and recorded spectra of standard samples of these elements.

32. Two types of apparatus are used for spectroscopic analysis: instruments with visual presentation of the spectra (styloscopes and stylometers), and instruments in which the spectra are recorded photographically (spectrographs).

33. Quantitative analysis is carried out by comparative measurement of the intensity of the spectrum lines either visually or with a polarizing photometer (stylometer).

34. In recent years automatic vacuum quantum measuring instruments have been increasingly used. They enable the content of all chemical elements, including C, P and S, to be determined very quickly (in a few tenths of a second). The precision of the measurements made with these instruments is two to three times that obtainable with visual or photographic instruments.

35. These vacuum quantum measuring instruments operate on the basis of the physical phenomena described above; but the process of capturing the light waves (spectrum lines), recording them, amplifying them and turning them into instrument readings is automated.

36. The specimens used for chemical analysis are average samples in the form of chips obtained by drilling, planning or milling.

37. In order to avoid serious errors in analysis, test pieces must first be cleaned before samples are taken from them, as they may have sand, slag, scale, oil, paint or other substances on their surfaces. Hard specimens should first be annealed or ground.

38. The elemental composition of specimens is determined by making various gravimetric, volumetric, calorimetric, photocalorimetric and other tests by established methods. Different methods give different degrees of precision,

and the method to be used must therefore be selected in accordance with the requirements. A drawback of chemical analysis is the time it takes and the need to keep a large stock of chemical preparations and reagents.

III. THE PREPARATION OF THE LIQUID METAL AND THE TESTING OF ITS QUALITY

The melting equipment

39. The properties of the iron from which castings are made depend to a large extent on the method of melting and the treatment of the liquid metal within the furnace. The more stable the chemical composition of the cast iron, and the more closely controlled the temperature at which the metal is melted and poured, the fewer are the deviations in the properties of the castings.

40. The latest process for melting grey iron, which consistently produces metal with a wide range of desired properties, is the duplex process, using a cupola furnace and an electric induction furnace.

41. Large cupola furnaces with an output of 25-50 tons of liquid metal per hour and a long period between overhauls are being installed in the foundries of modern automobile factories. Even with oxygen blast or hot blast equipment, however, the high-production cupola furnaces will not produce inoculated iron with special properties. For this the metal must be remelted in induction furnaces, where it is reheated and refined, its chemical composition is equalized and it is inoculated. The most commonly used types of these furnaces are the channel-type induction furnaces with removable channels.

42. The specific features of the charging and melting processes for producing malleable iron in cupola furnaces (the need to use up to 50 per cent steel scrap and to keep the content of carbide-forming elements down to an absolute minimum) and the ever-increasing use of alloys such as chrome, vanadium and molybdenum steels, for which the quantity of low-alloy iron in the charge must be increased, have forced a transition to melting in electric furnaces. Therefore the present and probably also the future process for producing malleable iron is the duplex process in which one electric furnace is used for melting into the solid charge and another for melting into the liquid charge, where the iron is reheated and refined. This improves the quality of malleable iron castings and produces iron with especially good physical and mechanical properties.

43. Electric (including induction) furnaces and gas furnaces are both widely used for melting non-ferrous metals. It appears, however, that in the future electrical induction furnaces with removable channels will be preferred as these give liquid metal of high quality. The necessary quality of the metal and consequently also of the casting cannot be ensured, however, solely by selecting the right kind of melting plant and using the right charge materials.

Measuring out the charge components

44. One of the most important requirements for obtaining liquid metal of a given quality is the precision in measuring out the charge components in accordance with their actual chemical analysis

45. If the metal charge components supplied to the factory are of constant composition and quality, they need only be measured out correctly according to the charge formula, for which purpose the most varied equipment, ranging from the simplest to automatic weighing devices, can be used. If, however, one or more of the charge components varies in composition, it is essential to work out a new charge formula each time the charge is mixed. The accuracy of measuring charge components is usually within the range of 0.5-1.0 per cent.

46. Coke and fluxes are generally measured out by volume. It is therefore essential to watch for changes in their lump size. If these occur, the volume must be recalculated or measurement must be by weight; but then allowance must be made for the moisture content.

47. In view of the importance of the measuring out-of-charge components, it may be of value to consider several modern methods. The mass production of castings, for example in the automobile industry, must be mechanized; in many cases complete automation of the measuring out-of-charge components is warranted. Since the most complicated melting plant, using a multi-component charge, is the cupola furnace, it may be advantageous to consider the application of the charge-component measuring process to this type of furnace.

48. For melting iron in cupola furnaces, the following systems of measuring out the charge components are used. From the storage areas to which ferrous charge materials have been delivered by railway wagons or motor vehicles, they are transferred by an overhead crane with a magnetic disc into feed bunkers, each set aside for a given material and usually designed to contain sufficient material for a whole shift or 24-hour period.

