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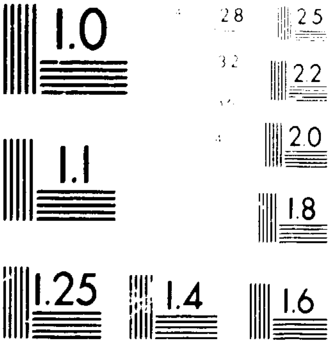

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

FINNAL REPORT

of

THE CONTRACT NO. 82/101

14299

between

THE UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

(UNIDO)

and

THE WELDING RESEARCH INSTITUTE OF OSAKA UNIVERSITY

(JWRI)

for the

provision of technical services through UNIDO

to

THE WELDING RESEARCH INSTITUTE

in

INDIA

UNIDO Project NO. DP/IND/79/026

Activity Code: DP/02/31.8

December 20th, 1984

Prepared by

Prof. Dr. Yoshiaki ARATA

The Welding Research Institute

Osaka University

CONTENTS

1. INTRODUCTION

1. General Aspect of the Project

The aims of the Project and of the Contract are to provide assistance to the Government of India in the field of the research consultancy and training, and in particular;

- -to carry out some fundamental research which might arise during the course of applied research,
- -to concern with applied research in welding technology and
- -to render assistance to scientific and technical teaching institutions in conducting post-graduate programmes in welding engineering.

The Project is consisted by Project Area Services, Home Office Services and Home Office Support Services.
The Project Area Services are twelve man-months -- one and half man-months for eight exparts each -- consultrancy at Welding Research Institute, in Tiruchirapalli, India. Exparts are sent in three groups.
The Home Office Services are Twenty-seven man-months -- three man-months for nine trainees each -- training at Welding Research institute of Osaka University. Trainees are received in two groups.

Training for the first group of four fellows were commenced from May 18, and finished on August 17, 1983.
Second group of five fellows started the training from September 11, and completed on December 10, 1983.
The principal concept of training were to give the trainees deep knowledges of specialized welding field through conducting very fundamental researchers, and also to give them the wider and actural

informations by visiting many leading companies and laboratories in Japan.

The first group of three exparts commenced their consultancy services on September 6, and expired their duty on October 20, 1983.

Consultancy services by second experts group of three members were started from January 7, and terminated on February 21, 1984.

The service by third consultants group was commenced on September 26 and was completed on November 7, 1984.

The aims of the consultancy are rather same as that of training at JWRI, namely to give basic philosophy of fundamental research and actual informations from Japanese industries through giving lectures and discussion.

Consultants made several industrial visit in India and prepared the Final Report including the recommendation to the Grovernment of further action to be taken.

1.2 Progress of the Project

<u>Pre-entry to the Contract</u>

The abridged history untill the complement of Contract was as follows;

Sep. 13th, 1982	Request for proposal by UNIDO
Dec. 7th, 1982	Proposal to the Project by JWRI
Dec. 30th, 1982	Telex of Contract Award from UNIDO

Jan. 5ht, 1983	Telex confirming acceptance and Entry into Effect of the Contract
Jan. 25th & 26th, 1983	Briefing at UNIDO, Vienna
Feb. 18th, 1983	Signed the Contract by Mr. D. Gardellin for UNIDO
Apr. 28th, 1983	Signed the Contract by Prof. Dr. Y. Arata for JWRI

Training of WRI Members at JWRI, Osaka University

Training of WRI Members were conducted in two different groups at JWRI, Osaka University.

Training for the first group of four fellows were commenced from May 18, and finished on August 17, 1983.
The areas of training specified in the original contract were

* Solid phase welding process
* Electron microscopy
* Weld thermal cycle simulator and weldability testing
* Residual Stress measurement
* Welding design, distortion and fracture mechnics

However, the trainees who reached JWRI were placed by WRI in the areas of followings without prior notice on area amendment.

* Solid phase welding process (K Sampath)
* Residual stress measurement (T K Mitra)

* Welding design, distortion and fracture mechanics (H Dattarajan)
* Laser welding (C Karthikeyan)

"Electron mictoscopy" and "Weld thermal cycle simulator and weldability tes.in" were cancelled, sice training on these two areas (Mr S Manoharan and Mr B Natarajan) was already executed from Decemberm 25, 1982 to March, 24, 1983, as a separate project prior to the "Entry into the effect of Contract", while "Laser welding" was shifted from 2nd training group.

Second group of five fellows started the training from September 11, and completed on December 10, 1983.

Original areas of 2nd training group specified in the Contract were;

* Laser welding
* Welding consumables and flux shielded process
* MIG/MAG welding and arc physics
* Controls, instrumentation and computer application in welding

Taking account of the telex from the Head of WRI, India, dated August 3, 1983, the contractor modified the training subjects as follows:

* Plasma sprayihg (Ashok Seshadri)
* Solid phase welding processes (Ramesh Sharma)
* MIG/MAG welding (A Raja)
* Welding consumables (C P Ravichandran)
* TIG welding process (T Radhakrishnn Nair)

"Laser welding" was already shfted to 1st group and "Controls, instrumentation and computer application in welding" was cncelled by the circumstances of WRI, India. Instead, "Plasma spraying", "Solid phase welding process" and "TIG welding process" were added to the programme.

Consulting Sevices at Project Area

Consulting Services at the Project area were consulting services on September, 6, and expired their duty on October, 20, 1983.

The experts and areas are as original, namely

* Prof. Dr. K. Horikawa	on Welding disign
* Mr. T. Matsuyama	on Plasma welding and spraying
* Mr. S. Ohkita	on Micro-structures and cracking of weld metal

Consulting services by second experts group of three members started from January 7, and it continued to February 21, 1984.

Experts and areas specified in the Contract were

* Dr. Nagai	on Electron beam welding
* Prof. Dr. N. Iwamoto	on X-ray diffractometry and slug structure

As per the health condition of Prof. Iwamoto, his mission was reserved, and, instead, Prof. Matsunawa and Mr. Hiramoto were shifted from 3rd consultant group and sent to Project Area with Dr. Nagai (The Contractor advised this replacement to UNIDO, Vienna by the telex dated December 19, 1983, and no objection from UNIDO). After they reached to the Project Area, Prof. Matsunawa and Dr.Nagai could not but change their areas as follows:

* Prof.Dr.A.Matsunawa	on Laser welding and arc physics
* Dr.H.Nagai	on Electron beam welding and pressure welding
* Mr.S.Hiramoto	on MIG/MAG welding

The modification was due to the facts that another consultant on Laser welding was placed from UK in the same period and also the Laser and Electron Beam machines in WRI were neither commissioned nor usable.

As to the balance of sending two more experts, the original plan was to be executed in March/April in the fields of;

* X-ray diffractometry and slag structure by Prof.Dr.N.Iwamoto
* Controls and instrumentation by Mr.H.Akashi

However, due to the climate condition at porject area and also to the health condition of Prof.Iwamoto as well as to Mr.Akashi's company's situation, the contractor proposed to UNIDO Head Quarter the substitution of consultants and the execution time. The proposal was accepted by UNIDO through telegram dated September 17th 1984 and the final two consultants were sent to the project area on September, 26 in the specified fields of

* Automatic welding process and welding physics by Prof.Dr.A.Matsunawa
* Finite element method by Prof.Dr.K.Horikawa

Two consultants who were placed as the second time missions in the same project completed their duties on November, 7, 1984.
All the consultants made industrial visits during their stay to BHEL High Pressure Boiler Plant in Tiruchirapalli and other public and private sectors in Madras, Bangalore, Cochin, and Pune, which gave them important informations to conduct missions in WRI, Tiruchi.

Final formation of the Project Team

Due to the above described amendments from the original contract, the final formation of the Project Team was as follows:

Prof.Dr.Y.Arata (Director General)	Team Leader
Mr.K.Soda (Secretary General, JWRI)	Secretary General (relating to administrative matters)
Prof.Dr.K.Horikawa	Technical Secretary Co-team Leader, 1st and 3rd Consulting Group. Consultant in "Welding design" and "Finite element method". Training staff for welding design, distortion and fracture mechanics

Prof.Dr.A.Matsunawa	Technical Secretary Co-team Leader, 2nd and 3rd Consulting Group. Consultant in "Laser welding and arc physics" and "Automatic welding and welding physics" Training staff for TIG welding process.
Mr.T.Matsuyama	Consultant in "Plasma welding and spraying"
Mr.S.Ohkita	Consultant in "Microstructure and cracking of weld metal"
Dr.H.Nagai	Consultant in "Electron beam welding and pressure welding"
Mr.S.Hiramoto	Consultant in "MIG/MAG welding"
Prof.Dr.I.Okamoto and Prof.Dr.M.Naka	Training staff for "Solid phase welding process (I)"
Prof.Dr.Y.Ueda	Training staff for "Residual stress measurement"
Prof.Dr.S.Miyake	Training staff for "Laser welding"
Prof.Dr.K.Inoue and Prof.Dr.A. Ohmori	Training staff for "Plasma spraying"
Prof.Dr.T.Enjo and Prof.Dr.S. Kikuchi	Training staff for "Solid phase welding process (II)"
Prof.Kr.F.Matsuda and Prof.Kr.M. Ushio	Training staff for "MIG/MAG welding"
Prof.Dr.N.Iwamoto	Training staff for "welding consumables"

Reporting to UNIDO

Each end of consulting service, Co-team Leaders visited UNDP Office in Delhi and made informal de-briefing meetings.

The written reporting was done to UNIDO Head Quarter, UNDP Office in New Delhi as well as the Government of India in the following sequences.

Progress Report despatched	August, 10, 1983
Interim Reoprt despatched	January, 17, 1984
Draft Final Report despatched	November, 10, 1984
De-briefing Meeting at UNIDO, Head Quarter in Vienna	November, 19 to 21, 1984
Final Report despatched	December, 20, 1984

2. Training at JWRI

2.1. Description of training

The names of trainee, their fields of study and supervisors were listed as below.

1) Hariharan DATTARAJAN

Project Number: DP/IND/79/026/31-03

Field of Study: Welding Design, Distortion and Fracture Mechanics

i) Measurement of residual stress in the welded plate

ii) Threshhold stress intensity factor range of fatigue for HT 80 high strength steel

iii) Fractographic analysis of fatigue fractured specimen

Training Period: May 18, 1983 - August 17, 1983

Supervisors: Prof. Dr. Kohsuke HORIKAWA

Mr. Hiroyuki SUZUKI

2) Tapan Kumar MITRA

Project Number: DP/IND/79/026/31-04

Field of Study: Residual Stress Measurement

i) Theoretical and experimental aspects of residual stress measurements using resistance strain gauges and sectioning technique

ii) Theoretical and experimental aspects of three dimensional residual stress measurement in thick welded plate

Training Period: May 18, 1983 - August 17, 1983

Supervisors: Prof. Dr. Yukio UEDA

Dr. Hidekazu MURAKAWA

3) Krishnaswamy SAMPATH

Project Number: DP/IND/79/026/31-05

Field of Study: Solid Phase Welding Process ---Brazing and Soldering---

i) High temperature brazing of ceramics to metals

ii) Fluxless vacuum brazing of aluminum

iii) Evaluation studies for brazing and soldering fillers

Training Period: May 18, 1983 - August 17, 1983

Supervisors: Prof. Dr. Ikuo OKAMOTO

Prof. Dr. Masaaki NAKA

Dr. Tadashi TAKEMOTO

4) Chinnathambi KARTHIKEYAN

Project Number: DP/IND/79/026/31-12

Field of Study: Laser Welding

i) Dynamic observation of beam-hole during laser welding

ii) Special and temporal intensity distribution of high power (15kW) CO_2 laser beam

iii) Delta ferrite content in weld metal of stainless steel by pulsed YAG laser

Training period: May 18, 1983 - August 17, 1983

Supervisors: Prof. Dr. Yoshiaki ARATA

Prof. Dr. Shyoji MIYAKE

Dr. Nobuyuki ABE

2.2. Lectures and Technical Discussions

Intensive lectures and technical discussions were delivered to each trainee in various fields. Main titles of lectures and discussions are;

