

# A Case Study: In-Situ Weld Repair of Steel Casting of Grade C12A ASTM A 217M

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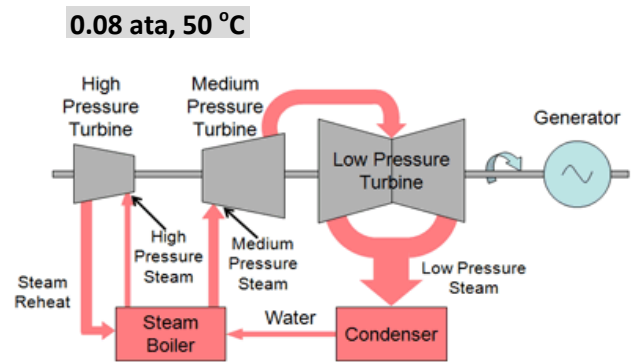
**Abstract** - Steam turbine components, operating at high temperatures and/or stresses may develop cracks. As a preventive maintenance practice, Residual Life Assessment is done and time to time overhauling attempts to detect these cracks so that proper action can be taken in time. During overhauling of Main Steam (MS) strainer of Maithon Power Ltd power plant two large sized cracks were observed. These cracks cannot be left as such as it may cause a catastrophic failure which may cause unit to shut down and a huge power generation loss and can also cause a loss of human resource. Casting cannot be used as such. Either it has to be replaced which can take a longer time as its manufacturing takes time. It can be reused after successful salvaging by in-situ weld repair followed by repair evaluation and assessment after applicable testing in line with the applicable code and specification. It was decided for in situ weld repair and hence Preheating, inter-pass heating and post weld heat treatment procedures (PWHT) was established for the material grade C12 A ASTM 217M of which strainer was made up of. After PWHT weld region was machined and further hardness was measured across the weld using Eco-tip machine to validate that weld repair has been completed with all the acceptable limits of hardness required as per the design requirement. This paper gives details of all the works carried out for In situ weld repair.

**Key Words:** C12A, Steam Turbine, Strainer housing, Power Plant, WPS, PWHT, CHROMOCORD-9M, OERLIKON, NDT.

## 1. INTRODUCTION

This paper addresses the crack detection and its weld repair of main steam strainer of Maithon Power Ltd. plant which has got capacity of 525 MW and this was commissioned in July 2012. Steam turbines are high speed rotating machines operating at extremes of temperature and pressure. The temperatures range from 535° C at the HP (High pressure) & IP (Intermediate pressure) inlets to 50°C at LP (Low pressure) turbine exhausts, whereas the steam pressure varies from 170 ata at HP turbine to 0.08 ata at LP turbine. Over and above this, the rotating components rotate at 3000 rpm.

The flow chart of steam in typical power plant can be seen below



Multi Stage Steam Turbine Generator

Fig. 1: Steam path flow in power plant

In India, Bharat Heavy Electricals Ltd. as the manufacturer of steam turbines is the major agency to carry out this work. Most of the components have certain specific locations, depending on design & unit rating, where cracks occur. For components working at temperatures above 450°C, creep phenomenon becomes very important. The major components that work in the creep range are the HP & IP rotors, steam chests, strainer housings, valves, casings, diaphragms, interconnecting pipes, blades nozzles etc. On the other hand components working in the low temperature zone are also highly stressed due to their large sizes and also have problems due to erosion and corrosion. Main steam strainer housing was taken up for defect removal and in-situ weld repair, followed by local PWHT [1] in accordance with ASME Section IX [2] with controlled parameters to minimize distortion to the controlled dimension and also to ensure defect free, sound weld and Heat Affected Zone (HAZ) area by implementing suitable non-destructive techniques

Main steam strainer is a component of steam turbine whose main function is to filter the steam coming from boiler and then let it enter into HP turbine. Main steam strainer is placed just before the HP turbine which is shown below