49. From the feed bunkers the charge components are loaded in sequence into the measuring container, which is usually the bucket of a skip elevator or a loading crane. They are measured out by one of the following methods:

(a) The charge components are transferred from the bunker by a weighing apron conveyor which, when the loading bucket reaches it, is switched on, delivers the necessary quantity of material, and is then switched off. The bucket passes in sequence under bunkers situated on each side of it and is filled with charge components in accordance with the present adjustment of each delivery apparatus, after which it arrives at the cupola furnace for discharge. This process is controlled from a single control panel.

(b) The charge materials are delivered from the bunkers through vibrating feed chutes into a charge bucket mounted on a mechanically-driven weighing carriage with a cabin for the operator. He drives the carriage in turn to each bunker, switches on the chute, and switches it off when the required weight has been delivered. The switching on and off of the chutes can be automated.

(c) The charge components are picked up by a crane and poured into a charge hopper fitted with a weighing device and situated over the loading container. The charge component weights are recorded on perforated tape and automatically compared with the calculated figures. The charge composition is corrected if necessary by addition of material. A computer accurately calculates the weight of each component required in a given charge, and any deviation from the established figures is taken into account in the next batch.

(d) The charge components are transferred from the bunkers through measuring conveyors or vibrating chutes to a central apron conveyor that feeds the cupola furnace. This process can be fully automated.

50. The delivery of the charge into the cupola furnace is governed by the level to which the furnace shaft has to be filled. This is measured by a mechanical and radio isotopic level-measuring apparatus sending signals either to the control panel or directly to the system controlling the measuring of components into the loading container and their transfer to the cupola furnace.

51. The use of electronic computers makes it possible to automate the calculation of the furnace charge, solves the problem of finding the correct proportion of charge materials needed to give the desired chemical composition to the iron to be produced, and enables the best possible charge composition for a given chemical composition of the resultant iron to be achieved at minimum expense. The information fed into the computer for this purpose consists of the chemical composition of the raw materials and of the alloy to be produced, the list of materials necessary for each type of alloy, the amount

of waste, the technological limitations of the various components and the availability of the materials.

52. The methods used for preparing and measuring the charge for the melting of metals in electric furnaces, whether of the arc or the induction type, are basically in no way different from those described above, but attention must be paid to some of their special features.

53. A main requirement that admittedly concerns industrial safety more than quality control is that all materials loaded into electric furnaces must be dry.

54. Electric-arc furnaces are usually charged with a special measuring bucket or box, induction furnaces with special (usually stationary) charging equipment also fitted with a measuring container. The materials are measured out by weight.

55. During the oxidizing period the carbon content is tested from time to time. In the process of de-oxidizing the steel it is essential to keep a careful check on the temperature so as to avoid overheating, and also on the degree of de-oxidation (the specimen must be perfectly solid when broken open and must not contain any gas bubbles). The temperature must also be checked before pouring. If all the melt is not poured off at once - i.e. when the furnace capacity is several times that of the ladle - the chemical composition of the metal must be checked during pouring and, if necessary, corrected by addition.

Checking the melting process

56. Besides measuring out the charge materials to give a required charge composition, and loading them into the furnace at the appropriate time, constant checks must be carried out during the melting process if metal of the desired quality is to be obtained.

57. As stated above, the main type of melting plant used in the foundries of automobile works, and that in which control of the melting process is the most complicated, is the cupola furnace; it will thus be highly valuable to consider at this point the control of the melting process in this type of furnace.

58. The main indicators that must be checked in the cupola furnace process relate to the chemical composition and temperature of the metal, the blast

and the exhaust gas. The checking of the chemical composition of the metal usually consists of an analysis of its C, Si, Mn, P and S. As a rule the period between such analyses is not more than 30 minutes. The chemical composition of the metal is checked by the spectroscopic and chemical methods described above.

59. Various instruments are used for measuring the temperature of the metal. The most widely used ones are optical (luminosity) and radiation pyrometers. They do not, however, give the necessary accuracy or continuity of measurement, and temperature measurements with them are not immune from subjective errors of the operators.

60. A more highly perfected method of measuring temperatures uses thermoelectric pyrometers (thermocouples) made of metals and alloys with high melting-points such as platinum, platinum/rhodium and tungsten/molybdenum. They will measure both periodically and continuously.

61. Channel temperatures are measured continuously with chromatic pyrometers operating on the principle of the spectrum ratio. This is determined by separating two spectrum brilliances with a red and a blue colour filter and establishing the ratio between them. The logarithm of this ratio is directly proportional to the inverse magnitude of the colour temperature and, as is well known, the difference between the colour temperature and the true temperature is not great for (liquid) ferrous metals. When a chromatic pyrometer is used, the optical properties of the metal and of the film covering it are of much less importance than in radiation and luminosity pyrometers.

