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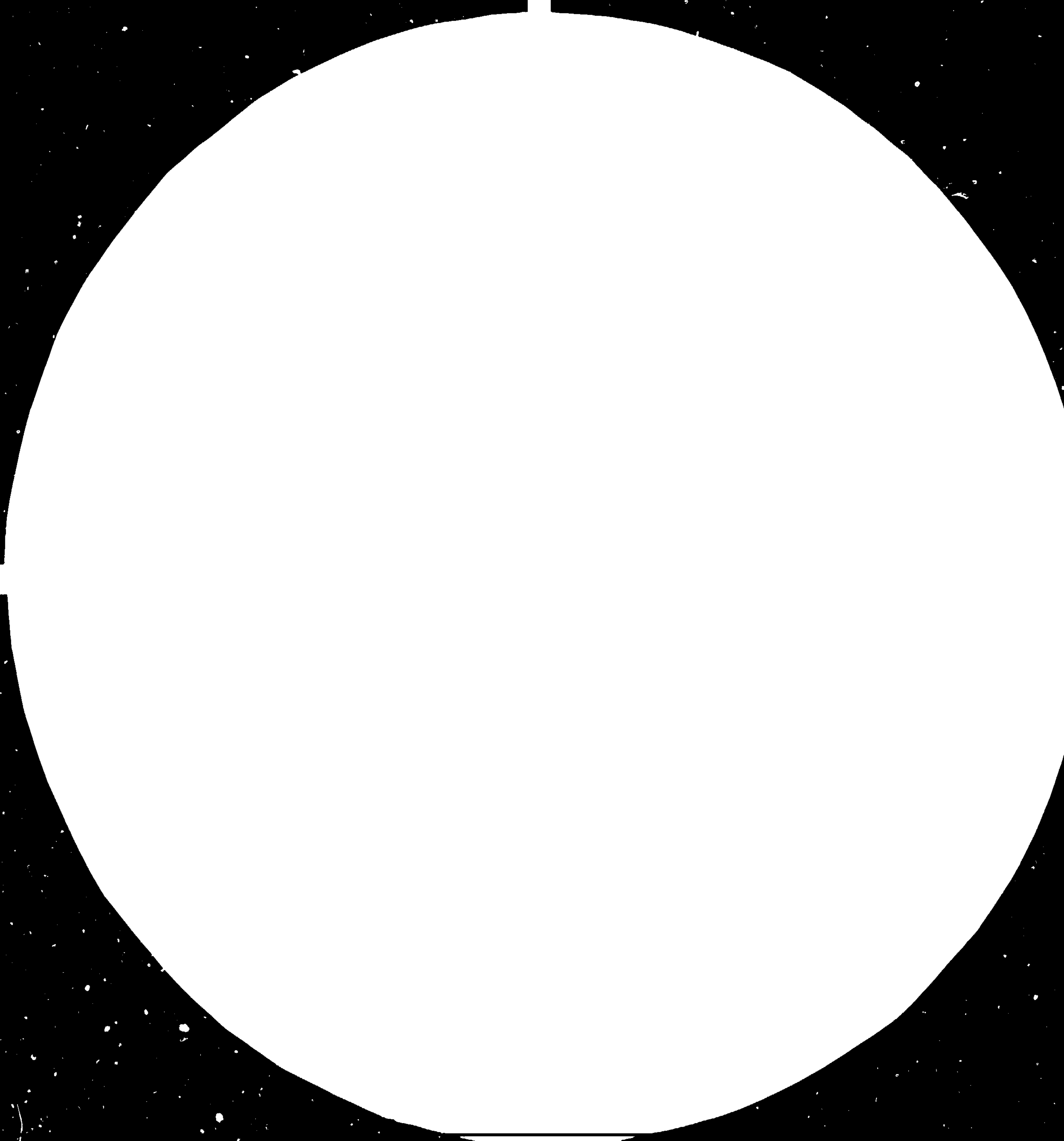

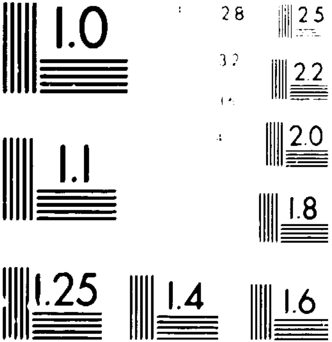


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# APPROPRIATE WELDING TECHNIQUES FOR MAINTENANCE*

by

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## 1.0 INTRODUCTION

It is reported that Jost enquiry conducted in 1966 estimated that each year British Industry lost in excess of £ 500 million through worn engineering components and their consequential effects. On the same basis, a figure of £ 500 million may be appropriate at today's cost.