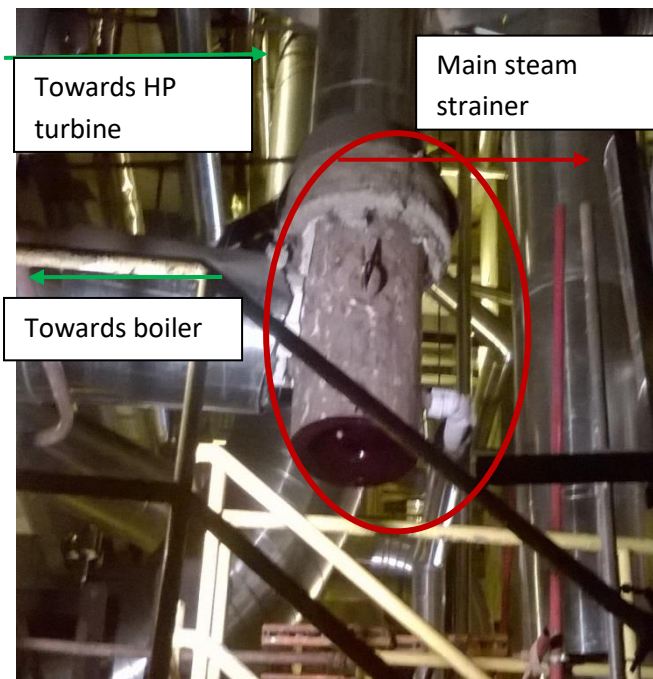


Fig. 2: Steam path flow in power plant

During annual overhauling, main steam and hot reheat strainer were removed and NDT inspection was carried on strainer and its housing. 2 Nos of cracks after excavation (110 mm (Length)) X 42 mm (Width) X 40 mm (depth) and (175 mm (Length)) X 135 mm (Width) X 63 mm (depth) were in Main Steam strainers. The location of these cracks are shown in red color mark in the drawing shown below in Fig. 3.

The materials of the components of the turbines are chosen to withstand the high stresses and temperatures. The HP & IP rotors are forged from steels that retain good strength at high temperatures, whereas the LP rotors have high fracture toughness at lower temperatures. Due to the intricate shapes, turbine casings and steam chests are cast components. As the pressure is high the walls of these casings are thick. Thicker components need more time for thermal equalization and when this is not provided as in fast startups, cracking may occur. Main steam strainer housing made up of grade C12A material was observed to have reported defects during overhauling and casting was taken up for defect removal and in-situ weld repair [3], [4]. As this casting has a lead time of approximately six months so it cannot be replaced with new one immediately therefore it is desired to opt for in-situ repair to overcome the anticipated power loss because of plant shutdown. C12A casting is of Martensitic stainless steel which requires special care during each stage of weld repair for successful salvaging and subsequent evaluation of end results of non-destructive evaluation and hardness. Chemical composition of casting of strainer is shown in table below.

Table 1: Chemical composition of C12A as per ASTM 217A in weight % is

C	Si	Mn	P	S	Cr	Mo	V
0.08	0.20	0.30	≤ 0.020	≤ 0.01	8.00 - 9.50	0.85	0.18
-	-	-				-	-
0.12	0.60	0.60				1.05	0.25
Ni	Al	Nb	N	Ti	Zr		
≤ 0.40	≤ 0.020	0.06 - 0.10	0.030 - 0.070	≤ 0.010	≤ 0.010		

Magnetic Particle Inspection (MPI) of Main Steam strainer was carried out. During MPI, a crack was observed in the casting of the strainer. It became imperative to remove the crack and therefore the area was repaired by weld deposition in a short duration in order to bring back the unit in operation at the earliest.

### 1.0 VISUAL AND NONDESTRUCTIVE EXAMINATION OF CASTING

Visual inspection of MS strainer housing was performed. Insulation of the strainer housing was removed and scaling & rusting present over the outer surface was cleaned by grinding. MPI [5] and Dye Penetration Test (DPT) [6] was performed on all the accessible areas of inner and outer surfaces of the casing. DPT was also performed inside the housing on all the accessible areas, i.e. up to 900 mm from the bottom face. MPI was performed with wet fluorescent method. No indications observed on the surface and sub-surface.