62. The blast is checked for the following parameters:

(a) The pressure at the tuyère, usually determined by a pressure gauge of membrane type that measures the pressure and automatically regulates it to a given value.

(b) The temperature, which is determined by a thermocouple with a recording device.

(c) The flow, which is determined by a measuring diaphragm fitted with a recording device.

(d) The humidity, which is determined by various instruments that take gas samples and measure their water content.

63. In recent years systems have been developed for the continuous conditioning of the cupola furnace blast, indluding conditioning for humidity. The control in these is automatic.

64. The gases given off by the cupola furnace are checked for composition and temperature. Since an important feature of the combustion of fuel is the CO_2 and CO content of the exhaust gases, these components are measured with gas analysers, either periodically or continuously.

65. Periodic analysis is done with chemical (usually portable) gas analysers on the principle of absorption of the various components of the gas mixture by appropriate chemical reagents. They are accurate within 0.05 per cent, but since an analysis takes 45 minutes, they are generally used for double-checking and laboratory measurement. By contrast, chromatographic analysers will complete an analysis in two to three minutes but are accurate only within one per cent.

66. The regulation of the cupola furnace process according to the composition of the exhaust gases calls for constant determination of their CO content, and more particularly of their CO_2 content as the main index to the melting process. Electrical, magnetic and mechanical gas analysers are used for this purpose.

67. Electric gas analysers operate by comparing the thermal conductivity of furnace gases with that of air or by measuring the amount of heat generated when a mixture of inflammable gases is burnt in them. The volumetric content of the component sought in the sample is determined by measuring the change in the temperature-dependent electrical resistance of wires running through the instrument.

68. Magnetic gas analysers work on the magnetic properties of gases. When the gas is subjected to an unequal magnetic field in these instruments, thermomagnetic convection of the gas flow passing through the instrument (magnetic fanning-out) is set up. The intensity of this phenomenon depends on the amount of the component sought in the gas mixture and is measured by the change in the electrical resistance of a heating element cooled by the gas flow.

69. Mechanical gas analysers operate by comparing the specific gravity of the gas under analysis with that of air at uniform temperature and humidity. Optic-acoustic gas analysers are not very accurate but enable changes in the gas composition to be monitored continuously and can therefore be used to advantage in automatic process control. Gas temperatures are measured with thermocouples.

70. When necessary, the melted metal is tested for gas content. In one of the latest tests of this kind a metal sample is re-melted in a special vacuum resistance furnace with a tubular heater and run off. This speeds the process of extraction of the gases, which are analysed in a gas chromatograph

71. When iron, steel, and other metals are melted in electric-induction and arc furnaces, the main factor tested is the chemical composition of the metal. The main elements whose content is determined in steel are C, Mn and Si. In the casting of special alloy steels, however, or to conform to the technical conditions of the production process or the requirements of the user, analyses may be carried out to determine the contents of other elements. The methods and equipment for checking the chemical composition of steels are the same as for cast iron.

72. An automatic control apparatus for checking and correcting the composition of steel has been developed recently. It consists of a quantum meter, a decision-taking computer that determines the necessary amount of corrective additive and an electronic weighing device It shortens by more than one half the process for obtaining steel of a given composition.

73. When alloys are melted, their physical and mechanical properties, structure and certain technological properties must also be checked Although the data are usually determined and used after the melting and even the casting have been completed, these checks are nevertheless essential; and, if there have been excessive deviations in the quality of the metal, the castings already made can be scrapped

74. When the physical and mechanical properties of alloy melts are checked, tests are usually made of the metal's hardness, tensile strength, and bending and impact resistance According to the technical requirements for the product, the strength, yield point, relative elogation and relative contraction may also be determined at the same time as the tensile strength

75. The hardness of a metal sample or part determine its capacity to resist forces at its surface: it is a feature both of the metal's mechanical properties and of its structure. The testing of castings for hardness is therefore extremely widespread. The hardness recorded depends on the method of measurement. Hardness values obtained by different methods can be compared by reference to tables and empirical formulae.

76. The Brinell hardness figure for a casting is determined by pressing into its surface a hardened steel ball under certain well-defined conditions. The figure is deduced from the ratio of the applied force to the surface area of the spherical indentation. Hard materials are tested by pressing a diamond cone into their surface (the Vickers method).

77. The Rockwell method and instrument for hardness testing are extremely quick and easy to use, but the accuracy of this method is not very high. Its special feature is the double loading: first a light preliminary blow is delivered, then a final blow under heavy loading. The depth of the indentation is measured with a special gauge simultaneously with the impact of the ball or cone.

There are also dynamic methods of determining hardness, such as the resilient recoil method used in the Shore apparatus. This method, however, does not give consistent readings.

78. Tensile strength (elongation), bending and impact strength tests are carried out by well-known machines on special test pieces standardized for mechanical testing. These are usually as-cast and unmachined.

