

Hard facing of Sleeves and Bottom Plate of Grid Plate for PFBR

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Abstract

BHAVINI is constructing Prototype Fast Breeder Reactor(PFBR), forerunner of FBRs, a 500 MWe sodium cooled, pool type, mixed oxide (MOX) fuelled reactor at Kalpakkam. Presently PFBR is in the advanced stage of construction. The reactor basically consists of Main Vessel housing the Primary sodium circuit. Main Vessel contains the primary sodium and supports the Core, Grid Plate, Core Support Structure, Core Catcher and Inner Vessel. The principle material of construction of these components is SS 316LN. The coolant, liquid sodium, acts as a reducing agent, removes the oxide film formed from the surface of the Stainless steel and provides a clean metallic surface. When two such surfaces come in contact under high pressure and temperature, self welding (galling) can occur. To avoid this, hard facing is done on the matching surface. Grid Plate is having such interfacing components like Core subassemblies supported on top of the GP sleeves and GP bottom plate supported on Core Support Structure at bottom. Hardfacing using Nickel base cobalt free Colmonoy alloy is carried out on inside diameter of sleeves and on the Bottom plate using PTAW process. This paper presents the experience during hard facing of Sleeves and Bottom plate of Grid Plate.

1. Introduction

The Prototype Fast Breeder Reactor is a 500 MWe, Pool type reactor with all the reactor assembly components including Core and primary sodium circuit contained in a single vessel called main vessel. All the core subassemblies, inner vessel, and in-vessel transfer post are supported on grid plate (GP). Grid plate is bolted to the core support structure (CSS) at its outer periphery. The entire load is transferred to the main vessel through CSS. The material of construction for grid plate is SS 316LN as per PFBR specification. In order to prevent self welding, hard facing is carried out at all matching surfaces like top chamfer and inside diameter of sleeves, bottom surface of bottom plate, top and bottom bearing pads of intermediate support locations of grid plate. Process of hard facing is established taking into consideration the practical feasibility of the two extremities – hard facing on large and continuous annular tracks (ID 6360 & 6750) on bottom plate and constrained location on the inside diameter ($\varnothing 81.3\text{mm}$ for 27mm width) at 468 mm from the top of sleeve. These hard faced surfaces were machined to meet flatness, parallelism, concentricity, straightness requirements and hence, various mock ups

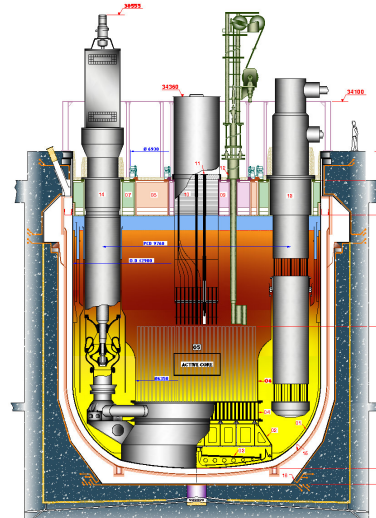


Fig 1: Reactor assembly

were performed towards establishing the procedure. Preheating and maintaining the temperature at 650°C during hard facing and controlling distortion was a challenge. Independent fixtures were designed for sleeves and bottom plate to enable deposition by automatic Plasma Transferred Arc Welding (PTAW) machine. After finish machining, the dimensional tolerances was respected while meeting all the chemical, mechanical properties & metallurgical characteristics as per the specification. This paper address all the manufacturing challenges faced in order to achieve crack free deposition and the specified dimensional requirements during hard facing of bottom plate and sleeves for grid plate.