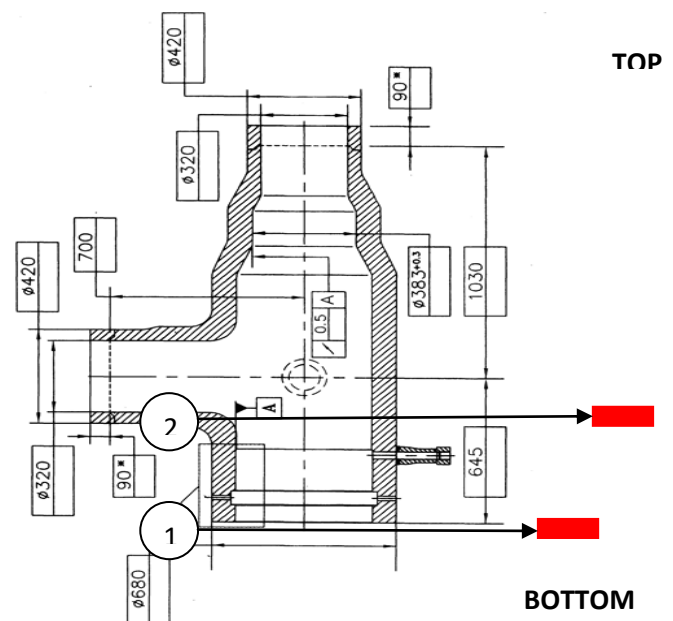


Fig. 3: Rough Position of crack found in dye penetrant test.

Following defects were observed during the DPT inside the housing:

- Cluster and isolated blow holes between 700 mm to 900 mm in the bottom (refer Fig. 4(a), (b))
- **Defect 1** - Six nos. of linear indications in the excavated area (refer Fig. 4(c))
- **Defect 2** - One more linear indication was observed in the right side of the inlet (refer Fig. 4(d)).

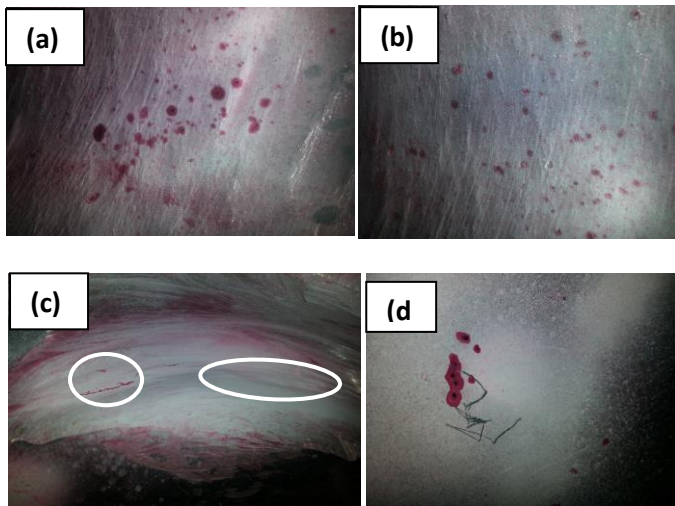


Fig. 4: Observations during DPT (a), (b) Porosity on inner surface (800 mm from bottom), (c) 2 nos. of large cracks of 27 mm and 35 mm and 4 nos. of small cracks of length 5mm, 5mm, 17mm and 10 mm, (d) New crack observed (right side from the inlet)

### 3.0 REPAIR PROCESS

#### 3.1 Removal of observed defect indications by grinding at Defect 1.

Liner indications observed in excavated area of Defect 1 during DPT on inside surface were removed by grinding and complete removal was ensured by repeating the DPT (refer Fig. 5).

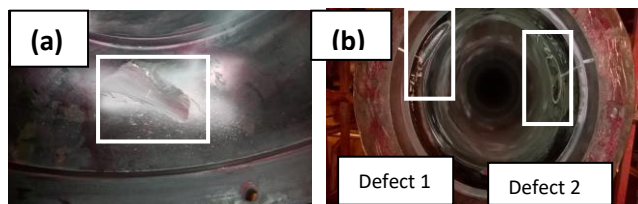


Fig.5: (a) Surface after removal liner indications (b) View of defects from bottom side

The excavation size for this defect was:

- Length :110 mm
- Breadth : 42 mm

- Width :40 mm
- Position: 195 mm from bottom.