79. In practice the need quite frequently arises for data on the structure of a metal and on other properties such as its flowability, coefficient of linear contraction, tendency to formation of shrink holes and tendency to chilling. Special technological test pieces developed for these tests are usually designed to bring out as clearly as possible the technological property (index) of the metal which it is desired to determine.

80. For example, in order to determine the response of a cast iron to chilling, wide use is made of a stepped, wedge-shaped test piece whose varying section gives several different cooling conditions in a single specimen and makes it possible to determine within the required limits of accuracy the variations in this property.

81. Metallographic analysis is used in determining the macro- and microstructure of metal and alloys.

82. The macrostructure of a metal can be determined on a specially-prepared specimen with the naked eye. It indicates the fineness of the structure of the specimen, the presence of segregation, defects due to shrinkage and segregation, the effect of gas porosity on the specimen, and the presence

of slag inclusions and oxide scabs. The advantage of **macrostructure** examination is that it reveals both the metallurgical and the technological origin of a defect.

83. In order to study the microstructure of a specimen, it must be magnified 30-1500 times under a metallographic microscope. Examination of the microstructure may reveal contamination of the metal with non-metallic inclusions, the grain size, the details of the micro-grain construction, and the number and form of graphite inclusions. Micro-analysis is carried out on specially cut and polished specimens. The structural components are fully analysed by microscopic examination of a polished specimen etched with special chemical reagents. Mechanical and electrolytic equipment is used for the polishing of specimens. The results of macro- and micro-structural analysis are used in compiling quality reports on specimens.

IV. THE PREPARATION AND CHECKING OF MOULD AND CORE MIXTURES

84. If properly conditioned mould and core mixture components have been selected in the correct proportions, the quality of the moulds or cores made from them is decisively influenced by the method of their preparation.

85. One of the primary requirements in the preparation of these mixtures is use of equipment that ensures high-quality mixing of the components. Furthermore, in view of the volumes of the materials to be treated, the preparation of the mixture must be highly automated to achieve a consistent quality and and high productivity.

86. Paddle-type mixers, auger-type mixers, roller mills and high-speed pendulum-type centrifugal roller mixers are used for the preparation of mould and core mixtures in modern foundries. The last two are the most widely used in mass production.

87. In roller mills, mixing is done by the sliding and rolling of rollers in a circular trough. The sand grains are turned and coated with a liquid binder and the mixture is, so to speak, ground down. To speed and improve the process, modern roller mills are made with several rollers mounted on two, three or four axes fastened to a strengthened centre post and arranged at angles of 180°, 120° and 90°. Vanes are fixed between them to guide the mixture from the centre to the periphery of the circular trough.

88. Centrifugal roller mills mix by the rapid rotation of a rotor placed on an axis in the centre of the circular trough and fitted with rollers on vertical axes and with guide vanes. The guide vanes throw the mixture onto the inner walls of the trough, where through friction against the walls and the working surface of the rollers the particles of the mixture are given different speeds of movement and are intensively displaced (rolled over) in relation to each other, thus becoming evenly covered with the binding liquid. This type of mixer gives good mixing and the highest productivity.

89. In order, however, to prepare core and moulding mixes of the required quality, the components of the mixture must be accurately measured out and loaded in a definite sequence. The components can be measured out either by weight or by volume. Volumetric measuring equipment is preferable when using conditioned materials of consistent quality.

90. In modern mass-production foundries, such as those of automobile plants, automatic systems for preparing mixtures are used in which the transport, measuring-out, charging, mixing and dispensing units are all automatic. Checking of the parameters of the mix during its preparation is of particular importance in these circumstances, as it reduces the preparation time.

91. When automatic systems are employed for the preparation of moulding mixtures, the main variables are usually the temperature and humidity of the used (burnt) mixture loaded into the mixers along with the other components. Although it is true that special equipment such as evaporation cooling units has recently come into use to stabilize the properties of the used mixture, nevertheless in the majority of cases the beaten-out used mixture is still loaded straight into the mixing equipment, causing fluctuations in the temperature and humidity of the mixture being prepared.

92. As the humidity of the moulding mixture determines to a considerable extent such very important properties as its strength, density, and gas permeability, the need to check it is clear. It is also clear that regulation of the humidity of the mixture could, if it were possible, keep the properties of the mixture within the desired limits.

93. Automatic humidity regulation would require an instrument giving instant readings only of the moisture content of the mixture. This parameter can be determined by direct, electrical, radioactive, thermal or chemical means. The most common of these procedures is the electrical one, based usually on

the measurement of capacitance. This method utilizes the fact that the dielectric constant of water is considerably (several tens of times) greater than the dielectric constants of the other components of the mixture. The method of checking humidity by measuring the electrical resistance of the mixture is also successfully used. Although the magnitude of the electrical resistance is affected by the contents of other components of the mixture besides water, the influence of these interfering factors can be ruled out when the mixture is of consistent composition.