### 1.1 Maintenance:

For any industry today, be it small, medium or large fitness to withstand the restraints posed due to diminishing finances, competition, technological advancements and catastrophic breakdown is a must. Within the available resources, it is relatively easy to combat the threats posed by breakdowns. With due care, the least we can do is to increase the cycle time between the recurring breakdowns. The precautionary measures taken to achieve the goal is commonly called by engineering management "Maintenance Management".

### 1.2 Importance of Welding:

Fabrication is one of the most important manufacturing activity. Rivetting, mechanical joining and crimping which were the major techniques employed in fabrication in early years, have lost the race to welding which today enjoys the enviable position amongst all the basic manufacturing processes. Welding which originally was an "art" has undergone the metamorphosis as "science" and today it covers the high technology area also. From the days of Kjellberg, in 1901 who has been accredited in inventing the first covered electrodes, welding technology covers the usage of Electron Beam and Laser techniques to join the metals and even plastics. Usage of welding as a basic manufacturing process goes deep down to micro levels today in the production activity. We are indeed indebted to our forefathers who invented/developed/innovated the existing welding techniques, so as to encompass the whole gamut of industrial requirement. We can repay this debt best by expanding our vision and using these techniques in most innovative manner. Developing countries like ours are today passing through the most critical phase. All these years we have been breast-fed and were under the tutelage of developed countries from whom we have established the industrial infrastructure. With the borrowed technology, it should be our endeavour to assimilate these technologies and adopt it suitably depending upon our individual needs and then disseminate to the other developing countries.

1.3 Role of National Welding Research Institute:

It was in this context, that the formation and establishment of a fullfledged National Welding Research Institute (WRI) with liberal technical assistance from UNDP/UNIDO was established by Government of India. Sustained efforts from all agencies concerned during past five years have enabled this Institute today to be one of its only kind in the world having its umbilical connection with a leading public sector fabrication industry like Bharat Heavy Electricals Limited (BHEL).

The research efforts of the Institute have been translated successfully in very many industries in India due to its unfailing stress on applied research. To cater to the needs of the country more effectively, research engineers at the Institute have applied existing welding technology in diversed areas.

All machine parts are having limited life due to inevitable constant and prolonged use and a degree of wear and tear takes place. Maintenance experts world over face this problem and many-a-times due to inadequate insight into the welding technology, the decision of replacement of the damaged part is made. Invariably the lead time for such machine parts is long, resulting in the stoppage of production activities, leading to loss of revenue. Majority of such examples, in retrospection, have been found to be ideal examples for reclamation by welding. It has been further amply proved that cost of reclamation has been many times less than the replacement. It is in this context that judicious choice and implementation of various welding techniques play a vital role in reconditioning of worn-out parts. Failure of the component, be it crack, wearing out or loss of surface properties, different welding techniques can be suitably employed to achieve the original properties. Diverse case studies arising out of the consultancy projects undertaken by this Institute, clearly indicate plus points of welding as an effective tool for reclamation and repair in industrial applications. Some of the interesting examples are enumerated in this paper for ready reference and some also indicate immense cost benefits rendered thus.

## 2.0 CASE STUDIES

### 2.1 Hardfacing of Sugar Mill Crusher Rollers:

#### 2.1.1 Need:

Due to the abrasive action during cane crushing the sugar mill crusher rollers teeth get wornout regularly and thereby reducing the crushing efficiency and increasing slippage. Such rollers are sent for reshelling once in two seasons costing around Rs.45,000/. The rollers once reshelled can be effectively used for crushing another 6 lakhs tonnes of cane. To reduce the frequency of this reshelling, special hard facing electrode is deposited on the roller teeth. This practice has been followed extensively in various other sugar producing countries but has not caught on in the Indian industries extensively due to the exorbitant cost of these consumables, which are being imported at the moment. WRI developed this electrode as part of the industry oriented project and extensive trials were carried out in an adjoining sugar mill for obtaining the complete feedback and now applied in sugar mills all over India.