#### 3.2 Removal of indications by Grinding at Defect 2.

After grinding to a depth of 15 mm, a new crack was observed in the circumferential direction to a length of approx. 15 mm (refer Fig. 6).

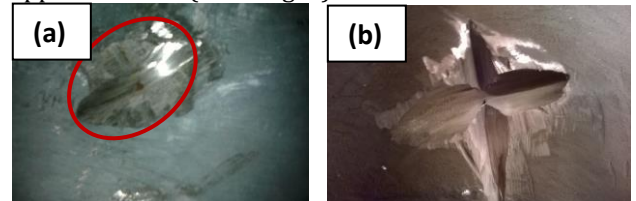


Fig 6: (a) After grinding to a depth of 15 mm, (b) Grinding to get the circumferential crack

Ultrasonic Testing (UT) [7] was carried out for sizing and location of the defect. Defect with a length of 30 mm and at a depth of 15 mm (refer Fig 7(a)) was confirmed by Ultrasonic testing which motivated to go for further grinding in order to complete removal.

After significant cutting and grinding, a defect free surface was ensured and same was confirmed by conducting DPT. Final dimensions of the excavated area (refer Fig. 7(b)) were as follows:

- Length: 175 mm,
- Width: 135 mm,
- Depth: 63 mm,
- Height from bottom face: 340 mm
- Remaining thickness: 27 mm

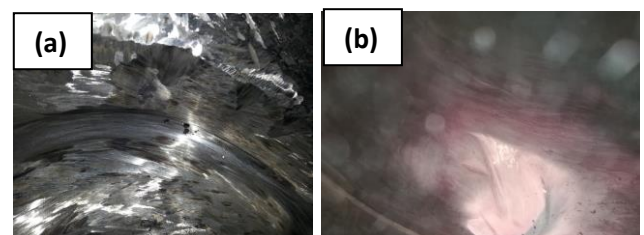


Fig. 7: Observation after grinding 15 mm (a) and final excavated area (b)

Because of tooling limitation and the defect depth approaching to greater than 50 mm, different tools were used for complete removal of the defect. Following tools were used during the defect removal process:

- Grinding wheel
- FF2 machine
- Carbide drill bit of 6 & 7 mm
- Carbide Cutter (Conical & Cylindrical)

### 3.3 Coiling and Insulation

Proper coiling and insulation was installed in order to maintain a homogeneous temperature and also to minimize the heat losses. Thermal insulation also maintains an acceptable temperature gradient. Thermocouples were placed at various locations to measure and monitor the temperature. Thermal insulation of soak band, heated band, which may be axial and through thickness, was done as suggested by the ASME section IX.



Fig 9: Insulated outer surface of the housing to minimize heat loss.

### 3.4 Preheating & Welding

Preheating was done to raise the temperature of the parent steel before welding. It is used for the following main reasons:

1. The slower cooling rate obtained due to preheating encourages hydrogen diffusion outside from the weld area [8] as Hydrogen gets more time and temperature enough for diffusion (particularly the time above approximately 100°C) at which hydrogen diffusion rate is significantly higher than that at ambient temperature. The reduction in hydrogen reduces the risk of cracking.
2. To slow the cooling rate of the weld and the base material, potentially resulting in softer weld metal and heat affected zone microstructures with a greater resistance to fabrication hydrogen cracking

Preheat can be applied through various means [9]. The choice of method of applying preheat will depend on the material thickness, weldment size and the heating equipment available at the time of welding. Preheat temperature was kept at 200-300 °C as drawn from applicable WPS and PQR to and was substituted by flame heating to enable the welder to

complete the job inside the housing which has an ID of approx. 500 mm. It is important to apply preheat correctly, with appropriate monitors and controls, and also to monitor the interpass temperature (the temperature of the work piece between welding the first and subsequent passes), to ensure that it does not fall below the preheat temperature. Continuous monitoring of the temperature was done using a Thermal Chalk & Pyrometer (refer Fig. 10).

Welding was performed in-line with the approved repair procedure and approved WPS [10] with matching electrode (E-9018-B9), having dia of 3.2 mm & 4 mm CHROMOCORD-9M supplied by M/s OERLIKON.