94. Frequent periodic checking of the mould and core mixtures is necessary in the production of castings. Although the results of the tests are not known until after the mixture has been delivered to the plant, they give guidance in keeping the properties of the mixture within the required limits. The mixture properties determined in such tests are the following: humidity, gas permeability, and compressive strength in the wet state; gas permeability, compressive strength, shearing strength and tensile strength in the dry state; thermal expansion; yield under given load in one second; tensile strength in the hot state; spreading under pressure in the hot state; and surface strength in the dry state.

95. These various parameters are determined, using standard instruments, at intervals varying with the conditions of production, the stability of the technological process, the quality requirements and other factors.

96. Recently, particularly because of the increase in the practice of ramming moulding mixtures with a press, a number of methods and instruments for determining the flowability of moulding mixtures have been developed. They have made it possible to determine the ease with which a mixture can be displaced in the same direction as the force applied to a given volume of the mixture. There is also a large range of non-standardized tests to determine shatter index, mouldability index, and so forth.

97. It is usually mandatory for mould mixtures to be given regular checks for moisture content, gas permeability, and compressive strength in the green state. Core mixtures are tested for humidity, gas permeability, compressive strength in the green and tensile strength in the dry state.

V. THE PREPARATION AND TESTING OF FOUNDRY MOULDS AND CORES

Testing the pattern and casting-box equipment and the core boxes

98. Before newly made patterns and core boxes are used to prepare moulds and cores, they are tested to ensure that their shape and dimensions are correct. These tests are made by marking out with templates and gauges, projecting the contours of patterns or core boxes, and using special measuring instruments, including toolmakers' microscopes. Tests are also made of the accuracy of the location of the pattern on its base and the cleanness of finish of the surfaces of the patterns and core boxes.

99. After this, the new patterns and core boxes that have passed this first stage of testing are used to produce the moulds and cores that are assembled and used for casting. The dimensions of the castings obtained are checked by marking out, placing them in special measuring devices and so forth; the results enable one to decide whether the patterns and core boxes are satisfactory.

100. The other elements of the casting equipment, such as the flasks, pattern bases, pins and bushes are tested, particularly with respect to the quality and accuracy of developed surfaces such as pattern bases and the fit of flasks.

101. As the various elements of the equipment are subject to wear in use, periodic tests of their shape and dimensions must be made. Maximum operating lives are established for patterns, casting boxes and other equipment, after which they are either completely overhauled or scrapped.

102. Increasingly wide used has recently been made of cast iron, including high-strength cast iron containing spheroidal graphite, for the manufacture of patterns and core boxes for the mass production of castings. Equipment made out of this material is several times as strong as that made of aluminium, and consequently it keeps the required dimensions considerably longer.

Mould and core production processes

103. Various methods of producing moulds and cores are used in modern foundries, but the most widespread methods are jolting and pressing, or straight-forward pressing, for the production of moulds, and sand blasting for the production of cores.

104. The processes used for the manufacture of moulds and cores have a significant and sometimes a decisive effect on their quality. To obtain castings of good quality, it is essential to attain consistency and stability in the degree and nature of the ramming of moulds and cores. The density of the moulds is the most objective and physically the most soundly based index of their quality, as it determines their strength, gas permeability, and other physical and mechanical properties.

105. The method that most generally satisfies the requirements for high and consistent density throughout the mould is the combined ramming-jolting process with simultaneous or subsequent pressing with a shaped or multi-plunger pressure head. To obtain not only a good but also a consistent quality of mould, care must be taken in the ramming process to regulate the size of the portion of mixture loaded into the mould, the number and power of the blows of the jolting table, and the amount and nature of the pressure applied. This is best achieved on automatic moulding machines. For the preparation of moulds for castings of moderate height and uncomplicated configuration, the best ramming effect is obtained by a single pressing action. In this case, straight-forward presses are used, and the automation of the process is simplified.

106. The most modern and highly perfected process for preparing cores is to harden them in boxes. Thermoreactive or other bonding resins that harden when heated or even at ordinary temperatures are used for this purpose. Mixtures containing them are loaded and packed into core boxes by sand-blasting machines. After being hardened in the boxes, cores made of these mixtures assume their final dimensions; and, because of their high strength in the hardened state, they do not change these dimensions during transport and assembly.

107. When prepared wet sand cores must be transported for drying, it is essential to protect them from the effect of shocks, jerks, etc. Because of the low strength of the mixture in the wet state, these shocks might lead to "settling" of the cores and consequently to changes in their shape.