#### 2.1.2 Development

This special electrode is directly deposited on the roller when the crushing is in progress without any difficulty.
The technique involved in depositing is quite simple involving appropriate position and angle for the deposition, apart from the fact that the electrodes should not continuously deposit the weld metal as

in case of normal welding but it should only deposit on the base metal as fine globules. The precautions should be taken not to have spray transfer or very large globules in which case weld metal would not stick to base metal in former and too much weld metal would be deposited in latter case. The electrode has been also very successfully used on the roller mounted on lathe during non-crushing season.

While depositing on roller mounted on the lathe, parameters would have to be suitably adjusted since due to the quenching action, globules tend to be in bigger size. This hard face deposit despite its high hardness (750 VPN on cast iron and 600 VPN on mild steel) has been found to have excellent machinability with carbide tipped tools. This machining is essential since even after hard facing, due to uneven loading pattern, non-uniform wear takes place on the roller teeth.

2.1.3 Advantages:

Rollers so hard faced after putting into service, have proved that slippage could be totally eliminated, crushing efficiency increases by 5% and hard facing gives a clear cost benefit ratio of 400%, when compared with reshelling even on a conservative estimate (See Box). Reshelling is the operation performed after the roller teeth are worn out beyond required limits by breaking the outer cast iron shell and the roller shaft is once again reshelled.

Hard Facing of Sugar Rollers Leaves Sweeter Taste

| | | |
|---|---|---|
| Cost of reshelling | = | Rs.45,000/-(Carried out giving an output of 6 lakhs tonnes minimum of cane crushed) |
| Cost of hard facing | = | Rs.1,875/-(15 Kgs. of electrode @ Rs.125/- per Kg. giving output of 1 lakh tonnes of cane crushed) |

$$\text{Cost benefit ratio} = \frac{\text{Cost of reshelling per lakh tonnes of cane crushed}}{\text{Cost of hard facing per lakh tonnes of cane crushed}}$$

$$= \frac{7,500}{1,875}$$

$$= 400\ \%$$

The cost benefit ratio so worked out has not taken into consideration other factors. (This is a conservative figure).

Dual advantage of such an electrode which deposits effectively both during on and off seasons can be very well exploited by sugar industries. During the seasons, hard facing can be done even when crushing is on, thereby reducing the down time to almost nil and during off-seasons, the rollers could be repaired in advance with hard facing deposits. The cost benefit ratio which gave a rosy picture had been possible only due to the indigenisation of these consumables which were hitherto available in Indian markets at almost 200% - 250% higher prices. Such experiments on 'Lab-to-land' basis would revolutionise the conventional maintenance techniques.

## 2.2 'Hot-Arc' - An Innovative way for Reclamation:

### 2.2.1 Weld Surfacing:

Weld surfacing is a technique which can be used not only as a manufacturing process but also as an excellent tool for repair and reclamation when additional metal is required to be deposited on the base metal either to build up to the required dimensions or to impart desired properties such as resistance to wear, abrasion impact or corrosion. In either applications, the prime objective is to conserve the most precious resources - money and material. The hot arc technique of weld surfacing employs manual metal arc welding process. The technique is quite simple and can be adopted by welders with little skill to obtain without distortion of the job, a defect-free weld.