2. Description of grid plate

The grid plate ($\varnothing$ 6.8 m and 1 m ht) is a bolted box type structure consisting of top and bottom plates of 50mm thick interconnected by 1758 sleeves and an outer cylindrical shell. Both the plates are perforated in identical triangular patten (135 mm pitch with a tolerance of ± 0.1 mm on co-ordinates of hole locations with respect to the reference axis). The corresponding holes are connected by 1758 sleeve assemblies consisting of sleeves, sleeve top and bottom nuts. The core subassemblies have a line contact support with 45° chamfered hard faced surface provided on the top of sleeves. The feet of the core subassemblies enter into the sleeve assemblies. Sodium enters the inlet plenum in grid plate through four pipes connected to the nozzles of shell. It then enters inside the subassemblies thorough the holes in the sleeves and slots at the feet of core subassemblies.

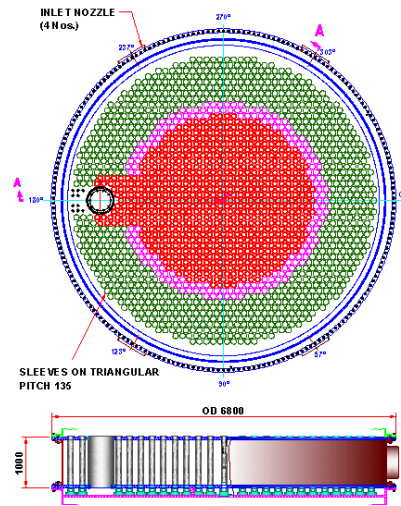


Fig II: Grid plate

3. Requirement of hardfacing for sleeves

The grid plate sleeves supports vertically all the 1758 subassemblies in their predetermined zones and permit their insertion and withdrawal of subassemblies. The subassembly comes in contact with the sleeves at two points, one at the top of the sleeve where the subassembly is supported and the other on the inner surface of the sleeve at $\varnothing 78.8$ H7 for a width of 25mm at 468mm from the top of the sleeve. Top of the sleeves is having a conical surface in order to provide line contact support to the core subassemblies. These surfaces are hard faced to prevent galling of subassemblies with the sleeves and also to minimize wear during subassembly insertion / removal.

4. Requirement of hard facing for bottom plate

Grid plate is supported on CSS by bolting the bottom plate with CSS flange. Bottom plate is 50 / 55 mm thick and $\varnothing 6800$ mm. The interfacing surface between GP and CSS is

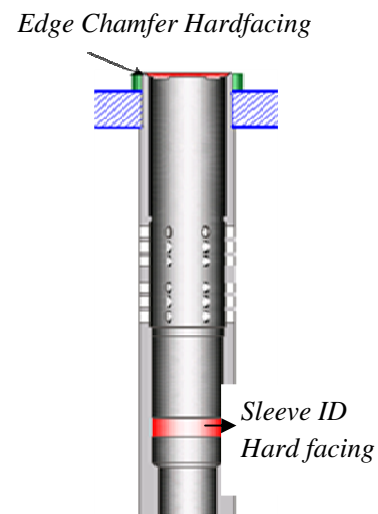


Fig III: Typical grid plate sleeve

subjected to galling or self welding under the influence of Core load during reactor operating temperature of 670K. During reactor operation, there will be relative radial thermal expansion between GP bottom plate and CSS flange due to thermal transients. Hence, radial movement should be permitted to avoid harmful thermal stresses being developed at these locations. Therefore hard facing is carried out in the bottom face of bottom plate at two annular locations – one at ID 6360 mm and the other at ID 6750 mm for 20 mm width. These hard faced coating should have sufficient bond strength during thermal cycles without flaking. Also, grid plate serves as a plenum for distributing the coolant sodium flow to the subassemblies hence sealing between the bottom plate of grid plate and CSS is required. Any cracks in the annular tracks will create a leak path for the sodium plenum. Achieving crack free deposition is therefore crucial. Dimensionally, the hard facing profile, thickness, horizontality of hard facing tracks, the relative height between the two hard faced tracks are to be respected.