Checking the quality of moulds and cores

108. Casting moulds (half moulds) are usually checked after manufacture by visual inspection and by inspection of the denseness (hardness) of their working surfaces. In the visual inspection, attention is paid to the state

of the surface of the mould and the presence of external defects such as crumbling, cracks or damage. The denseness is tested indirectly by measuring the surface hardness of the mould with a special hardness-measuring instrument. These are of several kinds, but the principle of operation is the same for all of them. A spring-loaded ball or cone held a given distance above the working surface of the mould is pressed into the surface. Its hardness is related to the distance to which the ball penetrates. This distance is transmitted through a system of levers to a pointer moving over a scale usually graduated into 100 units of hardness.

109. When it is necessary, for research purposes or when developing technological processes, to determine the denseness at different points in the mould, various sampling devices such as drills or tubes are used, by means of which a set amount of mixture can be removed from a given point in the mould. By careful weighing of the sample it is possible to determine the denseness of the mould at this point. After drying or hardening, the cores are inspected and their shape and dimensions checked on special test equipment.

VI. THE HEAT TREATMENT OF CASTINGS AND ITS CHECKING

110. Iron and steel castings may be subjected to different forms of heat treatment for various purposes.

111. Iron castings may be annealed to remove or reduce stresses, annealed remove or increase hardness by distribution or solution of graphite, hardened and tempered to increase hardness or improve their structural basis, or graphitized.

112. Continuous-operation tunnel furnaces and elevator-type electric furnaces are used for the graphite-annealing of malleable iron castings. In elevator furnaces, which are much used in the automobile industry, annealing can be carried out without a special protective atmosphere.

113. In continuous furnaces, castings are protected from intensive oxidation and decarbonization by being specially packed in sand in heat-resistant boxes, which are then coated with clay. In more modern continuous furnaces, annealing is carried out in a special protective atmosphere, and heat is supplied by gas-heated radiating tubes.

114. Since at the high temperatures necessary for graphite-annealing, castings often lose their shape and dimensions, these are corrected in presses with special dies

115. The quality of annealed castings is checked by examining their macrostructure, their mechanical properties, and their microstructure For examination of macrostructure, castings are provided with lugs, which are knocked off after annealing so that a visual analysis can be made at the point of breakage In order to determine their mechanical properties, specimens are cast and annealed before a test.

116. Heat treatment is one of the essential operations in the production of profiled steel castings. The most widely used forms of heat treatment of steel castings are annealing and normalizing. The object of annealing is to effect recrystallization, reduce the grain size, improve the mechanical properties and remove residual stresses. Normalizing serves the same purposes when the required effect cannot be obtained by annealing. When it is necessary to achieve particularly good mechanical properties, heat treatment consisting of hardening and tempering is used.

117. Alloy steels are given special heat treatment depending on their composition. The quality of heat-treated steel castings is checked by mechanical tests and metallographic analysis.

118. In the heat-treatment plant, the variables tested are the temperature in the various zones of the working area and the composition of the gas medium with which they are filled In modern heat treatment plants, the temperature is controlled by thermo-couples connected to a continuously operating automatic apparatus, that not only fixes but also regulates the temperature within given limits

119. The requisite atmosphere is created in the working area of the equipment by supplying a gas mixture of the requisite composition in the necessary quantities To avoid deviation of the composition of the furnace atmosphere outside the limits dictated by the technological process, the atmosphere is continuously tested, particularly by "dew-point" tests; when a change occurs in the composition of the atmosphere, the control apparatus actuates the mechanism regulating the supply of the gas mixture The composition of hardening media is also periodically tested.

120. When the heat treatment of castings is carried out in stages involving different temperatures, lengths of time and speeds of heating or cooling, these parameters must be checked and regulated with particular care. This also applies to the checking of the heat treatment of castings produced by different methods.

VII QUALITY CONTROL OF FINISHED CASTINGS

121. The quality of finished castings can be checked either by examining each casting or by spot testing. The properties and qualities tested depend on the purpose to which the castings are to be put and the corresponding technical conditions; but the basic tests are for chemical composition, hardness and structure, soundness (including testing for surface cracks), air-tightness, geometrical dimensions, and cleanness of surface. In certain cases, when necessary, specimens are cut off from the body of a casting, or from special lugs cast on it, for mechanical testing.

122. The simplest and most usual method of checking castings for surface defects, deviations in geometry (deformation) and cleanness of the surface is by visual inspection. However, it is not usually possible by such inspection to verify that the quality of the casting satisfies all the test requirements. It is therefore necessary to resort to the testing methods and instruments whose functions and principles are described below. Methods of determining the chemical composition, hardness and structure of components have been described above.

123. Increasingly wide use has recently been made of non-destructive methods of testing the hardness and structure of castings by magnetic analysis. This technique is based on the dependence of the magnetic properties of metals and alloys upon their chemical composition and structure, and may be carried out in a fraction of a second. The magnetic analyser has magnetizing coils supplied with alternating current of adjustable strength, and measuring coils connected up to detect the induced voltage. A standard specimen with the required structure is placed in one coil and the test piece in the other. The electrical equilibrium of the system then depends upon the correspondence of the structure of the test casting with that of the structure of the standard specimen.