### 2.2.2 The Problem:

The hot arc technique was evolved during reclamation of diesel locomotive cam shafts. These cam shafts hardened to 62 HRc and were found to be wearing out during service at one of the cam lobes. The extent of wear was around 2 to 4 mm and the chemical composition of material was -

| | | |
|---|---|---|
| C - 0.2 % | Mn 0.70% - 0.90% | S,P 0.04% Max |
| Si - 0.30% | Ni 0.40% - 0.70% | Cr 0.40% - 0.60% |
| Mo - 0.15 - 0.25% | | |

Since these shafts were imported, the landed cost and the lead time for the supply was enormous and it was mandatory to salvage these shafts by establishing suitable procedure for hard facing of the cam lobe, thereby conserving precious foreign exchange and also increasing the availability of these cam shafts in time. Various procedures were attempted and finally a suitable procedure giving desired weld quality was established. This procedure employed manual metal arc welding (MMAW) with a buffer layer of austenitic stainless steel weld metal and three-layers deposit of high speed (composition outlined in Procedure-A). Subsequently, another improved procedure was established using Hot Arc technique.

PROCEDURE-A

i) Worn out cam lobe was first ground to a depth of 8mm and liquid penetrant testing was carried out for ensuring removal of all defects.

ii) Consumable used : Buffer layer - dia 4mm, austenitic stain less steel 5 Nos.

Hard facing layer - dia 3.15mm, high speed steel 27 Nos.

iii) Parameters used : Buffer layer - 120-140 Amps, DC-ve Preheat-Nil

| | |
|---|---|
| Hardfacing layer | - 95-120 Amps, DC-ve preheat - 300°C |

Stringer bead technique was followed.

iv) Interpass temp. : 300°C

v) Post heating : Nil (slow cool to room temperature but covering with asbestos cloth)

In the above procedure, due to the nature of the HSS electrode, elaborate cleaning of the slag was required to be carried out. Moreover, due to the preheat and slow cooling, it took almost about 2 hours for one lobe to be hard faced but one was not in a position to guarantee crackfree deposits and also without distortion.

### 2.2.3 Hot-Arc Technique:

This technique also employs MMAW but in this, weld pool is never allowed to solidify until the desired height of the build-up is achieved. This technique is, in short, a modified casting process. To achieve this, the highest diameter of electrode is used with the maximum current and the weld area is covered on the sides using water-cooled copper shield bars so as to contain the molten metal and to optimize the solidification rate.

As soon as one electrode is consumed, to maintain the continuity and the molten pool, the arc has to be restarted with another electrode. This was better achieved by using two electrode holders simultaneously The copper shoes were specially designed to suit the jobs.

Since the height of the weld deposit required is difficult to assess during welding, due to high welding current, large molten slag and high feed rate of electrode, the height is maintained by using calculated quantity of electrodes. After the desired height is reached, weld is allowed to cool to the room temperature which is achieved very fast due to the chilling effect of the copper shoes. After the slag is removed, the weld surface is very smooth and finish grinding may be carried out for achieving the desired tolerances. This technique does not require any preheat and buffer layer. The consumable used was low alloy martensitic steel of composition - Cr 6.5%, Mo 1.0% and C 0.6% which gives 62 HRC surface hardness. After 7 mm deposit 10 Nos. of dia 6.3 mm electrodes, were used at 350 Amps. The total welding time for one lobe was only 15 minutes and it took only ½ hour for completion of one cam lobe.

The technique due to its inherent advantages of lesser operator skill requirement, defect free weld and lesser time is very much suitable for jobs of repetitive nature and where the area to be deposited is small.

### 2.2.4 Economics:

The economics of this technique when compared with conventional method taking into account only the cost of consumables used is given (See box).

| | | |
|---|---|---|
| Cost of consumabies | : | 5 x Rs.6.00 + 27 x Rs.10.00 = Rs.300 (@ Rs.6.00 per austenetic electrode and @ Rs.10.00 per HSS electrode) |
| Cost of consumables | : | 10 x Rs.8.00 = Rs.80.00 (@ Rs.8.00 per martensitic electrode) |

$$\text{Cost benefit ratio} = \frac{\text{Cost of consumables using Procedure-A viz, Rs.300.00}}{\text{Cost of consumables using Hot Arc Technique viz, Rs.80.00}}$$

$$= \underline{\underline{375\ \%}}$$

This calculation does not take into account either costs involved such as cost of preheating, and time taken for completion of one job. If these factors are taken into account, the ratio would be further boosted since there is no preheating in Hot Arc Technique and it takes only 20 % of the total time taken by Procedure-A.