Extra weld deposition was also performed in order to counter the shrinkage upon cooling as solidification of weld matter involves volume changes. In this case an austenitic phase is transforming into a martensitic phase which involves a volume expansion of 4 %. Because of this phase change in weld metal and adjacent area i.e. HAZ will experience residual stress [11] caused by phase change as well as thermal stress induced because of heating and cooling.

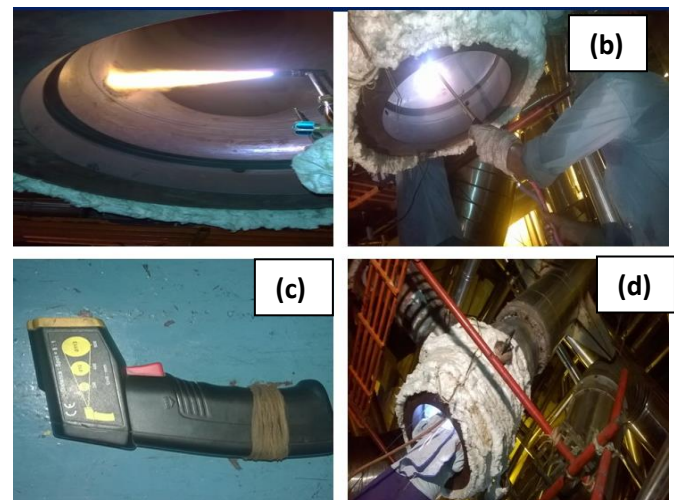


Fig 10: Preheating and improved heating using flame (a), (b), (c) Pyrometer (d) Local heating arrangement

### 3.5 Post Weld Heat Treatment (PWHT)

Local PWHT needs careful planning to ensure that heating and cooling rates are controlled. Uneven or rapid heating can give rise to harmful temperature gradients producing thermally induced stresses that can exceed the yield stress.

Temperature gradients may be axial and through thickness. The through thickness temperature gradient is caused by heat losses from the internal surface and is a function of both thickness and internal diameter, the larger the diameter, the greater the effect of radiation and convection losses. Therefore a large area of the casing was properly insulated to

minimize heat loss and maintain an acceptable thermal gradient.

PWHT was completed in around 6 ½ hrs. Soaking was done at 720° C for 10 hours and cooling was started thereafter. Controlled cooling was completed in about 13 hrs. Heat Treatment regime was selected to aim minimum distortion (refer Fig. 11)

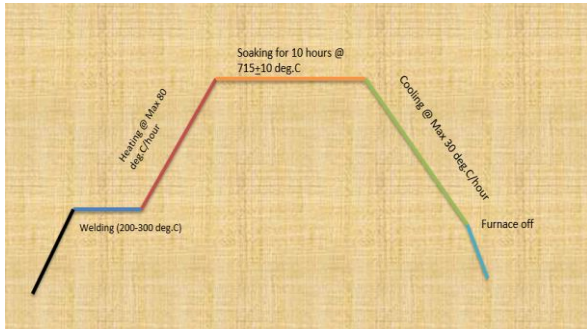


Fig. 11: PWHT Process (Heat Treatment Regime)

### 3.6 Machining

After PWHT, grinding and machining was done to level the surface. The surface looked as shown below

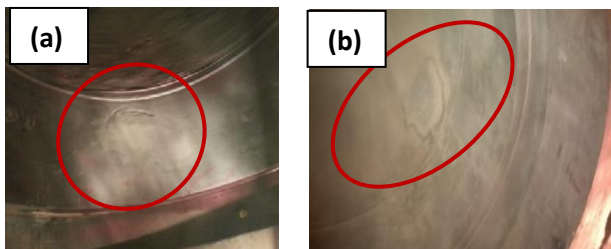


Fig 12. Surface after grinding in defect 1 area (a) and defect area 2(b)

### 3.7 Precautions Taken

3.7.1 4 nos. of thermocouples (2 inside at each defect locations and 2 outside in same plane of each defect at 90° anticlockwise apart from defect locations) were installed to measure the temperature homogeneity throughout the cross section as shown in Fig. 13.