Lectures:

1) Prof. HORIKAWA: "Application of fracture mechanics to the design of bridges" (To Dattarajan and Mitra)
2) Dr. MURAKAWA: "Fundamentals of finite element analysis of welding residual stresses" (To Dattarajan and Mitra)
3) Dr. NAKAGAWA: "Metalographic interpretation of fracture modes" (To Dattarajan and Mitra)
4) Dr. JUPTNER (Visiting Researcher at JWRI from Bremen Institute of Electron and Laser Beam Technologies, FRD): "Optimization of laser beam welding parameters by theoretical calculation of temperature distribution and vapour channels" (To Karthikeyan)

Discussions:

1) Prof. UEDA and Dr. MURAKAWA: "Stress Measurement, stress relaxation by sectioning and cutting, and stress relief by mechanical methods (with Dattarajan and Mitra)
2) Mr. SUZUKI: "Application of FEM on K-calculation"(with Dattarajan and Mitra)

3) Mr. OHKURA (Visiting Researcher at JWRI from Faculty of Engineering, Osaka Univ.): "Imperfection and Buckling Strength of Thin-walled Welded Structures " (with Dattarajan)

4) Mr. HAYASHI (Visiting Researcher at JWRI from Nagaoka Univ. of Technology): "Fracture Toughness assessment by J-integral" (with Dattarajan)

5) Prof. OKAMOTO: "Meausurement of wetting in soldering" (with Sampath)

6) Prof. NAKA: "Joining method of ceramics to metals: (with Sampath)

7) Dr. TAKEMOTO: "Vacuum brazing of aluminium" (with Sampath)

8) Prof. ARATA: "Evaluation of beam characteristics of electron and laser beams" (with Karthikeyan)

9) Dr. MIYAMOTO" "Measurement of beam-material interaction during laser processing" (with Karthikeyan)

10) Prof. MATSUNAWA: "Measurement of beam-material interaction during laser processing" (with Karthikeyan)

11) Dr. KATAYAMA: "Microstructures of austenetic stainless steel in laser and arc welding processes and their hot cracking susceptibility" (with Karthikeyan)

Each trainee enjoyed the daily free discussions with faculties and graduate students during his own research trainings, and also with many specialists during his technical visits.

2.3 Welding design, distortion and fracture mechanics

Under the supervision of Prof. Dr. K. Horikawa and Mr. H. Suzuki, Mr. Hariharan Dattarajan was engaged in the following subjects.

1) Measurment of Welding Residual Stresses.

2) Fatigue Crack Growth

1) Measurement of welding Residual Stresses:

Specimen : 500 x 105 x 6 mm Bead on plate

Material : H.T. 80

Welding Process: Submerged Arc Welding

The Specimen was ground and bead weld was laid on it using SAW process. After welding the plate was marked and the strain gauges were fixed on both sides of the plate.

Procedure for strain gauge fixing:

i) Polishing the surface with emerry sheets (with different grades)

ii) Marking for the strain gauge location

iii) Againg Polishing at 45° diagonally to the marked lines

iv) Applying acetone and clean the surface

v) Fixing the strain gauges by proper cement

After fixing the strain gauges moisture-proof material was applied and dried. Totally 22 gauges were fixed, 11 on the weld bead side and 11 on the other side of the plate. The strain gauges were connected to the strain meter and initial strains were recorded. The specimen was cut on the lines marked by hand-saw without heating. After subtracting the initial value from the final value, the residual stress at that location was noted.

2) Fatigue crack growth studies:-

Practical limitations in fabrication, inspection of many structural components prohibit complete elimination of flaws. It is therefore necessary to find out whether cracks eminate and grow from these flaws and also the rate of crack growth. To analyse the possibility of crack growth under the fatigue loaded condition, threshold stress intensity factor range (K_{th}) concept (below which fatigue crack growth will not occur) is useful in many structures. Near threshold fatigue crack growth rates (FCG) are very much important to designers since at the early stages of crack growth suitable remedial action can be taken. The knowledge of K_{th} and very slow propagaion rates are also important for the study of stress interaction effects, particularly those where FCG retardation occurs after an overload in a spectrum loading sequence. In Fracture Mechanics analysis of crack growth, it is utmost important for a material to characterise its FCG rate relationship with K (da/dn vs K). In most of the cases the value of K_{th} is extrapolated from the available data. It is practically difficult to define K_{th} since it depends upon the measurement sensitivity, length of observation and technique employed. (ASTM-STP-738).

Low FCG rate data can be established by a loading programme which results in either increasing or decreasing K as the test progresses when load amplitude is constant, K- values increase with crack extension in most specimen geometries. The constant-load amplitude, K-increasing technique is a satisfactory method for da/dn 10^{-8}m/cycle. This method requires a pre-crack that has been growing at or below the test load. When near-threshold rates are sought, such pre-cracking becomes very time consuming and practically impossible.

To expedite pre-cracking, loads are often shed in decrements as large as possible until the targeted da/dn or K value is approached. The load amplitude is then maintained constant, and da/dn data acquired as K increases with crack extension. Use of this technique requires considerable test experience with the material of interest so that crack arrest and transient effects are avoided.

The use of K-decreasing approach allows the pre-cracking step to be accomplished more efficiently. Crack propagation data can then be obtained as load, and K gradually decreases according to a predetermined schedule. This method is more attractive since valid FCG rate information can be established while working down to the targeted Da/Dn. More over the K-decreasing process may be halted at any crack length, the load range fixed and the test resumed as a K-increasing test in accordane with ASTM E 647. Conducting a K-decreasing test followed by a K-increasing test with a single experiment provides an excellent tool for assessing repeatability and/or sorting out transient FCG processes which might confound interpretation of the test results. A K-decreasing test is somewhat more complex than the K-increasing test, but the advantages of the K-decreasing approach seem to far outweigh the added complexity.

The material selected for the experiment is HT 80.

The results of the experiments are summarized below:

		K_{th} - $Kg/mm^{1.5}$
1	Base material with R= 0.7	13.0
2	Base material with R= 0	26.0
3	Stress relieved with R= -1	24.0

From the above it can be concluded that the stress ratio considerably affects the fatigue crack arrest threshold K value very much

2.4. Residual stress measurement

Mr. Tapan Kumar Mitra was supervised by Prof. Y. Ueda and Dr. H. Murakawa in the field given below.

1) Theoretical and experimental aspects of Two Dimensional residual stress measurement in weldments using resistance strain gages and sectioning technique.
2) Theoretical and experimental aspects of Three Dimensional residual stress measurement in thick welded plates.

1) Two dimentional residual stress measurement

Two experiments had been conducted.Residual stress measurement in a HT 80 steel plate of dimension 500x100x6 mm having a bead on plate weld (SAW). Two direction strain gages (for x and y) and sectioning technique were employed. KYOWA UCAM-8B equipment was used. Sectioning was done using a band saw machine. Aspects emphasized were fixing of strain gages and making of soldered balls at the outer tip of S.G. Lead wire. These soldered balls were gripped by crocodile tip clips for better electrical contacts while measuring strains. Strain gages were fixed on both the top and bottom surfaces and averages of readings were taken for computation.

The second experiment was also conducted on HT 80 plate of 500x100x6 mm size. The aim of this experiment was--

i) to observe the variation of stress along the length of the weld viz. at the starting end, mid section, and at the finish end of the weld,

ii) to measure the principal stresses and shear stresses at the starting end and finishing end of the weld.

A small groove was made and single pass SAW was deposited. The S.G.s fixed were all three direction gages to measure x, y and xy. S.G.s were fixed on both top and bottom faces and average of readings for the corresponding top and bottom face gages were taken. After making initial measurements, sections AA & BB were cut at the starting and finishing ends of the weld. Change of strains by these cuttings were measured. Stress relaxation was observed only at the end sections. There was no effect on the mid-section gage series. Complete sectioning was done subsequently. Area of about 10x10 mm containing one gage was separated by sectioning using band saw and x, y and xy were measured. Stress values were computed from initial readings and readings after end cuttings for all the S.G. locations.

Computer programming was made for stress calculation. Near the weld starting point and mid section the weld was found to have the maximum stress while near the weld finishing end the HAZ was found to have higher stress than the weld.

2) The Measurement of Three Dimensional Residual Stress

The method of measurement of three dimensional residual stress established by JWRI is based on the concept of inherent strain and involves FEM analysis.

Several discussion sessions were held with Dr. Murakawa, Dr. Kim and Prof. Dr. Ueda of the group with which he was associated regarding the general theory of FEM stress analysis and general review of numerical methods for solving partial differential equations as well as for the three dimensional stress measurement technique. The experiment had been under progress on an electron beam welded thick plate and involves the use of nearly 200 strain gages (incl. 3D, 2D and 1D gages) and a careful cutting of tranverse and longitudinal sections.

2.5. Solid phase welding process---Brazing and soldering---

Mr. Krishnaswamy Sampath conducted experiments in the following subject under the supervision of Prof. I Okamoto, Prof. M. Naka and Dr. T. Takemoto.

1) High temperature brazing of ceramics to metals

2) Inert-gas brazing and vacuum brazing of aluminum

3) Evaluation studies on brazing and soldering fillers

1) High Temperature brazing of ceramics to metals.

Alumina ceramics was joined to Kovar alloy, using amorphous copper-titanium filler. Three different brazing conditions were used for the study to evaluate the shear strength of the brazing joint. A maximum shear stress of 19 kg/mm^2 was attained at 1150°C, 30 minutes brazing time and 10^{-5} torr vacuum level, the temperature dependence of the joint strength was also evaluated up to 700°C. Besides the effect of thermal shock on joint strength was also measured. SEM analysis of the joint interface and fracture surface of the shear test specimens were also carried out.

2) Inert-gas brazing and vacuum brazing of aluminum.

Inert-gas brazing and vacuum brazing of aluminum tubes with square end caps made of alclad material, was carried out to study the brazability and fillet size of brazed joints and their relation to the presence or absence of a central hole on the square end caps. As many as 60 assemblies were brazed in three different brazing conditions viz. vacuum at 10^{-5} torr, carrier-gas at 10^{-1} torr, and dry nitrogen at atmospheric pressure. The trials indicated that the brazability improves at 10^{-5} torr, and when there was no hole in the square end caps. Holes when present in the end caps, reduced the size of the fillet. The tendency deteriorated when the hole size increased.

3) Evaluation studies on brazing and soldering fillers.

A study was carried out to measure the wetting force of a lead-tin solder alloy and its effect on the surface condition of the copper specimen. The study indicated that the wetting force decreased with decrease in cleanliness of the specimen and the wetting time increased with a decrease in cleanliness. However it could be reduced by suitably selecting and active flux.

A spread area test was carried out to study the influence of time and temperature on B-CuP-2 type brazing filler. The study indicated that the spread area depends on the amount of liquid filler available to spread. The availability of the liquid filler generally increases with time and temperature but may be limited due to metallurgical reactions with the base material forming precipitates or solid solutions by isothermal solidification. The rate of heating also influenced wetting or distortion and introduced geometrical constraint to the flow of liquid filler.

A filler test was also used to assess the ability of a filler to form fillets in T joints. The fillet area and the depth of penetration of the filler were used as scales to differential between two or more fillers that can be used for a given application.

2.6. Laser welding

Mr. Chinnathambi Karthikeyan was engaged in the following three subjects.