Typical applications for this technique would be filling up of shafts, cams, shanks, etc., where area involved is small. The technique has limited applications where grooved or curved areas are involved due to difficulties in designing suitable copper shoes and fear of slag entrapment.

## 2.3 In-Situ Repair of Hydrogenerator Runner:

### 2.3.1 The Scenario:

Power generation is one of the most vital industries and as the nerve centre of entire production activities in any country. Timely availability of power attains the highest importance, especially so in the developing countries, since gap between demand and supply is quite wide. It is in this context the power plant engineers and welding technologiests should join together to evolve an optimal mix of in-situ and workshop repairs. This becomes a reality especially when inaccessibility and hostile site conditions coupled with urgency of putting the power plant into operation force engineers to resort to repairs at site under tremendous constraints.

2.3.2 The Failure:

A similar situation arose when hydro generator 1 at the Pong Power Plant (Fig.2), developed cracks in all the blades of the imported runner during the summer of 1979. When the runner blades were inspected, the damage was found to be extensive and serious. All cracks had initiated from the trailing edge of the blades and some had even propagated upto the crown. In all, 11 blades out of 15 had been found to be cracked. The intricacy of the repair would be best understood by the fact that the joint when prepared for welding was irregular having varying root gaps from 10 to 40 mm and depths upto 70 mm.

2.3.3 The Constraints:

Such a severe repair normally warrants elaborate welding procedure with due precautions and subsequent stress relieving in the furnace either in a workshop or in-situ. However, the investment in a furnace is not so recurrent a problem and was not economical coupled with time constraints. The inaccessibility and configuration of the job along with 13 Cr 4 Ni material totally ruled out the possibility of local stress relieving. At this stage electricity board authorities approached WRI for furnishing an economical and quick in-situ repair procedure. The runner blade materials was DIN GX-6 Cr Ni Mo - 134 having chemical composition as

| | | | | | |
|---|---|---|---|---|---|
| C | 0.052% | Mn | 0.75% | P | 0.005% Max |
| S | 0.004% Max | Si | 0.47% | Cr | 12.54% |
| Ni | 4.03% | Mo | 0.40% | | |

This conforms to normal martensitic grade of stainless steel (13% Cr, 4% Ni). Welding of such materials normally calls for use of matching filler materials. However, matching martensitic filler materials also warrant elaborate preheat, post weld stress relieving in absence of which proper mechanical properties of weld metal are not guaranteed. Moreover, due to the high thickness variation (10 times), even the heat input control would be a serious handicap. If this is not maintained and if the interpass temperatures are allowed to rise above 250$^{o}$C, coarse microstructure would be formed to leading to loss in toughness properties and also enhancing susceptibility to cracking. Preheating and subsequent stress-relieving could also lead to substantial distortion of blades.

## 2.3.4 Selection of Filler Material:

In view of the above and also the enormous amount of weld metal to be deposited, it was of paramount importance to choose suitable filler material that would impart good mechanical properties, high corrosion resistance, fracture toughness to the weld metal and would also have minimum susceptibility to cracking. After proper choice of filler material, it was also essential to adopt appropriate weld sequencing that would take care of distortion aspects by balancing the heat input during welding through sequencing.

After careful analysis and study, the field was narrowed down to AWS E309 - 16, E309 Mo 16 and E308 L. The all weld composition of these electrodes is -

| | | |
|---|---|---|
| E 309 - 16 | : | 25% Cr, 12% Ni |
| E 309 - Mo 16 | : | 25% Cr, 12% Ni, 2.5% Mo |
| E 308 L | : | 18% Cr, 8% Ni, (extra low carbon) |

All the above consumables are basically depositing austenitic stainless steel weld metal which was chosen due to their inherent low susceptibility to hydrogen crackings and avoidance of preheating and post weld stress relieving. Choice of Mo bearing weld metal was chosen mainly due to its properties of improving tensile strength and corrosion resistance. Wherever excessive cracking had taken place, buttering with 309 Mo 16 was recommended. E 309 Mo 16 was chosen for filling up the groove.