5. Deposition by Colmonoy – 5 Alloy using PTAW Process

Even though Stellite alloys (Cobalt based) hardfacing material are most widely used due to their excellent strength high temperature, galling resistance, better impact strength at high temperature and corrosion resistance, these alloys are form Cobalt⁶⁰, a gamma emitter, due to the irradiation in the reactor environment. It will be difficult to repair / inspect / maintain the components such as primary sodium pump, intermediate heat exchanger, control plug etc., due to the presence of gamma field from cobalt⁶⁰. Hence nickel based Colmonoy is considered to avoid the risk of induced gamma activity. PTAW process was chosen due to low dilution of weld deposition with the base metal and meeting the required hardness values of 45 to 50 HRC. Thinner coatings were therefore preferred due to better thermal shock resistance and reduced accumulated residual stresses.

6. Welding Procedure qualification for hard facing

The welding parameters are optimized to minimize the magnitude of residual stress, to eliminate the risk of micro cracking, dilution of deposit and de-lamination of the hard face deposit. The preheat temperature, coating thickness, heat input, deposition process and the geometry of the component were finalized bases on extensive mock up. Accordingly travel speed, oscillation distance, gas supply were decided to achieve the desired metallurgical and dimensional results. Same was chosen for grid plate as well. Table I indicates some of the parameters of welding procedure qualification. The welded coupons were subjected to metallographic examination, micro hardness (tangential & longitudinal), surface hardness, thickness measurements, IGC & bend test and chemical analysis. The test results were meeting the specification requirements.

7. Hard facing of bottom plate

Extensive mock up were performed during Technology development of bottom plate hard facing. Since, preheating has to be carried out at 650°C and subsequently, PWHT at 750°C with controlled heating and cooling cycles, large furnace have to be qualified. Bell type furnace was used. Controlling the distortion of 70mm thick Ø 6830mm plate during preheating, hard facing & subsequent heat treatment was significant. Hence, dummy load

trials were performed with thermocouples on top face in concentric patterns at different diameters. Location of bottom plate, its alignment, supports inside the furnace were decided to ensure free to expand due to heating. Proper fixtures were provided during heat treatment to control distortion. For simultaneous movement of 4 automatic PTAW machines circumferentially, fixtures have been exclusively developed along the concentric grooves of hard facing (ID 6360 & 6750 mm)



Fig IV: Hardfacing simultaneously by 4 PTAW machines

Difficulties were faced during hard facing since preheating temperature has to be maintained at 650°C. Deposition was carried out by 4 sets of PTAW torches mounted on X-Y slides moving on 4 carriages with variable speed control which moves on a specially made centralized fixture. Each carriage covered 0 - 90°, 90 - 180°, 180 - 270° and 270° - 360° segments respectively. Each carriage was manned by a welding operator. Preheating was done by the bottom coils of the furnace. Welding sequence was 'Start' from each quadrant, weld in the outer groove in the Clockwise direction and 'End' in the limit of each quadrant (one quarter of the circumference). Then the torches were shifted to Inner groove and weld in the inner groove in Anti-clockwise direction with all the 4 torches operated simultaneously. Once hard faced, the deposited areas were immediately covered with Ceramic wool. All the preordained welding parameters were strictly respected and thus, a crack free hard faced deposit was achieved on both the annular tracks. Practically no distortion was observed before and after hard facing of bottom plate

Sufficient machining allowance was kept at every stage of fabrication in order to meet the final dimensional requirements. Subsequent to hard facing, PWHT was carried out at 750°C with controlled heating and cooling rates. Details of heat treatment cycle are covered in para 9. After heat treatment, the annular tracks were machined with the flatness and parallelism requirements of 0.2 mm w.r.t the top face. Hard facing was also carried out in the production test coupon and the test results of these deposits are recorded.