1) Dynamic observation of beam hole during laser beam welding
2) The beam intensity of laser beam with respect to time and space
3) Delta-ferrite content in laser welding of stainless steel in pulsing mode with Nd-YAG laser

Subjects 1) and 2) were mainly supervised by Prof. Y. Arata, Prof. S. Miyake and Dr. N. Abe, while subject 3) was assisted by Prof. A. Matsunawa and Dr. S. Katayama,

1) Dynamic Observation of beam hole during Laser Beam Welding

The dynamic behaviour of beam hole in steel material during Laser beam welding with 15kW machine was studied using high speed camera in various welding modes and different gas pressures and the results are given below:

i) In continuous welding (CW) mode, when there is no assist gas, the beam hole is very unstable and shallow. With gas flow rate of 36 lit/min, narrow and deep wedge type beam hole is formed. With the further increase in gas flow rate, only the top width of beam hole increase with the reduction in penetration.

ii) In pulse mode, the beam hole is narrow and deep, the shape and the depth of beam hole finds no considerable change with increase in gas flow rate.

iii) In oscillation mode, with amplitude of 2 mm and frequency of 3Hz, the beam hole becomes the combination of bowl type and wedge type, when the gas flow rate is 42 lit/min. In the case of 54 lit/min, the bead was sound and the beam hole is still deep. The oscillation mode has got the combined merits of continuous mode and pulsing mode. It can penetrate deeper than the other two modes with the same input Laser power of 7.5 kW and also the weld beam is sound.

2) The beam intensity of Laser beam with respect to time and space

The beam intensity of Laser beam in 15kW machine at various power levels with respect to the time and space was studied with an "Intensity Meter". The meter contains 8 vanes made of Aluminium rotating at 3,000 r.p.m. by an attached motor. The study revealed that the beam intensity was not steady over the period of time and was varying between the range ±10% (approx). This study will be very useful in assessing the performance of the equipment like beam stability etc.

The same study was extended to 5kW Laser machine. Comparatively the beam stability was good with respect to time and the variation was within the limits of ±5% (approx).

3) Delta-Ferrite content in Laser welding of stainless steel in pulsed Nd-YAG Laser

With 200W Nd-YAG Laser machine, the stainless steel samples were spot welded in pulsing mode to find out the delta-ferrite content in three conditions viz. a) no gas purging b) Argon shielding and c) Helium shielding. As the Laser process exhibits very high rate of heating and cooling, the delta ferrite content in the weld is reduced very much below the minumum required level. As the delta-ferrite content is reduced, the hot cracking effect of weld is increased. To improve its level, various purgings were tried out with different flow rates and the results are given below:

i) The delta-firrite content in stainless steel Laser weld was very small in all 3 cases viz.a) no gas purging b) Argon shielding and c) Herium shielding. The attributed reason may be very high cooling rate.

ii) From the micro analysis of grain structure, the cooling rate was found to be 10^5 to 10^6 °C/sec. The reason is, the welding was done in pulsing mode (no other mode is possible in this machine), so the peak power was high with the pulse width of 3.5 ms. The cooling rate can be reduced by keeping the low power in CW mode.

iii) But this reduced delta-ferrite content stainless steel welding has an advantage of improved corrosion resistance property. But enough care should be taken to avoid hot cracking.

2.7. Technical Visits

The following technical visits were arranged for individual and group.

Jun 17: Osaka Industrial University (Sampath)

Jun 20: Sumitomo Special Metal Co. Ltd.(Osaka area, Sampath)
Nihon Gemma Maugacturing Co. Ltd. (Solder alloys maker, Osaka area, Sampath)

Jul 13: Rigaku Coorporation Ltd. (Measurements equipments, Tokyo area, Mitra)

Jul 14: Fujitsu Computers Ltd. (Tokyo area, Four fellows together)
Isuzu Automobile Industries (Tokyo area, Four fellows together)

Jul 15: Kawasaki Steel Co. Ltd., Chiba Works (Tokyo area, Four fellows together)

JAL (Japan Air Lines) Maintenace Base (Tokyo area, Four fellows together)

Jul 27: Kobe Steel Ltd., Structural Engineering Laboratory (Kobe area, Dattarajan)

Jul 28: Construction Site of Ohnaruto Suspension Bridge (Shikoku area, Dattarajan, Mitra and Karthikeyan)

Jul 29: Kawada Industries, Inc., Shikoku Plant (Shikoku area, Dattarajan, Mitra and Karthikeyan)

Construction Site of Kitabisan Seto Ohhashi Suspension Bridge (Shikoku area, Dattarajan, Mitra and Karthikeyan)

Mitsui Engineering and Ship Building Co. Ltd., Tamano Works (Okayama area, Dattarajan, Mitra and Karthikeyan)

Jul 29: Sharp Electric Corporation (Nara area, Sampath)

Aug 02: Kawasaki Heavy Industries Ltd., Kobe Technical Center (Kobe area, four fellows together)

Mitsubishi Heavy Industries, Ltd., Kobe Shipyard (Kobe area, Four fellows together)

Aug 03: Low Temperature Center of Osaka University (Four fellows together)

Aug 10: Mitsubishi Electric Corporation, Manufacturing Development Laboratory and Itami Works (Osaka area, Four fellows together)

Aug 12: Department of Welding Engineering, Osaka University (Four fellows together)

3. Training at JWRI (Group 2)

3.1 Description of training

Trainee's name, their subjects of research and supervisors are as follows.

1) Ashok SESHANDRI

Project Number: DP/IND/79/026/31-01

Field of Study: Plasma Spraying

i) Effect of spraying parameters on quality of coating by Al_2O_3 and Al_2O_3-TiO_2 powders

ii) Evaluation of spray-coated layer by destructive testing

iii) Interpretation and evaluation of sprayed coatings

Training Period: September 11, 1983 - December 10, 1983

Supervisors: Prof. Dr. Katsunori INOUE

Prof. Dr. Akira OHMORI

2) Ramesh SARMA

Project Number: DP/IND/79/026/31-02

Field of Study: Solid Phase Welding Processes---Ultrasonic and Diffusion Weldings---

i) Metallurgical investigation of dissimilar solid phase welds

ii) Ultrasonic welding of Al-Cu dissimilar combination

iii) Process variables of diffusion welding

Training Period: September 11, 1983 - December 10, 1983

Supervisors: Prof. Dr. Toshio ENJO

Prof. Dr. Seishi KIKUCHI

Dr. Kenji IKEUCHI

Dr. Toshio KURODA

3) A. RAJA

Project Number: DP/IND/79/026/31-09

Field of Study: MIG/MAG Welding

i) Metal transfer analysis by high speed motion picture photography

ii) Melting characteristics of flux cored wires and their dependence on high temperature resistivity

Training Period: September 11, 1983 - December 10, 1983

Supervisors: Prof. Dr. Fukuhisa MATSUDA

Prof. Dr. Masao USHIO

4) C. P. RAVICHANDRAN

Project Number: DP/IND/79/026/31-10

Field of Study: Welding Consumables---Fluxes for Submerged Arc Welding---

i) Determination of chemical composition, structure and crystalline ratio of fluxes before and after welding

ii) Effect of fluxes on chemical composition of weld metal

iii) Effect of fluxes on cross sectional bead geometry

Training Period: September 11, 1983 - December 10 1983

Supervisors: Prof. Dr. Nobuya IWAMOTO

Mr. Yukio MAKINO

Dr. Norimasa UMESAKI

5) Radaha Krishanan NAIR

Project Number: DP/IND/ 79/026/31-11

Field of Study: TIG Welding Process

i) Measurement of arc pressure in TIG acrs with solid and hollow cathodes

ii) Effect of arc pressure on weld bead formations

iii) Establishment of welding parameters in TIG welding of stainless steel and titanium

Training Period: September 11, 1983 - December 10, 1983

Supervisors: Prof. Dr. Akira MATUSNAWA

Dr. Seiji KATAYAMA

3.2. Lectures and technical Discussions

The following lectures and technical discussions were delivered to trainees during their research works at JWRI.

<u>Lectures</u>:

1) Prof. OHMORI: "Present state of ceramic spraying in Japan" (To Seshandri)

2) ibid: "Destructive and nondestructive evaluation of ceramic plasma sprayed coating" (ibid)

3) ibid: "Method of plasma and gas spraying" (ibid)

4) ibid: "Application of ceramic coating by plasma spray" (ibid)

5) Prof. ENJO: "Metallographic preparation and etching procedures for solid phase welded joints of dissimilar metal combination" (To Sarma)

6) ibid: "Insight into the process of diffusion welding" (ibid)

7) Prof. IWAMOTO: "General survey for flux chemistry and welding metallurgy" (To Ravichandran)

8) Mr. MAKINO: "General consideration to select welding flux for SAW and ESW" (ibid)

9) ibid: "Welding flux and basicity" (ibid)

10) ibid: "Relation between state of ions in welding slag and nonmetallic element or inclusion morphology in weld metal" (ibid)

11) ibid: "Simple theoretical consideration to assign infra-red absorption spectrum" (ibid)

12) ibid: "Infra-red absorption measurement and silicate chemistry related to welding flux" (ibid)

13) Mr. MAKINO and Dr. UMESAKI: "Analysis to interprete powder X-ray diffraction pattern" (ibid)

14) Dr. UMESAKI: "Principle of X-ray fluorescence spectroscopy, sample preparation and operation of X-ray fluorescence spectrometer" (ibid)

15) Prof. MATSUNAWA: "Cathode and Anode Mechanism of TIG arcs" (To Nair)

16) ibid: "Static and dynamic arc pressure associated by electromagnetic effect" (ibid)

17) ibid: "Measurement method of TIG arc pressure" (ibid)

18) ibid: "Effect of arc pressure on weld bead formation" (ibid)

19) ibid" "Static and dynamic effect of surface tension in fusion welding" (ibid)

20) Dr. V. KADYROV (Inst. Material Science, U.S.S.R.): "Detonation gun process" (To Seshandri)

21) Prof. Dr. I. Ohnishi (Prof. Emeritus, Osaka University, Technical Adviser, Sumikin Electrode Manufacturing Co.): "Production of Electrodes" (Group)

Discussions:

1) Prof. OHMORI: "Destructive testing of ceramic plasma sprayed coating" (With Seshandri)

2) ibid: "Blast erosion testing of ceramic plasma sprayed coating quality" (ibid)

3) ibid: "Effect of plasma spraying conditions on ceramic coating quality" (ibid)

4) Prof. ENJO: "Bonding mechanism of ultrasonic welding of alminium to copper" (With Sarma)

5) Prof. USHIO: "Metal transfer phenomena in GMA welding" (With Raja)

6) ibid: "Melting rate of wire electrode in GMA welding" (ibid)

7) ibid: "Method to take a high speed motion picture of welding phenomena in GMA welding" (ibid)

8) ibid: "Metal transfer phenomena of flux cored electrode and its melting rate" (ibid)

9) Prof. MATSUDA and Prof. USHIO: "Arc phenomena in case of self-shielded flux cored electrode" (ibid)

10) Mr. MAKINO and Mr. KAMAI: "Analysis of oxygen, nitrogen, carbon and sulfur in weld metal" (With Ravichandran)

11) Mr. MAKINO: "Analysis of duffusible hydrogen in weld metal using gas chromatograph" (ibid)

12) ibid: "Identification of welding flux using infra-red absorption method" (ibid)

13) Mr. MAKINO and Dr. UMESAKI: "Identification of welding flux using X-ray diffraction method" (ibid)

14) Dr. UMESAKI: "Elements analysis of welding flux using X-ray fluoroscence method" (ibid)

15) Dr. KOBAYASHI (Kobe Steel Co.): "Problems in welding consumables" (ibid)

16) Prof. MATSUNAWA: "Difference of arc pressure between solid and hollow cathode processes" (With Nair)

17) ibid: "Setting up welding parameters for full penetration welding of thin plate" (ibid)

18) ibid: "Photographic observation of arc geometry" (ibid)

19) Dr. KATAYAMA: "Microphotography of weld metal" (ibid)

3.3. Plasma Spraying

Mr. Ashok SESHANDRI conducted the following researches under the supervision of Prof. K. Inoue and Prof. A. Ohmori.

