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Applying laser welding in power plant part repair

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Abstract

Laser welding, acknowledged for the low heat input process, was initiated to refurbish a steam turbine rotor. The refurbishment involved applying a superalloy filler metal to the damaged areas on the turbine disk caused by heavy rubbing. The post weld heat treatment was established to minimize the residual stress after welding. The machining work was performed to remove cracks and finish the welded areas to original dimensions. The liquid penetrant test was conducted and revealed no defects. A notable characteristic of high hardness on the machined weldment was observed and attributed to a significant degree of work hardening. The maximum runout of the rotor was lower than that from the as received condition. The rotor mass unbalance was minimized and accepted according to the standard limit. The rotor then resumed operation for power generation. In addition, the consecutive projects showcased the success of laser welding in repairing critical power plant components.

Keywords: laser welding, steam turbine rotor, refurbishment, residual mass unbalance

1. Introduction

Steam turbine rotor is the main equipment in thermal and combined cycle power plants. In case of emergency shutdowns, the damages from rubbing such as scratches and cracks could be found on the rotor in the areas of journals, blades, and thrust collars. To cope with the forced outages, ordering a new rotor would not be an economical solution in terms of power generation loss because of a huge investment and long lead time. Therefore, refurbishment work plays a crucial role in recovering the rotor back to service again with optimal conditions at which dimensions, run outs and residual mass unbalances must be in acceptance criteria. To build up the material on the damaged areas, welding repair process is inevitably applied in accordance with welding procedure specifications.

In rotating machine recondition, the conventional welding processes for instance Submerged Arc Welding (SAW), Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) have been in general applied and contributed to high weld deposit rate with various kinds of filler metals subject to the rotor materials. In contrary, precision welding using laser beam promoting metallurgical bonding between additive and base material can be introduced to obtain high quality of weld with less deformation, dilution, residual stress, and good surface finish. In addition, low heat input from laser welding facilitates a small width of Heat Affected Zone (HAZ) [1-3] and minimizes microstructure change contributing to proper mechanical properties and consequently the long-term service of the weld joint [2,3]. In spite of low deposit rate, laser welding has been widely used for repairing molds and precision parts in various industries; Automotive, Aerospace and Electronic parts which large size of weld is not the majority [4-6].

Workshop and Spare Parts Division of the Electricity Generating Authority of Thailand (EGAT) has been implementing laser wire welding to recondition parts and equipment from power plants. This approach aims to minimize distortion, which is a primary cause of vibration problems in rotating machinery. In this paper, the reconditioning process of a steam turbine rotor using laser welding is presented. Besides, the successive projects in repairing steam turbine casings and turbine nozzles are displayed in brief to illustrate the broader potential of this technology in power plant maintenance.

2. Refurbishment processes

The steam turbine rotor in Fig. 1. having capacity output of 10.4 MW weighing 1,900 kg was deteriorated and transported from power plant to EGAT Workshop in Thailand for refurbishment. From incoming inspections, the rotor material was examined as a low alloy steel with 2.25% Cr and 1% Mo by material identification equipment. Cracks were found by liquid penetrant test on the outer axial surface of the rotor disk as shown in Fig. 2. due to heavy rubbing from stationary components. Microstructural analysis in Fig. 3. was performed using replica technique and revealed a martensitic structure with intergranular cracking on the damaged areas by the microscope with 200X and 800X magnification. This occurred due to rubbing, which generated high stress and overheating, leading to the change of microstructure and consequently cracks on the rotor disk surface.