2.3.5 <u>Welding Procedure</u>:

Detailed procedure with elaborate weld sequencing was recommended so that welding was carried out symmetrically around the neutral axis to control the distortion and residual stress build-up. The recommended procedure is given below:

i) Remove the crack completely and prepare double Vee-Edge for the joint. To reduce the stress build-up during welding and to reduce total weld metal to be deposited. As far as possible, prepare shallow double Vee where thicker sections are involved. Check the base materials for presence of any defects by LPI.

ii) Butter the joint with E 309 Mo 16 with reduction in the angle of Vee and also to make the joint uniform as far as possible for subsequent filling up. Use stringer bead technique and check the buttered layer for the presence of any defects by LPI.

iii) Fill up the remaining joint using E 309 Mo 16 using stringer bead technique and maintain interpass temperature at 100$^{o}$C. Take precautions to grind off the start and craters and peen the weld for distribution of residual stresses.

iv) Welding to be carried out in symmetrical fashion as per the sequence given, starting from the neutral axis and proceeding outwards, in down hand position. Neutral axis was to be so chosen that amount of weld metal to be deposited is balanced on either side of the axis

v) Root run given from one side is subsequently to be ground from the other side, dye checked and welded from back side. For the distortion control, welding is to be carried out alternately on either sides

vi) Immediately before the welding, the electrodes to be baked as per the prescription of the suppliers

vii) Interpass cleaning of slag, dye checking after every layer to be carried out.

2.3.6 Implementation:

This procedure was implemented by the customer for in-situ welding of runner 1 with a good degree of success. There were no problems as regards to the welding and distortion. Nominal distortion was observed which was ground of and subsequently runner has been reinstalled which is functioning statisfactorily till date.

This case study reveals a very vital factor in the repair and reclamation areas - i.e., it is always not necessary to adopt the concept of 1:1 replacement or matching replacement as long as the alternative suggested satisfies the functional requirements.

Many a times, we must also understand and learn to sacrifice little on the service life offered by new alternatives, provided it is giving satisfactory returns. This was amply proved by yet another case study wherein the Institute employed fracture mechanics approach to determine the influence of defects in the repaired component on the service life of a pressure vessel.

## 2.4 Learning to Live with a Defect:

WRI undertook on a fire-fighting basis, the repair of a hydraulic cylinder from a Plywood Company used for consolidating the 'plays'. The hydraulic pressure is 315 ata and the crack was noticed when the pressure did not build up.

It was reported by the user that the cylinder is subjected to a fluctuating load cycle of pressurising and depressurising to 315 ata @ 4 minutes per cycle of operation using oil-water emulsion as the working fluid. The component had been imported by the plant about 18 years before the defect arose and had been in operation for over 15 years. The chemical analysis done in our Institute showed inhomogenity particularly with reference to carbon as presented below /**/. It was also observed on close examination that the large cracks which led to leakage, were located in the junction between the flange and shell. The transition in this region was very sharp, with almost no radius between the flange and the shell leading to higher stress concentration.

/**/ Chemical Composition (%) of the Cast Steel

| C | Mn | S | P |
|---|---|---|---|
| 0.46 to 0.53 | 0.7 | 0.012 | 0.014 |

The user having no spare cylinder was put to heavy financial losses per day due to non-operation. After analysis of the problem, the repair procedure was worked out and taken up.

### 2.4.1 Repair Procedure:

The following procedure was adopted, MPI and UT were done to assess the location and depth of the crack in the function of the flange portion. The crack was completely removed by gouging and grinding. The gouging was done under a preheat of 250°C and the surface grinding for welding purposes was done to satisfactory clearance of MPI. At a preheat of 250°C, E 7018 electrodes, which have been dried at 350°C were used for buttering the sides to reduce the carbon migration in the final weld metal. Later the filling up was done in two phases - first phase to half the quantum of the groove and later the second phase of filler was carried out- an inter-stage stress relieving heat treatment was carried out at 600-650°C/4 hours between the two phases. The final post-weld heat treatment was also done at the same temperature range and soaking period followed by very slow cooling @ 30°C/hour to avoid stresses which could accumulate through faster cooling. The final inspection was done by UT. The sharp corners in any component depending upon the service conditions may give rise to concentration of stresses, which may lead to premature failure of the component. Hence, a submersible groove was machined to offset the concentration of stresses as the rounding of the corners projecting outside could not be tolerated due to assembly pattern.