1) Effect of spraying parameters on quality of coating by Al_2O_3 and Al_2O_3-TiO_2 powders
2) Evaluation of spray-coated layer by destructive testing
3) Interpretation and evaluation of sprayed coatings

1) Effect of spraying parameters on quality of coating by Al_2O_3 and Al_2O_3-TiO_2 powders

Plasma spraying of Al_2O_3 and Al_2O_3-TiO_2 ceramics on SUS304 stainless steel was carried out by using a 80kW Plasma Dyne Model 3600 equipment. In order to obtain good quality coatings, testing samples were made under the wide range of spraying conditions, particularly the stand-off distance and cross jet angle. The temperature rise and thickness of coated layer were measured immediately after each spraying.

2) Evaluation of spray-coated layer by destructive testing

The specimen obtained in the above were supplied to various microstructural and mechanical testings. Through microscopic observation and microhardness measurements, the quality and density of coated layer and their dependence to spraying parameters were clarified. Mechanical tests such as blast errosion test (B.E.T.), and tensile and shear strength tests were carried out in connection to spraying conditions.

3) Interpretation and evaluation of sprayed coatings

From the above various testings, the plasma sprayed coatings of two kinds of ceramics were evaluated and the following conclusions were derived.

i) Microstructure examination can only be a qualitative method and one has to combine other tests such as hardness and mechanical tests for more quantitative evaluation.

ii) Change in spraying conditions, particularly stand-off distance and cross jet angle are more significant for a higher melting point ceramic than the lower one. The difference can be interpreted by the heating and cooling process during spraying.

3.4. Solid Phase Welding Processes---Ultrasonic and Diffusion Welding

Ramesh SARMA was guided by Prof. T. ENJO, Prof. Y. KIKUCHI, Dr. K. IKEUCHI and Dr. T. KURODA for the following fields.

1) Metallurgical investigation of dissimilar solid phase welds

2) Ultrasonic welding of Al-Cu dissimilar combination

3) Process variables of diffusion welding

1) Metallurgical investigation of dissimilar solid phase welds

In order to obtain the broad knowledges of solid phase welding of dissimilar metals, various kinds of solid phase welds were collected and samples for metallurgical investigation were prepared. Welded joints by the following processes and metals combination were selected;

i) Explosive clad welds of

a) Titanium to Steel

b) Aluminium to Stainless Steel

c) Brass to Steel

d) Aluminium to Copper

ii) Ultrasonic weld of Aluminium-Copper

iii) Friction welds of

a) Aluminium to Steel

b) Aluminium to Stainless Steel

First it was instructed how to make a sample for metallographic studies of dissimilar metal combination, and then it was performed microphotograph studies of the solid phase weld joints mentioned above. From these studies, the trainee could understand how the bonding states, i.e., bond shape, intermetalic layer, diffusion of elements, porosities and cracks, and so on, were different depending on the welding process and metal combination.

2) Ultrasonic welding of Al-Cu dissimilar combination

It was investigated the process parameters of ultrasonic welding of Al-Cu combination using a 1000W ultrasonic welding equipment. In prior to the welding, the trainee was asked to prepare an anvil suitable for the above metal combination and also to roll the copper and aluminium plates to obtain the desired thickness of foils. Three basic parameters of ultrasonic welding, i.e., ultrasonic power, applied pressure and welding time, were changed, and the contribution of individual variable to the weld strength was clarified by the strip tensile test of each welded joint. It was found that the strength became lower when each process variable was either lower or higher than the optimum value. The reasons were interpreted by the insufficient bonding in case of lower values and the fatigue cracking in case of higher ones.

3) Process variables of diffusion welding

Insight on diffusion welding was obtained by witnessing the experiments at JWRI and other places, technical discussions and literature surveys. However, actual experimentations by the trainee could not be carried out due to the lack of time.

3.5. MIG/MAG Welding

Prof. F. MATSUDA and Prof. M. USHIO supervised A. RAJA in the following research subjects.

1) Metal transfer analysis by high speed motion picture photography
2) Melting characteristics of flux cored wires and their dependence on high temperature resisitivity

1) Metal transfer analysis by high speed motion picture analysis

Metal transfer characteristics of CO_2 shielded and self shielded flux cored wires were studied by high speed camera (Hycom camera) at the filming rate of 3,000 frames per second. Three different flux cored wires with CO_2 gas shielding and one self shielded type wire were investigated for electrode positive and negative polarities. It was clarified that the metal transfer mode and electrode tip shape were greatly influenced by the cross sectional shape of wire, metal/flux ratio and polarity.

2) Melting characteristics of wires and their dependence on high temperature resistivity

Measurements of melting rate was conducted for the wires used in the previous study in braod range of current and voltage. The melting rate characteristics of flux cored wires showed that the apparent effect of Ohmic heating in wire at higher current was less than that in solid wire in spite of using the similar steel in both flux cored and solid wires. The reason was investigated in detail by measuring the high temperature resisitivity of wires used. It was clarified that the high temperature resistivity of every wire including solid wire was substantially the same and the presence of flux gave little effect on high temperature resistivity. However, the actual heat capacity in flux cored wires were considerably higher than that of solid wire, and this difference was reasonably explained by considering the heat conduction from the outer metal sheath to inner flux which caused the reduction of resultant Ohmic heating in case of flux cored wire. The effect of electrode polarity on melting rate was also fully investigated and the importance of metal/flux ration in wire was realized.

3.6. Welding Consumables---Fluxes for Sbumerged Arc Welding---

C.P. RAVICHANDRAN was supervised by Prof. N. IWAMOTO, Mr. Y. MAKINO and Dr. N. UMESAKI in the following research subjects.

1) Determination of chemical composition, structure and crystalline ratio of fluxes before and after welding
2) Effect of fluxes on chemical composition of weld metal
3) Effect of fluxes on cross sectional bead geometry

1) Determination of chemical composition, structure and crystalline ratio of fluxes before and after welding

Six kinds of fluxes for submerged arc welding were prepared for the studies above mentioned. Three were commercially availble fluxes and the others were specially prepared at laboratory which were all $CaO-MnO-SiO_2$ system but different bacisity. Bead on plate welding was performed using the above fluxes and mild steel plate (SM41A) under the heat input of around 3kJ/cm. The change of chemical composition, structures and crystalline ratio of before and after the welding were investigated by means of X-ray flourescence (XRF) spectrometry, infra-red (IR) spectrometry and X-ray diffractometry. The quantitative XRF measurements showed that in almost all cases the Fe content in the slag increased after welding indicating the presence of FeO in the slag after welding was different depending on the flux used. The structure and crystal change were also investigated by IR spectrometry but there was not substantial differences among fluxes because they contained very little amount of crystals.

2) Effect of fluxes on chemical compositions of weld metal

Chemical composition of the weld metal was analyzed by sampling specimen obtained in the previous study. Particular interest in this study was the content of carbon, sulpher, nitrogen and oxygen after welding, and LECO C/S and N_2/O_2 analysers were employed. Measurements were done for all kinds of fluxes, and the results revealed that the N_2/O_2 content was influenced by the basicity and composition of flux. Diffusible hydrogen content was also measured by Yanagimoto H(d) analyser.

3) Effect of fluxes on cross sectional bead geometry

Penetration shape of every weld was observed and geometrical shape factors were compared with each other. Inspite of similar heat input conditions, the shape factors were considerably different depending on the fluxes used. It was approved that the fluxes prepared in laboratory brought deeper and narrower bead compared to the commercially available fluxes.

3.7. TIG Welding Process

Under the supervision of Prof. A. MATSUNAWA and Dr. S. KATAYAMA, Radha Krishnan Nair conducted the following researches in connection to TIG welding.

1) Measurement of arc pressure in TIG arcs with solid and hollow cathodes
2) Effect of arc pressure on weld formation
3) Establishment of welding parameters in TIG welding of stainless steel and titanium

1) Measurement of arc pressure in TIG arcs with solid and hollow cathodes

Systematic measurements of arc pressure of TIG arcs with various shapes of thoriated tungsten cathode were conducted preparing a specially designed water cooled copper plate with a very small hole that was connected to a semiconductor type pressure transducer. Two kinds of cathode, i.e., solid and hollow electrodes, were prepared in different diametere vertex angles and/or hole diameters, and the arc pressure was measured in terms of arc current and arc length. During the experiments, an arc shape was photographed in order to estimate the arc root area on the cathode and the divergence of arc column. It was quantitatively clarified that the arc pressure of TIG arc with hollow cathode reduced greatly compared to that with solid electrode even under the same arc current and length. The reduction was particularly eminent in higher current range and it reached to 80% less at the maximum. The pressure decrease in hollow cathode was due to the fact that the arc root was uniformly distributed around the periphery of hole and thus the net current density at arc root was effectively reduced compared to that in solid electrode, which caused the less plasma jet generation by electromagnetic force.

2) Effect of arc pressure on weld bead formation

The effect of arc pressure on penetration shape was studied for both solid and hollow electrodes process with same diameter, arc current and arc length. It was found that the deeper penetration and narrower bead width could be obtained in hollow cathode process if the hole diameter and vertex angel were suitably selected to the given current value. The most significant features of hollow cathode process were seen that the bead surface was smooth and flat and the unfavourable bead formation such as undercutting and humping were effectively avoided even at very high welding speed.

3) Establishment of welding parameters in TIG welding of stainless steel and titanium

General concept of determining welding condition was instructed by carrying out the full penetration welding of 3mm thick SUS 304 stainless steel and pure titanium plates using solid and hollow cathode processes. Among many welding variables, arc current and welding speed were taken as the two major parameters, and welding was performed changing one parameter under the fixed condition of another variable until the full penetration disappeared either by partial penetration of burn through. By the method, the welding window of full penetration welding for two materials were determined. Results showed that the hollow cathode process had much wider allowance of weldable conditions than the solid electrode process for both materials.

3.8. Technical Visits

The following technical visits were arranged for individual and group.

Sep 23: Japan Welding Show at Osaka (Group)

Oct 06: Seminar, Commission of Welding Processes, Japan Welding Society (Tokyo area, Group)

Oct 07: JAL (Japan Air Line) Maintenace Base (Tokyo area, Group)
Kawasaki Steel Co. Ltd., Chiba Works (Tokyo area, Group)

Nov 12: Nippon Coating Co. (Osaka area, Seshandri)

Nov 21: Osaka Transformer Co. Ltd., Welding Products Division (Osaka area, Seshandri, Raja and Nair)

Nov 22: Kawasaki Heavy Industries Ltd., Kobe Technical Center and Ship Building Division (Kobe area, Group)
Mitsubishi Heavy Industries Ltd., Nuclear Power Pland Division (Kobe area, Group)

Nov 29: Mitsubishi Electric Corportaion, Manufacturing Development Laboratory and Itami Works (Osaka area, Group)
Sumikin Electrodes Manufacturing Co., Main Factory (Osaka area, Group)

Dec 02: Industrial Research Institute of Hyogo Prefecture (Kobe area, Sarma)

Dec 05: Daihatsu Automobile Co. Ikeda Factory (Osaka area, Group)

4. Consulting at Project Area (1st Group)

4.1. Description of Consulting

Consultants have served to establish and operate the WRI, Thichirapalli, India, in their specific area, as stated bellow;

1) Prof. Dr. Kohsuke HORIKAWA

Occupation:	Associate Professor, Welding Research Institute, Osaka University
Qualification:	Doctor of Engineering Authorized Consulting Engineer Sixteen years experience in research, education and consultancy in design of welded structures
Post Title:	Consultant in Welding Design (Co-Team Leader)
Duration:	Sept. 6th to Oct. 20th, 1983 (1.5 months)
Duties:	To assist the group of researchers and engineers in; 1. Design of weldment for structures and pressure vessels subjected to both static and dynamic loading; 2. Residual stress calculation for welded structures and measurement by various experimental techniques. Effects of residual stress on weld design; 3. Structural analysis by Finite Element Methods; 4. Control of distortion in welding.