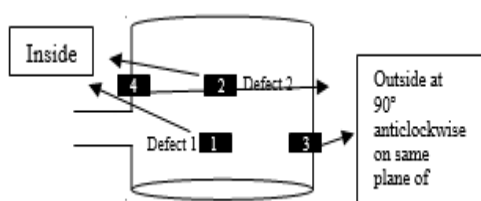


Fig. 13: Shows the location of thermocouples with respect to defect locations

- 3.7.2 Job was properly insulated and covered to minimize the heat loss.
- 3.7.3 Job was supported with a plate from base to minimize/restrict any axial distortion.
- 3.7.4 Arrangement, including 4 metallic blocks covered with thermal cloth and diagonally connected using reverse turn buckle (refer Fig. 14), was installed to restrict dimensional distortion.

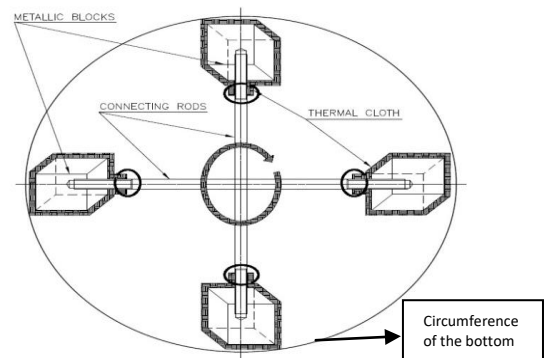


Fig.14: Fixture to minimize dimensional distortion

### 3.8 Final Inspection

- 3.8.1 Hardness Test done on Weld, Base Metal & HAZ and Results were found within the acceptable limits as per specifications.
- 3.8.2 DPT was done on the welded area and HAZ and no recordable indications were observed.
- 3.8.3 Dimensions of the strainer housing were found to be within the limits (<1 mm), signifying no distortions due to welding.
- 3.8.4 UT was done to ensure defect free weld surface and few indications observed in the core zone of Defect 2 which were found to be acceptable as per the requirements of the specifications
- 3.8.5 Hardness Testing was performed using portable Eco-tip machine. Hardness values are found to be acceptable as per the requirements of the applicable specification (refer Table 2, Error in reading: SD ±5).

Table 2: Hardness Values (HV) using portable hardness testing machine (Eco-tip)

Area	Hardness at Defect 1 (HV)	Hardness at Defect 2 (HV)
Weld	341,314,337,328	311,314,323,330
Parent	180,216,201,207	207,234,265,212
HAZ	345,352,363	349,354,339

### 3.9 Inspection/Assessment upon next overhaul

The repair area was undertaken for testing during next overhaul which was schedule 2 years later from the repair, the area was inspected non-destructively by using suitable NDT (DPT & MPI), no significant indication observed on the repair location. Repair area was etched using 5 % Nital solution to differentiate the weld and parent. Hardness of both the repair locations are were also tested. Table 3 shows the hardness values.

Table 3: Hardness Values (HV) using portable hardness testing machine (Eco-tip)

Area	Hardness at Defect 1 (HV)	Hardness at Defect 2 (HV)
Weld	320,315,322,325	301,309,303,307
Parent	202,207,185,197	201,209,221,219
HAZ	330,325,335	340,336,331

### 4.0 CONCLUSIONS

Excavation of the defects became very troublesome due to their location and accessibility. Excavated area were ensured to have defect free surface by DPT. Weld repair was completed in 13 hours, maintaining preheat & inter-pass temperature. Special arrangements like base support plate of 5mm and inside turn buckle were installed to take care of dimensional distortion, since any distortion would have resulted in rejection of casting. Welding was done with approved WPS/PQR followed by PWHT. In-situ repair of MS Housing (without dismantling) was a very challenging task due to locational and accessibility constraints. Casting was timely salvaged and post salvaged results were found satisfactory as per applicable specification. Successful repair has resulted in huge time savings and consequent cost savings by avoiding down time generation losses. Test result after assessment of casting upon next overhaul schedule two years later revealed satisfactory results in non-destructive evaluation and in-situ hardness test results which has validated the successful repair.

### ACKNOWLEDGEMENT

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