124. In certain cases such equipment is fitted with a cathode-ray tube by means of which the power generated in the second coil can be displayed in the

form of a sinusoidal curve, from the dimensions of which the hardness can be determined.

125. By using equipment operating on the above principle for the magnetic analysis of the structure of castings, it is possible to test every casting made from ferrite and perlite malleable iron high-strength ferrite iron. (Castings containing 1 to 2 per cent cementite, 10 per cent or more perlite or 10 per cent or more of metal containing flake graphite are scrapped).

126 Piston rings are tested on magnetic-impulse structure-testing instruments.

127. Because of the ever-increasing demand for greater reliability of castings, particular attention is given to testing for internal defects, i.e. testing of soundness. Such inspection can be carried out by visual or microscopic examination of a casting after it has been cut open for this purpose, but this procedure is time-consuming and can be used only for spot checks. In modern foundry practice - particularly when every casting must be tested - this method has been replaced by X-ray, ultrasonic, magnetic or fluorescent testing. All these are non-destructive methods and can be used if necessary to test an entire batch of castings. They give fully reliable results and supply data on the site, nature, and dimensions of internal defects.

128. Radium, thorium, and mesothorium are used as radioactive sources in this type of testing. Radium salts are placed in a silver capsule, which is then placed in an aluminium shell; mesothorium salts are placed in a glass capsule, which is placed in turn in a brass tube. The casting is placed between the radioactive source and a photographic film in such a way that an image is projected onto the film

129. Ultrasonic testing can reveal internal defects more than one metre from the surface of a casting, so that theoretically it can be used for castings of all thicknesses and dimensions. It is based essentially on the behaviour in the testpiece of ultrasonic vibrations set up by a piezoquartz disc. These vibrations are transmitted to the test piece through a medium such as water, oil, or vaseline. If there are any defects (heterogeneous points), the ultrasonic vibrations are reflected at the interface of the two different media. The reflected impulses act on a receiving quartz disc, setting up in it electrical signals, which are amplified and fed to a cathode-ray oscillograph on the screen of which they form peaks. The instruments used in

ultrasonic testing (ultrasonic microscopes, ultrasonic impulse testers) are thus based on penetration by ultrasonic waves and their reflection.

130. The magnetic method will detect cracks of any size. Magnetic powder is scattered on a magnetized casting and indicates all defects, because its particles are drawn in by the non-homogeneous magnetic field set up in the area of the defect. The method detects surface cracks in castings and also internal defects situated down to 10 mm below the surface.

131. The fluorescent method detects surface cracks and defects on castings of non-magnetic alloys such as austenitic cast iron. A fluorescent liquid is applied to the surface of the test piece and then washed off. The liquid that remains at points where there are cracks or defects reveals them by glowing when the surface of the casting is illuminated with ultra-violet rays.

132. Because of the relatively high cost of the equipment, these methods of non-destructive testing are mostly used for perfecting technological processes, for periodic (or spot) testing of castings, or for testing a whole batch of particularly important castings.

133. Hermeticity of castings is usually tested hydraulically. This type of test is made on castings that are to work under pressure, such as pump bodies, hydraulic amplifiers, and engine water jackets.

134. There are two main types of hydraulic tests. In one of them, all openings in the casting are sealed, and it is filled with water under pressure. In the other, the casting is sealed and submerged in water, and compressed air is pumped into it. Visual indication of any lack of air-tightness in the body of the casting is given by water leaks in the first type of test and streams of bubbles in the second.

135. The dimensions of castings are tested by laying out and using ordinary fitters' instruments on a layout block, or with test instruments of various designs, usually constructed specially for each particular type of casting. A method worthy of attention is that in which transparent templates with the outlines of a specific cross-section of the casting marked on them are placed on the same section cut through the body of the casting. By this method the geometry of complicated castings, such as engine cylinder blocks, and particularly of their internal cavities, can be tested extremely quickly and with sufficient accuracy.

136. Dimensions are usually tested only periodically (i.e. spot-checked). Only in special cases, where there are extremely strict requirements for the accuracy of the geometrical dimensions of castings, is a whole batch of castings tested in this way. Naturally, when all castings are to be tested the last of the methods described above, being a destructive method, is not feasible.

VIII. ACCURACY OF CASTINGS AND METHODS OF ACHIEVING IT

137. The accuracy of castings results from a large number of constants and variables in the technological process of producing them. It is influenced by the dimensional accuracy with which the patterns have been made, the accuracy of their mounting on the pattern base, the accuracy with which the pattern is mounted relative to the pins, the accuracy with which the pins and the apertures in the flask sockets have been machined, the accuracy of the matching pins, the accuracy and design of the working surface of the mould and core, the strength of their assembly, the deformation of the mould and core by static, dynamic and thermal effects of the molten metal, shrinkage of the metal, and a number of other factors. Most of these influence each other, and the calculation of their resulting interaction is therefore very complicated.