2) Mr. Tadashi MSTSUYAMA

Occupation: Chief Research Engineer, Takasago Technical Institute, Mitsubishi Heavy Industries, Ltd.

Qualification: Master of Engineering

Twenty years of experience in research, development and consultancy in welding procedures and fabrication for heavy compornents

Post Title: Consultant in Plasma Welding and Spraying

Duration: Sept. 6th to Oct. 20th, 1983 (1.5 months)

Duties: To assist the group of researchers and engineers in;

1. Development of plasma spraying facility at WRI;
2. Development of testing and acceptance procedure for plasma spraying;
3. Train counterpart personel in the field of plasma spraying and welding in various areas;
4. The developmental works like twin hot wire plasma welding, key hole welding of thin wall tubes;

3) Mr. Shigeru OHKITA

Occupation: Research Engineer, Products Research Institute, Nippon Steel Corporation, Ltd.

Qualification: Master of Engineering

Five years experience in research in microstructure and cracking in welds

Post Title: Consultant in Micro-structure and Cracking of Weld Metal

Duration: Sept. 6th to Oct. 20th, 1983 (1.5 months)

Duties: To assist the group of researchers and engineers in;

1. Weld thermal cycles and their estimation;
2. Weld hardening;
3. Weld CCT diagram and the micro-structures;
4. Mechanical properties of simulated weld thermal cycle specimens;
5. Hot cracking in welds;
6. Cold cracking in welds;
7. Reheat cracking in welds.

Consultants are also required to prepare the Final Report, setting out the findings of the mission and recommendations to the Government on further action which be taken.

4.2. Lectures

Following lectures were given;

1) Sept. 08, 'Basic concept of finite element method - 1' (by Prof. Dr. Horikawa)
2) Sept. 09, ' do - 2' (ibid)
3) Sept. 10, 'Virtual work concept for finite element method' (ibid)
4) Sept. 12, 'Finite difference method' (by Mr. Ohkita)
5) Sept. 12, 'Some topics of the developments in new welding technology in Japan' (by Prof. Dr. Horikawa)
6) Sept. 13, 'Basic concept of finite element method - 3' (ibid)
7) Sept. 14, ' do - 4' (ibid)

8) Sept. 15, 'Welding metallurgy of high heat input processes - 1' (by Mr. Ohkita)

9) Sept. 16, 'Basic concept of finite element method - 5' (by Prof. Dr. Horikawa)

10) Sept. 17, 'Arc physics' (by Mr. Matsuyama)

11) Sept. 19, 'Influence of residual stresses on fatigue crack propagation' (by Prof. Dr. Horikawa)

12) Sept. 21, 'Basic in TIG welding process' (by Mr. Matsuyama)

13) Sept. 22, 'Welding metallurgy of high heat input processes - 2' (by Mr. Ohkita)

14) Sept. 27, 'Non-linear finite element method - 1' (by Prof. Dr. Horikawa)

15) Sept. 28, 'Plasticity for finite element method' (ibid)

16) Sept. 29, 'Cold cracking - 1' (by Mr. Ohkita)

17) Sept. 30, 'Fabrication and installation of penstocks' (by Prof. Dr. Horikawa)

18) Sept. 30, 'Some topics of the development in new welding technology in Japan' (at the joint meeting of Indian Institute of Welding and Indian Institute of Metallurgy, by Prof Dr. Horikawa)

19) Oct. 01, 'Plasma welding and surfacing' (by Mr. Matsuyama)

20) Oct. 03, 'Application of fracture mechanics to the design of bridges' (by Prof. Dr. Horikawa)

21) Oct. 06, 'Cold cracking - 2' (by Mr. Ohkita)

22) Oct. 10, 'Prevention of cold cracking in welded structures' (by Prof. Dr. Horikawa)

23) Oct. 10, 'Narrow gap MIG welding' (at the meeting of Indian Institute of Welding, By Mr. Matsuyama)

24) Oct. 12, 'Plasma spraying' (by Mr. Matsuyama)

25) Oct. 14. 'Application of fracture mechanics to the design of bridges'

(for the course on "Design of weldment and distortion' conducted by the School of Welding - WRI, by Prof. Dr. Horikawa)

26) Oct. 14, 'Plasma cutting and hazards in plasma process' (by Mr. Matsuyama)

27) Oct. 14, 'Weldability of modern structural steel' (at the joint meeting of Indian Institute of Welding and Indian Institute of Metallrugy, by Mr. Ohkita)

28) Oct. 15, 'Non-linear finite element method - 2' (by Prof. Dr. Horikawa)

29) Oct. 17, 'Case studies preventing failure of bridges' (ibid)

30) Oct. 18, 'Hot cracking and reheat cracking' (by Mr. Ohkita)

Beside the technical lectures listed above, lectures on 'Japan Today' were given by Prof. Dr. Horikawa at Township Club on September 29, at Tiruchirapalli Management Association on October 15 and Get-together Party of WRI on October 17, 1983, for the mutual understanding of both countries.

4.3. Welding Design

Prof. Dr. Horikawa gave advices through discussions on following subjects;

1) Classified items

(Research Projects)

1) Early steel briges (with H. Dattarajan, G. Balakrishna, T. K. Mitra and V. P. Raghupati)

2) AMMO 52 (with G. Balakrishna and H. Dattarajan)

3) Residual stress re-distribution (with S. Surech and T. K. Mitra)

4) K-calculation by finite element method (with H. Dattarajan, G. Balakrishna and V. P. Rughupati)

(Discussions and Ad-Roc Consulting)

<u>Fatigue</u>

5) General concept of fatigue research and fatigue design (with G. Balakrishna, H. Dattarajan, V. P. Raghupati and S. Suresh separately)

6) Effect of micro-structures on crack growth rate (with T. K. Mitra)

7) Effect of residual stress on fatigue (with S. Suresh)

8) Crack growthr rate and plastic concentration factor (with V. P. Raghupati)

<u>Fracture Mechanics</u>

9) K-calculation by zooming technique of finite element method (with V. P. Raghupati)

10) Application of fracture mechanics to brittle fracture (with S. Suresh)

<u>Residual Stress</u>

11) Residual stress distribution (with P.R.Vishnu)

12) Thermo-elasto-plastic finite element method (with V. Veeraraghuvan and S. Suresh, separately)

13) Mechanical and thermal stress releaf treatment (with S. Suresh)

14) Hole drilling method for residual stress measurement (ibid)

Welding distortion and correction

15) Welding distortion (with S. Suresh)

16) Hot line bending (ibid)

17) Hot line correction (ibid)

Cracking in welds

18) Cold cracking (with S. Suresh)

Testing

19) Design of testing bed (with V. P. Raghupati)

20) Acoustic emmission (with J.P.Bhatia)

21) Ultra-sonic holography (with C. Mani)

22) Difussible hydrogen measurement (with S. Srinivasan and Mrs. Kamala)

Miscellaneous

23) Strengthening of crane girders (with H. Shreekantha Rao, BHEL Civil Disign Department)

24) Welding of reinforcing bar (ibid)

25) Warping of bix girders (with H. Dattarajan)

2) Early steel bridges

This research project is co-operative one between Railway Design and Standardization Office of Indian Railways and WRI.

In India hundreds of railway bridges have been constructed in 19th century after 1830 using cast iron and so called Early Steel.

Considerable numbers of fatigue crack were found in these bridges after more than hundred years of use.

Indian Railway wants to estimate remaining life of these bridges.

The consultant adviced:

- If initial crack is assumed, remaining life can be calculated by fracture mechanics procedures.

  He gave names of references.
- Estimation of the damage on crack initiation or remaining life to crack intiation is difficult, if not impossible, at present.

  This will be a future project.
- How to assume the size of initial crack depends upon non-destructive testing technique.

  He also discussed on the possible aplications of NDT.

3) AMMO 52

A boiler-maker wants to change a material of a certain boiler from SA 299 to AMMO 52. SA 299 is a steel grade's name after Indian Standard, and AMMO 52 is a brand name of such steel.

The maker asked WRI to evaluate the fracture toughness of AMMO 52 of 140mm in thickness and at 350°C.

The consultant adviced;

- It is not practical, if not impossible, to measure a fracture toughness of such thick plate and at such high temperature.
- Only practical way is to conduct some impact tests like Charpy Tests or Drop Weight Test at high temperature using standard specimen.
- Correlation of the test data from different testing procedure and influence of the sizes of specimen shall be discussed based upon the data at ambient temperature.

  Names of reference papers were given.

4) Residual Stress Re-distribution

This theme was proposed by the Consultant as a case study of how to conduct a experimental research.

The aim of the theme is to get some fundamental information for the research on fatigue crack propagation through residual stress field and to be a preparatory study of mechanical stress releaving.

Although some preparatory discussion were made at JWRI, when counter-part persons were there for training, specimens could not be made until the Consultant left the Project Area.

5) K-calculation by finite element method

This theme was also suggested by the Consultant as a exersise of finite element calculation, and to deepen the understanding of stress intensity factor.

K-value was to be calculated by stress method, strain method, compliance method, external work-done method and J-integral method on Compact Tension specimen.

He thought basic theory, out-line of procedure and mesh division.

Then, data input and computer operation were left to WRI personal.

It is very regrettable that date input was not completed when he was there.

4.4 Plasma Welding and Spraying

On this research field, Mr. Matsuyama consulted as follows.

1) Classified items

(Research Projects)

1) Key hole plasma welding (with A. K. Garg and S. S. Ananthan)

2) Plasma spraying (with A. K. Garg and S. S. Ananthan)

(Discussions and Ad-hoc Consulting)

3) Plasma cutting (with A. K. Garg, S. S. Ananthan and V. Balraj)

4) Plasma spraying general (with A. K. Garg and S. S. Ananthan)

5) Back bead by TIG welding (with A. K. Garg and S. S. Ananthan)

6) Narrow Gap MIG welding (with K. Padmanaban, K. L. Rhira and A. Garg)

7) Arc physics (with V. Balraj)

8) Electrode coating (with V. Balraj)

9) Overlay weld cladding with soft plasma, strip electro-slag, and plasma-hot wire (with A. K. Garg and S. S. Ananthan)

10) Welding of thermocouple (with S. S. Ananthatn and T. R. K. Nair)

11) Blow hole in heat-treated alloy steel (with S. S. Ananthatn)

12) Hard surfacing procedure with TIG, Plasma, SAW, and MIG. (with Mr. Dhanumjayadu and his staffs, BHEL and A. K. Garg, S. S. Ananthan, WRI)

2) Key-hole plasma welding

WRI have a plan to make qualification standard for welding procedure of tube butt joint by Key-hole Plasma Welding process for boiler plant, required from boiler maker such as BHEL. Many institutes and companies make studies for such needs by Key-hole Plasma Welding process. In actual plant, material used are carbon steel and stainless steel and tube sizes are 40mm to 80mm Dia., 5mm to 7.8mm thickness.

The consultant adviced for this test:

- For test piece material, at first step test,a flat carbon steel plate should be used, and the starting welding condition, regular welding condition with good root bead and finishing welding condition must be separately conducted. The method is the most effective and economical way to establish the optimum welding condition. After these tests, test piece should be changed to tube and then to stainless steel tube.
- A researcher should make plan for test with the image of final figures that will be ploted each welding test results. What kind of figure, what kind of data should be taken, a researcher should make plan prior to start experiment. Not only good welding condition but also not unsutable welding condition are equally very important. He gave reference.
- In actual production, surrounding condition can't be controlled as same as testing. Dimensional tolerance of fit-up of edges and of tube itself should be considered as allowable tolerance at standard welding condition for procedure test because this dimension are very critical.