Fig. V: Bottom plate Hard facing

8. Hard facing of Sleeves

Due to the difficulty in approaching the areas for internal hard facing using conventional welding equipment, a special type of equipment was developed. Fixtures were designed to rotate the sleeves at 45° inclination to meet the required deposition rate. The sleeves are proof machined maintaining groove ID $81.3^{+0.10}$ / 27mm width with 30° taper on both edges. The grooves were examined by visual and LPE examination. For 40 numbers of sleeves, uneven thickness in hard facing was observed. On detailed deliberations, the existing hard facing was removed and re-deposition was carried out followed by 750°C heat treatment. Distortion of

sleeves during hard facing was monitored as any bending will significantly affect the insertability of core subassemblies. Welding parameters were constantly monitored and recorded to be in conformance with the welding qualification parameters. After hard facing, the sleeves were kept in the Vermiculate powder for post cooling process. Finally, after hard facing at this crucial inaccessible location, machining was carried out and tolerance of $\varnothing 78.8$ (+0.030 / - 0.000) mm was achieved with concentricity requirement of $\varnothing 0.01$ mm at the extreme ends after 750°C heat treatment cycles.

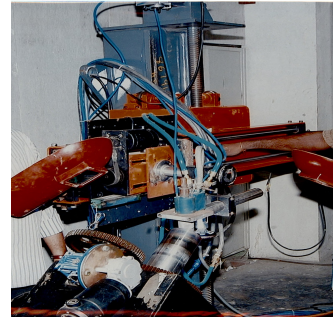


Fig VI: Chamfer HF using PTAW Machine

9. Heat Treatment cycle

9.1 Heat treatment cycle followed for hard facing of Bottom Plate:

Loading temperature in Furnace : 350°C (Max) as per specification	
HT Operation	Specification requirements
Hard facing operation carried out at 650°C	
Rate of heating	Up to 500°C : 30 to 40°C* ; 500° to 650°C : 20 to 40°C* & 650° to 750°C : 10 to 30°C*
Holding temperature	750°C $\pm$ 15°C
Holding time	2.5 min per mm
Rate of Cooling	750°C to 500°C : 20° to 40°C/hr ; < 500°C (Furnace cooling)

*The values were revised from the specification based on the results from welding procedures due to hard facing in open furnace covered with Ceramic Wool. Due to huge volume of the furnace, the required heating and cooling rates were difficult to achieve.

9.2 Heat treatment followed for hard facing of Sleeves:

- Loading temperature in Furnace : 350°C (Max)
- Rate of heating : Up to 500°C (Slow heating) + 500°C to 750°C (30° to 40°C/hr)
- Holding temperature : 750°C $\pm$ 15°C
- Holding time : 2.5 minutes / mm thick
- Rate of cooling : 750 to 500°C (20° to 40°C/hr with controlled air flow) and below 500°C (Furnace cooling).

Electrically Heated Bogie Hearth Furnace was used for heat treatment of sleeves after hard facing. 108 sleeves (18 x 6) are heat treated in a batch. Thermocouples were located in top, middle and bottom location of sleeves. The above heat treatment cycle were achieved for all the 1758 sleeves after hard facing.



Fig VII: Sleeves in electrical bogie furnace

10. Non Destructive evaluation of hard faced areas :

Liquid Penetrant Examination: LPE was carried out for detection of surface discontinuities viz., cracks, porosity in the hard faced areas using solvent removable visible penetrants. Few indications were observed at different location after hard facing of Bottom Plate. Based on the type of indication (not cracks) and considering the functional requirements of hard facing and location of the indications, they were accepted. After stabilizing heat treatment and

machining of hard faced areas of edge chamfer and inner diameter locations, no indications were observed.

Ultrasonic Examination : Ultrasonic Examination was carried out for detection of cracks and any lack of bond between Colmony hard face deposits and Sleeve / Bottom plate . Scanning was carried out for sleeves in ID78.8mm and on edge chamfer with radial, axial and circumferential scanning techniques. Scanning was carried out for Bottom plate after hard facing in the respective tracks by straight beam, angle beam & surface beam to detect lack of bonding between the parent metal and Hard facing deposition. Few point discontinuities were observed which were accepted after detailed review.