## 2.5 Plasma Applications:

In the case studies discussed above, the welding process followed has been basically manual metal arc welding. MMAW is very widely used due to its inherent advantages like ease in operation, lesser capital outlay, faster application, lesser skill requirement, ready availability and higher versatility when compared with more sophisticated processes of date. Of course not all processes can be successfully used for maintenance applications. Plasma spraying and plasma surfacing have been found to be quite advantageous in many a cases where conventional techniques have been found to be tedious, time consuming and not defect free.

### 2.5.1 Surface Treatment:

Surface treatment has been used since the earliest days of metal working to impart special properties to the base material. It is often the most economical and effective way to increase the service life of worn out parts, repair of under machined components and to impart wear, abrasion and corrosion resistance and other properties, whenever the deposition is of the order of few microns. Until recently thermal spraying process was most popular for this purpose but slowly plasma spraying is proving to be a better alternative (Table 1).

2.5.2 Plasma Spraying:

In plasma spraying, the plasma-ionised gas is created by constricting an arc through the water cooled copper nozzle and this plasma has a very high temperature between 10,000$^{\circ}$K to 20,000$^{\circ}$K and high speed of 3,000 M/sec. Due to such high heat input and speed involved, most of the materials in the form of powder or wire can be effectively deposited on the base material. Due to the high temperature and speed, the coating is also dense and adheres with porosity levels as low as 1%. Since there is no direct base material heating unlike in thermal spraying, distortion is also minimised to a greater extent. These features makes this process versatile and can be used effectively to spray metals and their alloys, ceramics, ceremets and plastics while the substrate may be metal, ceramic or plastic (Table 2).

2.5.2.1 Areas of Application:

The limiting factor for wider implementation of plasma spraying has been the high capital investment. However, the running cost of this equipment is comparable with other existing alternatives. Thus barring high initial cost, this technique scores by large margin over existing techniques due to its high heat input, speed flexibility and low contamination due to inert atmosphere . With its versatility in deposition of any material, plasma spraying has a pivotal plane in wide cross-section of industries such as power plant, automobile, steel cement, petrochemical, aerospace, etc. In such core industries where volume of maintenance activities is very high, plasma spraying facility would amply justify its presence. Some of the typical components where plasma spraying has been effectively implemented are - coal feeding nozzles, fan blades, worn out and undermachined large components like fan shafts. This process has its own limitations of the thickness of spray and the service conditions.

### 2.5.3 Plasma Surfacing:

By and large, fusion welding processes have been the most widely sought methods to combat problems of wear abrasion etc, by hard facing the worn out components. Some of the common fusion welding processes that are followed today for hard facing are MMAW, Gas Welding, SAW and Plasma Surfacing. The comparison chart (Table 3) clearly brings out the merits and demerits of each process. Among these, most of the welding processes are associated with either low deposition rates or higher dilution levels warranting higher number of deposit layers and larger dimensional allowances in the material to compensate for the distortion due to higher heat input rate. However, the plasma surfacing process has the combination of higher deposition rate (upto 6 Kg/hour) with less dilution levels (5% to 20%) due to its higher concentrated arc and due to better control on the heat input rate.

2.5.3.1 <u>The Process</u>:

Plasma surfacing is an arc welding process where an arc is created between non-consumable tungsten electrode and the job in inert atmosphere and is constricted through water cooled copper nozzle. Due to constriction of arc, plasma with a temperature of 10,000$^{o}$K to 15,000$^{o}$K is developed which is responsible for higher welding speed and higher deposition rates. Filler material is added in the form of wire or powders. Greater stand-off distance permitted in plasma arc, enables to maintain constant welding conditions throughout the surfacing and there is ease to feed a wire or powder into plasma instead of molten pool which in turn gives lesser dilution. The molten pool and weld metal is protected against atmospheric oxidation by inert gas and unlike SAW and MMAW there is no requirement of slag removal after welding and defects like slag inclusion are eliminated.