3) Plasma spray

New need of plasma ceramic spray procedure in WRI is to use this procedure for surface insulation coating of narrow gap MIG welding nozzle. But, now a days, ceramic spraying is highly expected for every kind of field in future.

The consultant discussed plasma spraying mechanism and its quality, then showed how to get high quality coating by the controls of power, additional shielding gas flow, atmosphere control and so on. He also adviced testing procedures to evaluate the sprayed layer quality by easier way.

4.5 Welding Metallurgy

Mr. Ohkita gave advices through discussions on following subjects;

1) Classified items

(Research Projects)

1) Thermal cycle simulater (with P. Ravi Vishnu)

2) Comsumables (with G. Ravichandran)

3) PPM problem (with P. Ravi Vishnu)

(Discussions and Ad-hoc Consulting)

Weld Thermal Cycles and Hardening

4) Estimation of weld thermal cycles and of maximum hardness using a book "Welding Note" (with Welding Metallurgy group)

5) Calculation of weld thermal cycles (with P. Ravi Vishnu and R. Veeraraghavan)

Microstructure

6) Formation of CCT diagram using Formaster (W.M. group)

7) Effect of cooling rate on microstructure (W.M. group)

Mechanical Properties of Weld Metals

8) Effect of microstructure on weld metal properties (W.M. group)

Hot Cracking and Reheat Cracking in Weld

9) Effect of welding conditions on hot cracking susceptibility (P. Ravi Vishnu)

10) Mechanism of hot cracking (P. Ravi Vishnu)

11) Reheat cracking parameter (W.M. group)

12) Solidification microstructure (W.M. group)

13) Hot cracking in low carbon weld metal (P. Ravi Vishnu)

Cold Cracking in Weld

14) Mechanism of cold cracking (W.M. group)

15) Calculation of hydrogen accumulation using FDM method (R. Veeraraghavan)

16) Diffusible hydrogen measurement (S. Srinivasan and Mrs. Kamala)

17) Evaluation of cold cracking susceptibility of modern structural steels. (W.M. group)

2) Thermal cycle simulater

This research project have been carried out by welding metallurgy group in WRI to evaluate weldability of steels.

By this machine, not only the HAZ simulation but also the formation of CCT diagram generation can be done, if the machine works sufficiently.

The consultant advised;

- Maintenance of simulater is essentially important subject to conduct researches on weldability.

- Sinthetic HAZ properties are a little different from the actual HAZ. Austenite grain size of simulated HAZ become larger than actual HAZ.
- Characterization of element in simulated HAZ is important to know chemical reaction at high temperature.

3) Consumables

Developments of welding consumables such as SMAW electrodes and SAW fluxes are very important projects in WRI. Recently, WRI has a new process to make SMAW electrode, but a process to make SAW flux has just started. The consultant advised;

- to make SAW flux, various processes must be fully checked.
- to make agglomerated type SAW flux in laboratory scale, no special machine is necessary.
  The consultant showed a simple method to make flux.
- to develop new type electrodes and fluxes, try and error is one of the important and perhaps only one realistic method.

4) PPM problem

PPM (pipe processing machine) project comes from pipe connecting SAW process in actual plant. Hot cracking is the serious problem when Indian welding wire is used, while no cracking takes place by the imported wires. The consultant advised;

- Change welding condition, namely reduce the welding speed. Smaller the strain rate, lesser the hot cracking.
- addition of carbon to weld metal can decrease hot cracking and showed a reference paper.

5. Consulting at Project Area (Group 2)

5.1 Description of Consulting

The second group of consultants served their missions at the WRI, Tiruchirapalli, India from January 9th, 1984 to February 17th, 1984 in the specific areas described below;

1) Prof. Dr. Akira MATSUNAWA

Occupation; Associate Professor, Welding Research Institute, Osaka University

Qualification; Doctor of Engineering

Sixteen years experience in research, education and consulting. Experts members of domestic and international academic bodies in the area of welding physics and welding processes.

Post Title; Laser Welding and Arc Physics* (Co-Team Leader)

Duration; Jan. 9th to Feb. 17th, 1984 (1.5 months)

Duties; To assist the counterpart personal, Mr. Balraj and other researchers of WRI in the fields of;

1. Fundamentals of arc and welding physics;
2. Evaluation of coated electrodes, its basic ideas and experimental methods;
3. Fundamentals of laser material processing

(*: Prof. Matsunawa was originaly placed as the expert in the area of laser welding as it was described in the Contract. However, he found at the time of his arrival that an another expert in the same area, Dr. W. Steen of Imperial College, London, UK, was placed in the same duration, and hence his mission was modified to the above areas after he arrived at the project area.)

2) Dr. Hiroyoshi NAGAI

Occupation; Senior Research Engineer, Technical Research Institute, Kawasaki Heavy Industries, Ltd.

Qualification; Doctor of Engineering

Sixteen years experience in R and D in welding processes and fabrication

Post Title; Consultant in Electron Beam Welding and Pressure Welding**

Duration; Jan. 9th to Feb. 17th, 1984

Duties; To assist the researchers of WRI in;

1. Optimization of welding variables in pressure welding processes
2. Welding of ferrous and nonferrous alloys by fusion welding processes
3. Selection of optimum welding condition in Electron Beam Welding of various materials and structures

(**: Dr. Nagai's specified area of consulting in the contract was "Electron Beam Welding", but he could not but change the duties as described above because the EB machine at WRI, Tiruchirapalli was not usable state.)

3) Mr. Seigo HIRAMOTO

Occupation; Senior Research Engineer, Research Institute for Production Engineering, Mitsubishi Electric Corporation Ltd.

Qualification; Master of Engineering

Eleven years experience in R and D of welding machines and processes

Post Title; Consultant in MIG/MAG welding

Duration; Jan. 9th to Feb. 17th, 1984 (1.5 months)

Duties; To assist a counterpart personal, Mr. Raja and research engineers of WRI in the fields of

1. Instrumentation and control of MIG/MAG welding machines
2. Selection of optimum welding conditions in MIG/MAG processes
3. Optimization of pulsed MIG/MAG welding
4. Welding of aluminium alloys by pulsed plasma arc process

5.2 Lectures

During the stay at WRI, Tiruchirapalli, the experts of second group delivered lectures in their specified fields. Particularly, they organized two special courses for specialists of many Indian research organizations and industries under the collaboration with other UNIDO experts, i.e., Dr. W. Steen from UK and Dr. J. Zeke from Czechoslovakia. (Refer Appendces 1 to 4.) The contents of special courses and lecture titles were as follows;

Special Courses:

1. Laser Material Processing, Feb. 7th-8th, 1984
   1) "Industiral Application of Laser", by Dr. W. Steen
   2) "Laser Cutting", by Dr. W. Steen
   3) "Laser Welding", by Dr. W. Steen
   4) "Beam-Material Interaction during Pulsed Laser Processing", by Prof. Dr. A. Matsunawa
   5) "Beam-Hole Behaviour in Laser and EB Welding", by Prof. Dr. A. Matsunawa

6) "Laser Operating paramenters", by Dr. W. Steen

7) "Industrial Heat Treatment", by Dr. W. Steen

2. New Trends in Fusion Welding Process, Feb. 14th-15th, 1984

   1) "Arc Properties and Recent Trends in Arc Welding", by Prof. Dr. A. Matsunawa

   2) "EB Welding Application", by Dr. H. Nagai

   3) "Modern Pulsed MAG Welding Process", by Mr. S. Hiramoto

   4) "Newer Trends in Flux Shielded Welding Processes", by Dr. J. Zeke

   5) "Plasma Arc Overlay Process", by Mr. S. Hiramoto

   6) "Newer Trends in EB Welding", by Dr. H. Nagai

   7) "Underwater Welding", by Prof. Dr. A. Matsunawa

3. Lectures for WRI and BHEL Members

   1) Jan. 24 "Electromagnetic Pinch Effect Related to Welding Phenomena", by Prof. A. Matsunawa

   2) do. "Selection of Welding Parameters in MIG/MAG Welding", by Mr. S. Hiramoto

   3) Feb. 06, "Weld Pool Behaviour and Bead Formation Phenomena", by Prof. Dr. A. Matsunawa

   4) do. "Beam Formation Characteristics of Pulsed MAG Welding", by Mr. S. Hiramoto

   5) Feb. 11, "Application of EB Welding (Part 1)", by Dr. H. Nagai

   6) do. "ibid. (Part 2)", by Dr. H. Nagai

   7) do. "Basic Concept and Specific Phenomena of Narrow Gap MIG/MAG Welding", by Prof. Dr. A. Matsunawa

   8) Fib. 17, "Educational System in Japan and Welding Research in Japanese Universities", by Prof. Dr. A. Matsunawa

5.3 Laser Welding and Arc Physics

Prof. Dr. A. Matsunawa conducted his missions through discussions and experimentations in the following subjects;

1) Classified items

(Research Project)

1. Evaluation of coated electrodes by electric characteristics of arc and their corelation to weld bead properties (with V. Balraj)
2. Development of hollow cathode TIG welding process (with R. K.Nair)

(Discussions and Ad-hoc Consulting)

4. All position pulsed TIG welding (with Ananthan, Nair, and Raja)
5. Arc initiation problem in high current arc furnace (with Mr. Mohanti)
6. Arc and weld pool behaviour in narrow gap welding (with Padmanaban)
7. Principle of arc sensor (with Padmanaban)
8. Hot wire TIG arc welding (with Padmanaban)
9. Narrow gap welding and EB welding in production line (with V. Pavaskar and V. George from Larson & Toubro Ltd.)
10. Bead formation stability in high speed submerged arc welding of thin sheet cylindrical vessel (with Sureth)
11. Signal processing and adaptive control in resistance spot welding (with Muthikurishunan and Agwan)
12. Flux cored wire for electro gas arc welding (with Rohira)
13. Laser welding and cutting (with Karthikeyan)

2) Evaluation of coated electrodes by electric characteristics of arc and their corelation to weld bead properties

The WRI, India is intending to establish an evaluation method of coated electrode's quality. However, arc phenomena of flux coated processes are extremely complicated compared with other arc processes. Therefore, the project must be started from the very basic studies on arc physics itself, and be gradually expanded the project scale in accordance with the accumulation of related data. The UNIDO/UNDP expert adviced as follows;

-Measurable quantitative data such as arc current, arc voltage, their wave forms, average melting rate of electrode, and so on must be recorded, and the shortcircuiting frequency, arc distinction frequency and their spectrum pattern under the given volt-ampere condition must be statistically analysed and also correlated with the spattering amount and bead macrosectional parameters. At the first step, these processing must be done manually in order to grasp the basic concept of arc physics.

-At the second stage, it is desirable to develop a computor processor for the above mentioned analysis. After the establishment of an automatic measuring system, organize several welders groups, ranking skilled to unskilled grades, let them to demonstrate welding in their own ways, ask them their impression of the electrode under testing. This is very important because welders have the instinctive but more accurate informations than the modern sophisticated machine can collect. However, welders usually have not trained to express the phenomena in scientific language, and thus it will be necessary to prepare a suitable categorization that he can understand in his own understanding.
By comparing the welders evaluation with the scientific data obtained by machine, some standard interpretation of statistical data can be established as a measure of evaluation.

-It should be noted that the above evaluation is only made by the aspect of arc physics. Final evaluation of electrode must be done from the properties of welded joint. Therefore, collection of data concerning to the weld bead shape parameters and varicus mechanical and metallurgical properties must be done in parallel with the electrical measurements. Namely, this subject is beyond the ability of single person, and thus it is necessary to organize a long term project group consisted of arc physisists, welding metalurgists and welders.

3) Development of hollow cathode TIG welding process

A TIG process is one of the high quality welding processes but its problem is the inefficiency. A new method to overcome this process inferiority, and employment of hollow cathode was developed in Japan by systematic researches on arc physics. The WRI, India showed a strong interest on this process and started a project in its own way. However, due to the lack of basic data and know-how, they encountered to several difficult situations. The UNIDO/UNDP expert consulted this subject and gave the counterperson following suggestions.