The indications in LPE & UE observed are very minor in nature, when compared to the criticality of hard facing deposition. The effect of these indications was reviewed in detail and was accepted.

11. Dimensions after final machining of hard faced areas:

There was practically no distortion after hard facing and subsequent heat treatment of Bottom plate. As sufficient machining allowance was kept during hard facing, the final dimensions were met as per the drawing requirements. Some of the relevant dimensions are as follows.

- a. Thickness of 2 hard faced tracks : Outer Track - 1.09 / 1.12 mm & Inner Track: 0.70 / 0.80 mm against 1mm (min) as per requirement
- b. Width of hard facing : 20.1 mm against 20mm
- c. Inner diameter of Inner track : Ø6359.89 / 6359.97 against Ø6360 mm
- d. Outer diameter of Outer track : Ø6789.6 / 6789.9 against Ø 6790 mm
- e. The Flatness of Inner track and Outer track are 0.2mm & 0.15 mm respectively against 0.2mm
- f. The Parallelism of Inner track and Outer track are 0.10m & 0.1 mm respectively against 0.2mm with respect to the top face of the bottom plate
- g. Surface finish better than 0.8 microns.

After machining the hard faced areas, un-machined areas were observed on the hard face tracks of Bottom Plate – one on the Inner track with 0.1mm depth and 15mm width and two on the Outer track of HF with 1mm depth & 8mm width & 0.6mm depth & 65mm width. Attempting to remove these areas by further machining will result in reduction of the bottom plate thickness by 1mm. The issue was critically reviewed. The presence of un-machined patches is insignificant as the loss of leakage flow due to un-machined area on the inner track (Depth of 0.1mm) is inconsequential and the variation was in the order of bottom plate flatness. Also the loss of load bearing capability due to the presence of 2 un-machined areas on the outer tracks is insignificant; hence, these patches do not pose significant importance during reactor operation. For Sleeves, all the dimensions achieved after final machining were found in order with the drawing requirements.

12. Test Results & Discussions:

The production test coupons (PTC) hard faced simultaneously along with the actual job viz., bottom plate and sleeves were subjected to testing as carried out during procedure qualification. The test results of PTC for bottom plate and sleeves are as follows.

12.1 Results of bottom plate hard facing:

The hardness at both tangential and longitudinal locations and surface hardness was 47.4 to 55.4 HRC. The marginal increase in hardness values was acceptable. The chemical analysis indicated that the elements are within the specified range.

Bottom Plate	C	Cr	B	Si	Fe (Max)	Co (Max)
Required	0.40–0.80	10.0–16.0	2.00–4.00	3.00–5.00	7.00	0.25
Achieved	0.51	12.21	2.30	3.91	6.3	0.22

The IGC test results (IGC with bend test & heat treated, IGC & bend) have revealed ‘No cracks or IG fissures’ in the bend surfaces. During Metallographic examinations at 10X, no cracks were observed in the base metal, fusion and hard faced zone. No linear defects and lack of fusion were noticed. The examination at 250X magnification did not reveal any micro cracks. Thus based on the satisfactory PTC test results, the hard face deposition on the bottom plate is sound and meeting all the technical requirements.

12.2 Results of sleeves hard facing in Central region & on 45° edge Chamfer:

PTC Samples were taken from the Central region and from 45° chamfer regions of fuel, absorber rod, inner boron carbide, steel shielding & outer boron carbide subassembly sleeves. They were subjected to line hardness, surface hardness measurement & metallographic examination. Due to non availability sufficient hard faced material on the PTC, chemical analysis could not be performed. Achieved hardness varied from 41.2 HRC to 54.1 HRC (Surface) and 32.5 to 57.4 HRC (Line). During metallographic examinations, they were examined under 10X magnification using stereo microscope and at 250X using optical microscope. Macro and micro photographs are indicated in Figure. They revealed no micro cracks or any linear indication or lack of bonding. Based on the above test results, it is ascertained that the hard facing carried out on the actual sleeves is excellent.