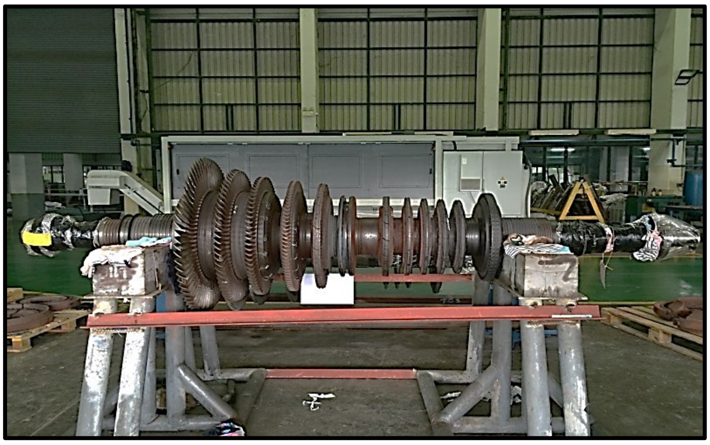


Fig. 1. Rotor having capacity of 10.4 MW

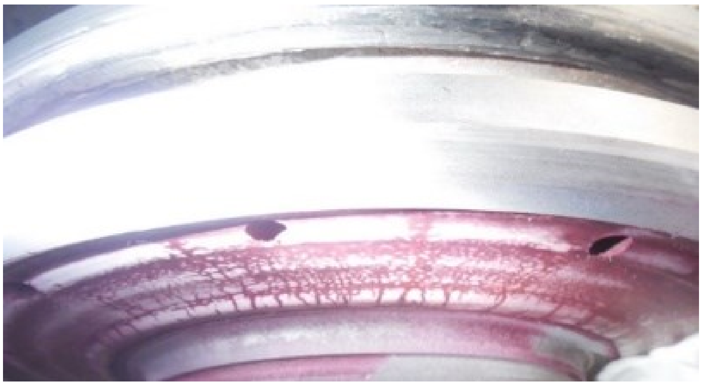
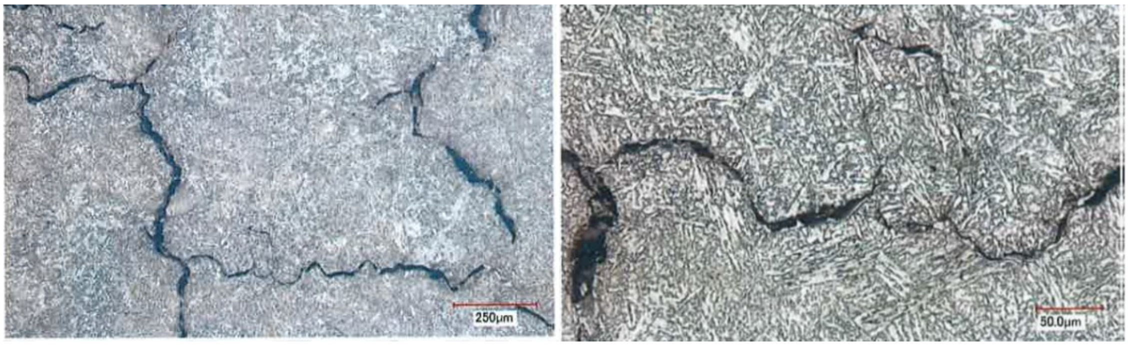


Fig. 2. Cracks on the rotor disk surface examined by liquid penetrant test



(a) (b)

Fig. 3. Microstructure of damaged areas on the rotor disk (a) Magnification 200X; (b) Magnification 800X

In building up the weld metal on the damaged areas, laser welding which provides low heat input [1] was applied to minimize the risk of rotor distortion, despite its low deposit rate. The portable laser welding machine equipped with a solid-state source of Nd-YAG 500 W generating laser beam with a wave length of 1064 nm, was used for this recondition project. The nickel based superalloy filler metal was selected for joining with the Cr-Mo base metal. Welding process parameters including power, laser beam diameter, pulse duration, frequency, shielding gas filtration, and filler wire diameter were summarized in Table 1.

Table 1. Laser welding parameters

Parameters	Value	Unit
Average power	500	W
Pulse duration	0.6	ms
Beam diameter	1.2	mm
Shielding gas flow rate	10	l/min
Pulse frequency	75	Hz
Filler metal wire diameter	0.8	mm

The laser welded specimens were arranged according to the welding parameters for liquid penetrant test, hardness test, and tensile test. The results showed that no indications were found on welded joint areas for liquid penetrant testing illustrated in Fig. 4. Micro Vickers hardness results in the area of weld, near fusion zone, and base metal were reported in Fig. 5. Tensile strength test results as shown in Fig. 6. indicated fracture areas on the base metal with the averaged value of 685.19 MPa. It meant that the strength of the weld metal was larger than that of the base metal.