- Optimum current range is strongly dependent on the cathode configuration, i.e., outer and inner diameters and depth of hollow. In suitably shaped cathode, an arc root is uniformly distributed along the edge of periphery which brings a stable arc. Therefore, it must be clarified the relation between cathode configuration and arc behaviours in wide ranges of current and cathode sizes.
- In general, an arc stability is improved by the generation of plasma stream which is associated with the electromagnetic pinch effect. However, too strong plasma stream causes the formation of unfavourable beads such as undercutting and humping. On the countrary, too weak plasma stream brings unstable arc, particularly at higher welding speed. The concept of hollow cathode process is based on the reduction of plasma stream, though, it should be noted that too much reduction of arc force is not beneficial and thus optimum condition becomes rather narrow in this

process.

-In case an cathode with through hole is employed, an axial gas stream is associated inside the hollow which causes a deflected unstable arc. Therefore, some suitable measure to restrict the gas flow generation in the hole becomes necessary. A usage of plug at the another end of cathode may be effective.

5.4. Pressure Welding and Electron Beam Welding

Dr. H. Nagai consulted and guided in the following subjects;

1) Classified items

(Research Projects)

1. Optimization of welding variables in pressure welding process
2. Welding of ferrous and nonferrous alloys by fusion welding processes
3. Selection of optimum welding condition in Electron Beam Welding of various materials and structures

(Discussions and Ad-hoc Consulting)

4. Narrow gap welding and overlay welding by submerged arc process (with M. Mohanty)
5. EB welding of 2014 and 5083 aluminium alloys and 0.25% Cast steel (with N. Viswanathan from Defence Research Development Laboratory)
6. TIG welding of 2219 Aluminium alloy (with K. Sampath)
7. Narrow gap submerged arc welding (with M. Mohanty)
8. Submerged overlay arc welding (with M. Mohanty)
9. Welding of Ti-6Al-4V alloy (with M. S. Rajendran from Kaveri Engineering Industries, Ltd.)
10. EB welding of cast steels (with C. Karthikeyan)
11. Trouble shooting of EB machine at WRI and its countermeasure (with

S. Muthukrishnan and V. S. Agwan)

12. Welding distortion in industrial line (with S. Suresh)

13. Welding of motor cycle flame (S. Suresh)

2) Optimization of welding variables in pressure welding process

A concept of feasibility study and development process until actual application were guided in case of pressure welding of austenitic stainless steel, pure copper, and their combination. Following items were particularly emphasized;

-A flow chart of development procedures were given, and the status of each step, its importance and evaluation method were fully instructed.

-Several items in the flow chart were demonstrated experimentally in order to give clear idea of conducting research. Specimen size of each material was initially determined from the view point of the machine used, and the effect of welding variables on the geometrical, mechanical and metallurgical properties of welded part was investigated.

3) Welding of ferrous and nonferrous alloys by fusion welding processes

In conjunction to the previous project, the said subject was undertaken in order to compare which process, fusion or pressure welding process, must be employed for the given materials. As there was not enough time to conduct experiamental investigation, the existing data of TIG welding in WRI were tried to compare with the results of pressure welding. However, due to the lack of enough data in TIG process, no concreate results could be extracted. Therefore, the expert adviced to counter person to conduct experiments just in the same way that was described in the previous subject.

4) Selection of optimum welding condition in Electron Beam welding

The subject was the original mission given to the expert. However, the EB machine in WRI was not usable state for this work. He checked the machine and following faults were clarified.

-The electron beam initiated under the condition of 20 kV-20 mA and 400 mm objective distance was very unstable and no sharp focusing was possible. Also, the filament life time was unbelievably short, maximum 2 hours which is extremely shorter than the normal life time of 100 hours, and the anode was damaged after the long operation.

-The above troubles were presumably associated by the thermal distortion of electron gun, especially the cathode and anode allignment. It should be necessary to replace the parts of whole gun.

5.5 MIG/MAG Welding

Mr. S. Hiramoto consulted and guided in the following subjects;

1) Classified items

(Research Projects)

1. Application of pulsed wire feeding MAG process to all position welding
2. Narrow gap MIG/MAG welding process

(Discussion and Ad-hoc Consulting)

3. Shielding problem in narrow gap welding (with K. Padmanaban)
4. Welding of aluminium and its alloys by reversed polarity plasma-arc process (with Sampath)
5. Bead formation and metal transfer phenomena in pulsed MAG arc welding (with A. Raja)

2) Application of pulsed wire feeding MAG process to all position welding

The said subject is one of the projects in MIG/MAG group of WRI aiming to apply the recently installed machine to circumferential welding of pipe. In general, a low frequency pulsed arc has an advantage for better sustaining effect of molten pool in various welding positions than in conventional DC processes. However, if the selection of welding condition or control method of machin is inadequate, the results are much worse than that of the conventional ways. The expert examined the machine and pointed out drawbacks of the machine system and recommended to remodel the machine suitable to the said purpose. He also suggested the necessary items to be made clear after the remodeling. Important suggestions are as follows;

-In contrast to the widely prevailed pulsed welding machine, the WRI's machine has controlling method that the arc current is pulsed by intermittent feeding of wire using a constant potential power source. This method is likely to accompany the arc instability due to the slow temporal responce of mechanical feeding system. Particularly, the machine is a push-type one and thus it is not appropriate for accurate control of wire feeding. The first suggestion was to reconstruct the feeding system from the push-type to pull-type or ideally to push-pull-type.

-The time constants of mechanical feed system and power source must be adequately adjusted in suitable range. Usually, the time constant of electric power source is higher than that of mechanical responce of feeding motor, the sequence of command signal of wire feeding must be in prior to that of power source. For this sake, the time constants of feeding mechanism and power source must be initially measured and an optional electronic control system must be designed and installed.

-As it was not possible to remodel the above items during the expert's stay, the further programme of research was discussed and advice. The most important item is to get the correlations between the pulse parameters and bead formation characteristics in four basic positions, i.e., flat, vertical down, overhead and vertical up positions. After established the optimum welding condition in each position, the circumfential welding must be started.

3) Narrow gap MIG/MAG welding process

A narrow gap welding of heavy section plate is an very important welding process because it can reduce the resultant heat input and distortion. In WRI, India, too, an original narrow gap welding process is under the development, but there were problems of unstable arcing and blow hole formation. Comments and sugestions by experts were as follows.

-In narrow gap MIG/MAG arc welding, the composition of gases is important item to be carefully controlled. As there is no premixed shielding gas available in India, gases have been mixed by the commercially available gas mixer. But, due to the unproper design of mixer, the precise mixing ratio has not been achieved. The experts pointed out the theoretical mistake of the mixer design and instructed how to mix gases correctly and stably. Also, they suggested to develop a right mixing equipment in WRI.

-The construction of torch developed in WRI had some problems in shielding effect of welding area and blow holes were likely to occur especially at the final layer. A suggestion of minor change of shielding nozzle design was given and the result was rather satisfactory. However, this prototype machine may not be applicable to very thick plate because sufficient electrical instulation is not provided at welding tip and wire guide assembly. Ceramics coating and employment of dual gas shielding method were recommended by the expert.

6. Consulting at Project Area (3rd Group)

6.1. Discription of Consulting

The third group of consultants served their missions at the WRI, Tiruchirapalli, India from September 26th, 1984 to November 7th, 1984 in the specific areas described below;

1) Prof. Dr. Akira MATSUNAWA

Occupation:	Associate Professor, Welding Research Institute, Osaka University
Qualification:	Doctor of Engineering Sixteen years experience in research, education and consulting. Expert members of domestic and international academic bodies in the area of welding physics and welding processes.
Post Title:	Automatic Welding Process and Welding Physics
Duration:	Sep. 26th to Nov. 7th, 1984 (1.5 months)
Duties:	To assist the counterpart groups, i.e., TIG and Plasma, MIG/MAG, and Arc Physics groupes, at WRI in the fields of; 1. Plasma key hole welding 2. Orbital pulsed TIG welding 3. Narrow gap welding 4. Low frequency pulsed MIG welding 5. Arc studies by high speed cinematography

2) Prof. Dr. Kohsuke HORIKAWA

Occupation:	Associate Professor, Welding Research Institute Osaka University
Qualification:	Doctor of Engineering Authorized Consulting Engineer Seventeens experience in research, education, and consultancy in derign of welded structures
Post Title:	Consultant in Finite Element Method. (Co-team Leader)
Duration:	Sept. 26th to Nov. 7th, 1984 (1.5 month)
Duties:	To assist the group of researchers and engineers in; 1. Basic knowledge of F.E.M. 2. Coding and installation of F.E.M. program 3. Execution of calculation on structural models

Consultants were also required to prepare the Final Report, setting out the findings of the mission and recommendations to the Government on further action to be taken.

6.2. Automatic Welding Process and Welding Physics

Prof. Dr. A Matsunawa conducted his missions though experiments and discussions in the following subjects;

1) Cassified items

(Research Project)

1. Plasma Key-hole welding-Back side bead optimization (Carg, Ananthan, Ashok)
2. Optimization of welding variables in pulsed TIG orbital welding (Carg, Nair)
3. Optimization of process parameters in narrow gap MAG welding (Padmanaban, Rohira)
4. Low frequency pulsed MIG/MAG welding (Raja)
5. High speed photography technique for arc study (Raja, Balraj)

(Discussions and Ad-hoc Consulting)

1. Role of ZrO_2 in Tungsten electrode for A.C. TIG (Carg, Ananthan, Ashok, Nair)
2. Bead formation in narrow groove by MAG process (Padmanaban, Rohira)
3. Relationship between power source and arc characteristics (Raja, Balraj)
4. Seam tracking-automatic welding (Padmanaban, Rohira, Raja)
5. Narrow gap TIG welding-Joint geometry, torch design and practical difficulties- (Carg, Ananthan, Nair)
6. Heat transfer in arc welding (Raja, Balraj)
7. Hollow electrode TIG process (Nair, Ananthan)

2) Plasma Key-hole welding-Back side bead optimization

In the Key-hole plasma welding, the optimum welding condition in much influenced by the torch design, especially by nozzle configuration, more than by the ordinary welding variables. Thus, the condition setting must be done individually depending on the nozzle used. The following advices were rendered on the experimental methods of determining optimum conditions.

- The most important variables in key-hole welding are the plasma gas flow rate, arc current and travel speed when the nozzle parameters are fixed, which are different from ordinary welding processes that are usually influenced by the latter two variables. It is, therefore, more complicated procedures of condition setting are required. One of the best way is to employ a mapping procedure in which the characteristic bead formation patterns are classified by domains.
- In a mapping procedure, percise observation of unfavourable or bad bead formation is particularly important, since one can get clear view how the each factor obstracts the sound bead formation.
- Mapping procedures must be first conducted for an ideal case, i.e., bead on plate welding at flat position. Once the mapping is completed for the ideal case, then the effects of other secondary factors such as gap width, joint misalignment, or welding postions can be easily understood by less experimentations.
- The above described method seems to be a time consuming process. However, in reality, the method is the most quick and economical way for optimization of welding variables. The method is more effective when there are many parameters to be cantrolled.

3) Optimization of welding variables in pulsed TIG orbital welding

Due to an excellent bead formation ability of TIG welding, the process is widely employed for root bead formation in various positions in spite of low efficiency welding process. In WRI the application of pulsed TIG arc to orbital welding of pipe is one of the important projects. In particular, the stable formation of root bead in each position is their urgent subject. The following advices were made;

- Before starting orbital welding, optimization of welding variables must be done by the flat plate welding in four characteristic positions, i.e., flat, vertical upward, overhead and vertical downward postitions.
- In each position the pulse parameters and their influence on bead formation must be fully investigated just in the same mapping method described in the above. Here, one must select the parameters that can be controlled externally. If the optimum condition setting is finalized in every position welding, the conditions for intermediate position can be easily deduced.