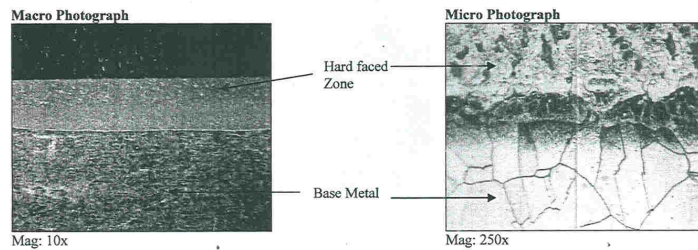


Fig VIII: Macro and Micro photographs

13. Surface Treatment for Hard faced parts :

Surface treatment was carried out on all the hard faced surfaces of sleeves and bottom plate. Chloride free acetone cleaning & alkaline cleaning were carried out followed by rinsing with de-mineralized water. Passivation with nitric acid and sodium dichromate were carried out at 50 to 60°C for 30 minutes. Again the components were cleaned with alkaline and dried. Necessary tests like visual, CuSO₄ test, wipe test, chloride & fluoride contamination test, tests for absence of acid & alkali were performed and the effectiveness of the surface treatment were confirmed.

14. Summary :

The tremendous efforts taken by the technology development team for grid plate has yielded best results. The methodology involved for hard facing of bottom plate during technology development was adopted for hard facing of bottom plate for PFBR and the final results presented highlight achieving all the technical requirements stipulated in meeting the chemical, metallurgical, dimensional requirements. PTAW process adaptation in industrial scale for hard facing Ø6.8m bottom plate and sleeve with ID dimension Ø81.3mm from 468mm from the open end is note worthy. The crucial hard facing operation was successfully

completed without any cracks and meeting all the dimensional requirements stipulated from the design considerations. All these shows hard facing technology is established and well suited for performing more such similar tasks for future FBRs.

Table: I - Welding parameters during hard facing of bottom plate and sleeves.

Parameters	Bottom Plate	45° Edge Chamfer	Sleeve ID
Base Metal	P No. 8 (SS 316LN)	P No. 8 (SS 316LN)	P No. 8 (SS 316LN)
Weld edge preparation	2 grooves with 4mm depth (Bottom width : 20mm / Top width : 27mm/ Taper : 45°)	OD : 115mm / ID : 83mm / Taper : 45° / Length of sleeve : 985mm	OD : 115mm / ID : 83mm / Length of sleeve : 985mm
Filler Metal	F No. 71 A No. 9 Homogeneous Powder (40 to 200 microns)	F No. 71 A No. 9 Homogeneous Powder (40 to 200 microns)	F No. 71 A No. 9 Homogeneous Powder (40 to 200 microns)
Position	1G	1G ; Job at 45° & Rotation	1G
Preheating	650°C min	150°C min	450°C min
PWHT	Indicated separately	Indicated separately	Indicated separately
Gas	Argon 99.999% for Gas(Powder), Centre (Plasma) & for Shielding	Argon 99.999% for Gas (Powder), Centre (Plasma) & for Shielding	Argon 99.999% for Gas (Powder), Centre (Plasma) & for Shielding
Electrical Characteristics	DC current Straight Polarity Ampere : 150 – 160 A Volts : 22 – 24 V	DC current Straight Polarity Ampere : 120 – 150 A Volts : 22 – 24 V	DC current Straight Polarity Ampere : 150 – 160 A Volts : 22 – 24 V
Technique	Weave Bead; Single layer with single pass	Weave Bead; Two layer with single pass / layer	Weave Bead; Two layer with single pass / layer

Reference:

1. *Specification for manufacture of Grid Plate [Internal Report]*
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