The development and establishment of plasma surfacing process has opened a vast area of application in the field of maintenance. Due to its inherent technological superiority over the existing processes and also the greater adaptability of the process to automation, this process would play a key role in the maintenance activities. A few of the wider range of components which has been plasma surfaced for increasing service life and effectively reclaming worn out components are valve wedges, stems, seat rings and under machined/sized machine parts.

## 3.0 CONCLUSION

Application of welding technology to solve the problems of maintenance has been long neglected mainly due to lack of knowledge and lack of foresight. It has been much easier to throw away the worn out or failed component and replace it with a brand new one when compared with the efforts required to make good the worn out components. Little do we realise that these efforts are well spent saving enormous amounts of money in the long run.

Our survival is not by instinct but by application of our mind, thought and action. The foregoing few experiences of the Institute and many such examples in very many similar situations, make a strong case for judicious selection of appropriate welding technique and implementation of the same to reap the harvest. The Welding Research Institute, Tiruchirapalli, India, considers this workshop a unique opportunity provided by UNIDO to share their experiences with the distinguished colleagues present here but also could involve themselves in any problems presently faced in developing countries. WRI would like to appreciate the efforts of UNIDO in this direction and also thank them for providing this excellent chance to propagate this message amongst the developing countries.

* * * * *

TABLE-1: FEATURES OF THERMAL SPRAYING PROCESSES

| | FLAME | ARC | PLASMA | DETONATION |
|---|---|---|---|---|
| Impingement speed, m/sec | 100 | 100 | 150 | 800 |
| Approx. Temperature, K | 3000 | 5000 | 20000 | 4000 |
| Typical deposit porosity, % | 10-15 | 10-15 | 1-10 | 1-2 |
| Typical adherence, $MN/m^2$ | 7 | 10 | 30 | 60 |
| Advantages | Cheap<br>High deposition rates | Cheap<br>Low contamination<br>Cool substrate | Low porosity<br>Good adhesion versatile<br>Low contamination | Very low porosity<br>Very good adhesion cool substrate |
| Limitations | Normally high porosity<br>Inferior adhesion<br>Heats work-piece limited | Only electrical conductors<br>Normally high porosity | Fairly expensive | Very expensive<br>Low efficiency |

TABLE-2: PLASMA SPRAYED MATERIALS

| METALS AND ALLOYS | CERAMICS | PLASTICS |
|---|---|---|
| Aluminium | Alumina | P.T.F.E |
| Chromium | Chromic Oxide | Ekonol |
| Copper | Titania | |
| Iron | Zirconia | |
| Molybdenum | Chromium carbide/Nickel | |
| Nickel | Tungsten carbide/Cobalt | |
| Silver | | |
| Tungsten | | |
| Zirconium | | |
| Cobalt | | |
| Titanium | | |
| Tantalum | | |
| Aluminium bronze | | |
| Stainless Steel | | |

TABLE-3: COMPARISON OF VARIOUS SURFACING PROCESSES

| Sl. No. | Process | Deposition Rate normal Range Kg/hr | Weld Dilution Normal Range % | Minimum Deposit Thickness mm | Filler Metal Form |
|---|---|---|---|---|---|
| 1. | Oxy-Acetylene | 0.5-2.0 | 1-10 | 0.75 | Rod, Powder |
| 2. | Gas Tungsten Arc(Cold Wire) | 0.5-2.0 | 10-15 | 2.00 | Rod, wire |
| 3. | Gas Metal Arc (Single wire) | | | | |
| | a) Short circuit transfer | 0.812.5 | 10-25 | 1.50 | Wire |
| | b) Spray type transfer | 3.5-6.0 | 20-70 | 3.20 | Wire |
| 4. | Submerged Arc (single wire) | 4.5-8.0 | 30-60 | 3.20 | Wire |
| 5. | Plasma Arc (Powder) | 0.4-6.0 | 5-30 | 0.38 | Powder |
| 6. | Plasma Arc (Single cold wire) | 0.5-6.0 | 5-20 | 2.30 | Wire |