4) Optimization of process parameters in narrow gap MAG welding

A narrow gap MAG welding equipment which was originally designed in WRI has been improved by advices made by the second consultant group of this project. (See page 65). Using this modified apparatus, the MIG/MAG group of WRI has conducted experiments by CO_2 arc process and obtained the optimum welding condition. In the second step, the group intends to establish the MAG process which is widely employed in narrow gap welding because of better quality than that of CO_2 process. However, the behaviour of MAG arc is quite different and an arc is more sensitive to welding parameters as well as the equipment mechanism. The expert gave suggestions and recommendations as follows;

- In case of Argon-rich shielding gas, an arc is much more affected by the side walls of groove than a CO_2 arc. Therefore, the arc voltage is carefully controlled and it is necessary to understand the bead formation phenomena and its relation to welding voltage. Here, it should be noted that not only the good bead formation condition but also the bad one must be fully studied. The counter group carried out the mapping procedures by this advice.

- After finishing the preparation of welding windows, it is necessary to reveael the reason of critical phenomena of bead formation. By intensive observation of an arc and weld pool behaviour during welding, one can understand the mechanism and get the knowledge if the window of bead formation can be enlarged or not. For this purpose, the group conducted the high speed photograph observation as well as electrical characteristics of an arc.
- For the further improvement of equipment, the expert pointed out some problems of the torch and recommended the redesign of equipment. He also suggested the necessity of seam tracking device and gave several idears.

6.3. Finite Element Method

Prof. Dr. K. Horikawa devoted to give good understand of F.E.M. technique through the execution of Program Coding, Data Generation and Numerial Calculation on structural models. He also made discussion and ad-hoc consulting on wide rage of welding mechanics.

1) Classified items

(Research Projects)

1. Calculation of stress intensity factor using SAP IV. (with G. Balakrishna and H. Dattarajan)
2. De-coding and re-coding of standard program for elastic analysis (ibid)
3. Thermal-elasts-plastic program (with S. Suresh)
4. Development of program for small size computor (with R. Ragupaty and Balusubramanian)

(Discussion and Ad-hoc consulting)

5. Throat size of deep penetrated fillet welds (with H. Dattarajan)
6. Residual stress measurement using Rosset guages (with S. Suresh)
7. Residual stresses in Spiral Pipes and UOE Pipes (ibid)
8. Creep testing rig (ibid)
9. Stress releaf embrittement (with P. R. Vishnu)
10. Thermorestor (ibid)

2) Calculation of stress intensity factor using SAP IV

BHEL has already installed a FEM program named "SAP IV" which was develloped by Califirnia Institute of Technology, U.S.A.

WRI research group intends to calculate stress-intensity factors of various shape of structural parts for consultancy, as well as with various method, stress-, displacement- external work-done-, compliance- and J-integral-method for the better understanding of stress-intensity factor.

This project was started last year when the Consultant was there as a member of 1st consulting group, but not yet finished after one year.

The bottle neck was the lack of enperience in the operation of said program.

The half of duration was devoted the counter person to be familiar with computer input using a simple model of flat plate with a hole.

Then stress analysis and interpretation to stress-intensity factors were conducted on CT specimen and a model of a rivet hole with a fatique crack.

Through the exercise, the stress-intensity factor calculation precedure was almost established.

3) De-coding and re-coding of standard program for elastic analysis

The Consultant gave a series of lecture of FEM as a part of 1st mission and WRI people start to code their own program, but not succeeded.

This occasion, the Consultant introduced a popular FEM program in his home country.

Through de-coding the Consultant gave explanations and the couter-part person re-coded the program adjusting to their computer system.

The program is specialiged in two dimensional elastic stress analysis and has simple input data system, while SAP IV is for general structural analysis and requires many controll data.

The consultant expects the new program will be convenient for their daily use.

4) Thermal-elasts-plastic program

The cousultant handed a list of a program developed by JWRI which is use to analys transitional- and residual stresses due to welding.

He also gave detailed explanation on it.

This program consists of two sub program,

Heat conduction analysis by F.D.M.

Stress analysis by F.E.M.

and data exchange between them are made through bulk memory.

The counterpart person snall install the program ofter consulting with Computer Officer of BHEL on the bulk memory system of the Company.

5) Development of program for small size computor

WRI owns a personal computor "APPLE III" and its operating system "VISICALC".

Computor system group insisted to conduct stress analysis on structural models by said system

The Conslutant give a lecture for them on the basic concept for computor assisted structural analysis especially using Finite Element Method and Finite Difference Method.

He also made examples of one dimensional spring model for REM two dimensional stress analysis model FEM one and two dimensional heat conduction models for FDM.

6.4. Industrial Visits

All of six consultants sent to Project Area had visited into the High Pressure Boiler Plant of BHEL during their duty periods.
Prof. Dr. K. Horikawa and Mr. T. Matsuyama had also visited The Indian Hume Pipe Co. Ltd., at Poone, one of the world wide leading maker of penstock for hydro power stations. They met Mr. B. Ramaswamy Iyenger and discussed on the welding of heavy thick extra-high strength steel for penstock use at first consulting mission.

During this third consulting service, both Co-team Leader, Prof. Dr. A. Matsunswa and Prof. Dr. K. Horikawa made a industrial trip to get the informations on the industries which use welding as the primary method of production, on the type of welding they use, on the problems they have, and on the requirements and/or prospectives for WRI.
The names of the organizations visited and the gentlemen discussed were as follows,

Hindustan Motors Ltd., Earthmoving Equipment Division,
at Tiruvallur, Tamil Nadu
    Mr. A. Krishna Swami, Manager, QA & Reliability
    and other engineers

Larsen & Toubro Ltd., Bangalore Works,
at Bangalore, Karnataka
    Mr. G. S. Narajana, Welding Engineer
    and another engineer

Ind-Suzuki Motorcycles Ltd.,
at Hosur, Tamil Nadu
    Mr. N. S. Sridhar, Manager, Production Engineering
    and other engineers

Bharat Earth Movers Ltd.,

at Kolar Gold Fields, Karnataka

Mr. Y. T. T. Rao, Exective Director

Dr. K. Aprameyan, General Manager, Research & Development

and other engineers

Bharat Earth Movers Ltd., Railcoarch Division

at Bangalore, Karnataka

Mr. J. Swaminathan, Exective Director, Railcoach Division

Mr. K. Narasimhan, Asst. General Manager, R&D

and other engineers

Cochin Shipyard Ltd.,

at Cochin, Kerala

Mr. B. R. Sawakar, Chief Manager, Engineering

Mr. Mani Iyer, Manager, Planning.

On the way back to Home Country, the Consultants had the chance to meet Mr. Akira Shinohara, Director (Production) of Maruti-Udyog Ltd., Gugaon, Haryana. They discussed on the technical transfer between those countries which have different cultures.

7. Summary and Recommendation

The Welding Research Institute of Osaka University (JWRI) has completed all duties described in the Contract No. 82/101 between UNIDO and JWRI, namely the 27 man-months training of research engineers from Welding Research Institute in Tiruchirapalli, India (WRI) at JWRI and 12 man-months consulting by Japanese Experts at the Project Area.

During the training and consulting in the period May, 1983 to November, 1984, the consultants placed at the project area and JWRI staffs engaged in training have put various comments regarding to the improvement and promotion of future activities of WRI. We understand the difficulty of putting comments in another country having different cultures. However, it may be our responsibility as a contractor to introduce the Japanese ways of thinking.

a) Requirement to Individual Researcher

In order to improve the research effeciency and productivity, the following points were particularly emphasised to individual researcher during the training at JWRI and consulting at the Project Area;

- The needs and/or aims of the theme must be clarified.
- The planning is to be fully discussed with related persons or groups and the time schedule of project must be clearly settled. For this sake, the employment of a flow chart system at any level of research and development is very effective.
- The research work must be done by researchers themselves. In general, a researcher is not a supervisor but an intellectual worker, and the

efficient research products can be achieved by their integrated experiences and knowledges.

- Data collection and processing must be done carefully. A scientific approach is very important but one must not over estimate an existing theory. The most important thing is the experimental results if the data are collected under the appropriately and carefully controlled condition.
- Not only the results of a research, the processes how they come and the reasons why they come are also essentially important. One must not abondon the bad results but analyse them, because they contains a lot of very important informations that obstract the good results.
- Cooperation and interaction with other researchers and/or groups are mostly needed in WRI. As the welding is a typical interdiciprinary technology, the effort of a single person is not enough to produce a new technology. Every researcher must share his data and knowledge and unite them to develop a new thing.
- Continuous efforts of modifing the existing methods and remodeling the existing equipments or machines are essentially required for R and D researchers.
- Though basic research is necessary to improve the potential of individual researcher, most of works must be directed to application due to the purpose and policy of WRI. It is desirable that each researcher categorizes his research whose proportion may be 20% and 80%, respectively.

b) Additional Equipments and Softwares Required for WRI

The WRI, India is a very well facilitated welding laboratory from the view point of international level. However, some additional equipments and softwares are needed for WRI because research activities sometimes completely stop due to the lack of necessary equipments.

- The number of electric/electronic measurement equipments, such as the volt/ampere meters, analogue/digital recorders, oscillograms, amplifiers, various kind of transducers, etc, are too small in WRI as its research scale. These data collecting equipments are essential things in research and hence it is desirable that WRI invests more money in these facilities.
- The arc welding power sources in WRI are mostly magnetic amplifier types but these machines are not appropriate for the next age welding technology. It is recommended that WRI develops its own thyristor controlled power sources.
- It is necessary to develop the data processing systems in every research group depending on its own requirement.
- The development of specified computor programmes on structural analysis is also needed to evaluate fracture or cracked welded joints and structures, though WRI has a large scale universal programme.

In spite of having very sophisticated equipments in WRI, their functions have not been fully derived at the moment. It might be better to install small size but easy to handle specialized equipments rather than large universal ones. It is an urgent subject to strengthen then the maintenance and supporting system and also the supply system of parts and consumables to those machines.

c) Future Research Subjects and Training

The final purpose of the WRI is to be a nationwide center of welding technology in India that can serve every necessary informations and know-hows of the welding and its related matters to the Indian industries, research organizations and others. For efficient contribution of WRI to industies, it may be reasonable to focus the main research targets on average levels of Indian technology. According to the Japanese experts' opinions, the research subjects in WRI had better be divided into four major areas, i.e., 1) Welding processes, 2) Welding materials and consumables, 3) Welding design and structural analysis, and 4) Nondestructive evaluation, and their well balanced researches must be conducted. Presently, the most significant subjets in Indian industries are the improvement of productivity and quality to which the welding technology can play an important role. From the technical view point, the manual welding process must be gradually replaced by the semiautomatic arc (CO_2 and MAG arcs) and submerged arc welding processes in order to improve the productivity in the majority of industries. Also, the present materials and consumables for welding must be greatly improved in order to acquire the high quality. Therefore, the most important research items subjected to the WRI are the full examination of the currently used welding processes, materials and consumables, and their correlations and also the exploitation of next generation welding processes and materials by improving the existing equipments and materials.

As to the future training of WRI engineers in foreign countries, it is recommended to send the selected capable specialists in the above mentioned four areas and also to send a couple of generalists who can take over every fields. Since it takes longer time to train a researcher than to train a technician, the duration of training should be more than six months, preferably one year, for the effective training.

In concluding this final report, we express herewith that we have absolutely satisfied the sincere, eager and enthusiastic attitudes of Indian trainees. Owing to the kind hospitality of the peoples at the Project Area, experts have enjoyed local life there, in spite of some physical difficulties.

I, as a leader of the Project, should mention here that the human relations between Indian people and JWRI's staffs were perfect and we could deepen mutual understanding each other.

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