138. Dimensional calculations of castings are based on calculations of the dimensional element systems of the casting mould, the components of which include dimensions and their deviations determined by factors in the casting process itself. By these calculations it is possible to determine the probable accuracy of a casting in the light of the various deviations due to the elements of the technological process and to solve the converse problem of distributing permissible inaccuracies over the various technological stages or elements, for given tolerances in the dimensions of the casting and for a given method of assembly of the casting moulds.

139. Dimensional calculations can be made only if the majority of the basic technological factors causing deviations are investigated and their role in the mechanisms governing changes in the rated dimensions of the casting or other determining parameters is established experimentally. This can be done by experimental and statistical investigation of the limits of variation of the basic technological factors and their influence on the dimensional deviations of the elements of the casting mould and the casting.

140. A wide range of material on the nature and magnitude of the effect of various factors in changing the dimensions of castings has already been accumulated in foundry technology. From this material and the experience of individual factories it is possible, with a well-defined degree of possible error, to set out dimensional and technological parameters of the casting process that enable the accuracy of casting to be brought within the required limits. Problems of checking and stabilizing the various parameters in casting operations are discussed in preceding sections of this paper.

IX. THE STATISTICAL QUALITY CONTROL OF CASTINGS

141. One of the most radical methods of achieving a high quality of foundry production is statistical quality control and regulation. Its main object is to reduce scrapping. According to available data, even the largest additional expenditures on statistical quality control are offset many times over by saving on scrapped castings.

142. Statistical quality control is carried out by three methods: rapid acquisition of information on the occurrence of scrapping or the causes for it, approaches to the operator to induce him to carry out his duties more efficiently, and analysis of the reasons for scrapping.

143. The simplest and most effective of these three methods of regulating quality is the first. Checking must be carried out at all stages of the production process because of the great variety of ways of reporting the reasons for scrapping, and of the length of time they take. A given parameter must be checked as soon as the operation in the production process that determines it is completed. Then the data must be promptly transferred to a control card, and the responsible person must be notified so that he can remove the reason for the scrapping.

144. When this method is used to control the production of castings, statistical data processing does not play a very great role, as the main factors are the organization of the checking and notification. Nevertheless, prompt and systematic completion of the control card and preparation of reports on the scrapping are of great importance, as in a great many cases they are an indispensable factor in the early uncovering of a new cause of scrapping and the determination and removal of both substantive and fortuitous changes in the level of quality.

145. The method of "operator stimulation" consists of the checking of individual workers. Its object is to eliminate evasion of responsibility and determine the person actually responsible for the scrapping. By the statistical method a worker's execution of an operation can be evaluated in the light, not of separate and often quite transitory and accidental rule-breaking and inaccurate work, but of all the material indicating his quality and skill. The conclusions thus reached are objective and beyond dispute for worker and management alike.

146. Statistical analysis of the causes of scrapping can detect unsuspected technological reasons for scrapping and separate the systematic from the fortuitous reasons. When necessary, statistical analysis is applied not to the finished product but to a particular parameter of the technological process. Appropriate control cards are completed and processed for this purpose.

147. Thus all the three foregoing methods of statistical regulation of casting quality can reveal the causes of scrapping and enable organizational and technical measures for their abolition to be devised. The most important tool in this statistical quality regulation is the control card.

X. CONCLUSIONS AND RECOMMENDATIONS

148. On the basis of this study the following conclusions may be stated:

(a) High casting quality is attained primarily by developing the most suitable technological process and selecting appropriate modern equipment and materials for carrying it out.

(b) To ensure the requisite quality of automobile castings, it is essential to carry out tests not only - and indeed not so much - on the finished casting as on the materials and the operations of the production process.

(c) It is extremely important to establish the permissible limits for fluctuations of the casting process at all stages, and also to take the necessary measures to give the casting process the requisite stability.

(d) All principal and auxiliary operations and materials must be continuously checked.

(e) Frequency of testing is determined by the actual production conditions, the stability of quality of the materials, the reliability of the equipment used in a given casting operation, and also by the quality requirements the product must satisfy.

(f) When selecting methods and equipment for testing casting materials and operations, the chief requirement is their capacity to guarantee a given frequency, accuracy, and speed of test operations. Economic considerations must also be borne in mind.

(g) One of the most effective means of attaining high quality in the mass production of castings is statistical quality control and regulation based on rapid transmission of information about scrapping, on worker stimulation, and on analysis of the causes of scrapping.

(h) In the planning and establishment of modern plants for the production of automobile castings it is advantageous to work out systems for full or partial automation of the processes of quality control, including checking of the operation of the equipment and the presence of materials, with operative transmission and assembly of the information at a central control point.

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