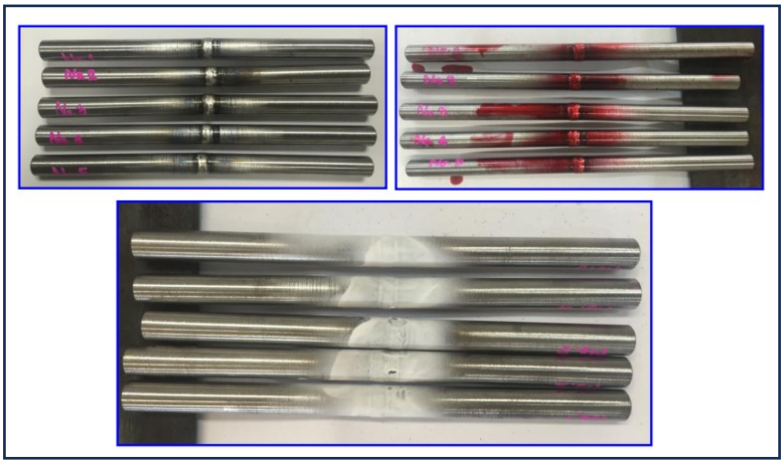
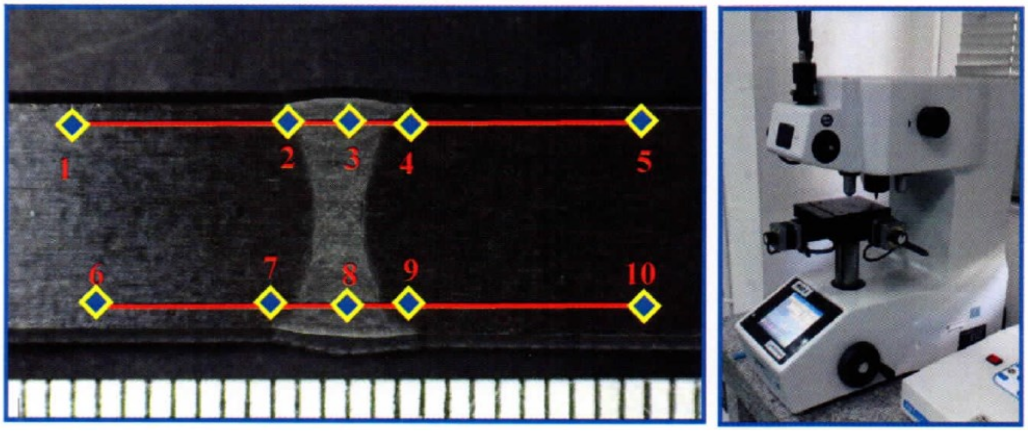


Fig. 4. Liquid penetrant testing of the specimens



Hardness HV0.5

Base metal	Near fusion zone	Weld	Near fusion zone	Base metal
(1) 231.6	(2) 240.1	(3) 238.4	(4) 254.1	(5) 240.6
(6) 238.1	(7) 243.0	(8) 248.0	(9) 254.0	(10) 279.0

Fig. 5. Microhardness results of the specimens

Specimen No.	Diameter (mm)	Area (mm^2)	Force Max. (kN)	Tensile strength (MPa)	Elongation %	Failure location
1	10.00	78.54	53.37	679.52	14.90	Base Metal
2	9.87	76.51	53.44	698.47	15.56	Base Metal
3	9.96	77.91	53.34	684.63	16.28	Base Metal
4	9.98	78.23	53.05	678.12	15.14	Base Metal

Fig. 6. Tensile test results of the specimens

The refurbishment process commenced with machining work on the damaged areas in order to remove cracks on the rubbed surface at which the microstructural change occurred. Subsequently, laser welding was carried out as per welding procedure specifications as shown in Fig. 7. A thermography camera was applied to monitor the temperature around the welded areas as demonstrated in Fig. 8.

Post weld heat treatment with heating pads and insulations was vertically processed on the scaffolding after laser welding completed so as to improve metallurgical aspects and to relieve stress of the weldment. The applied parameters included a heating and cooling rate, holding time and temperature.

After cooling down to ambient temperature, the rotor was set up on the lathe and machined at the welded areas to original dimensions as shown in Fig. 9. Non-Destructive Testing (NDT) including visual inspection, liquid penetrant testing, and dimension checking were conducted by certified quality control staffs. The new turbine blades were installed in the turbine groove before performing rotor run out and low speed balancing.

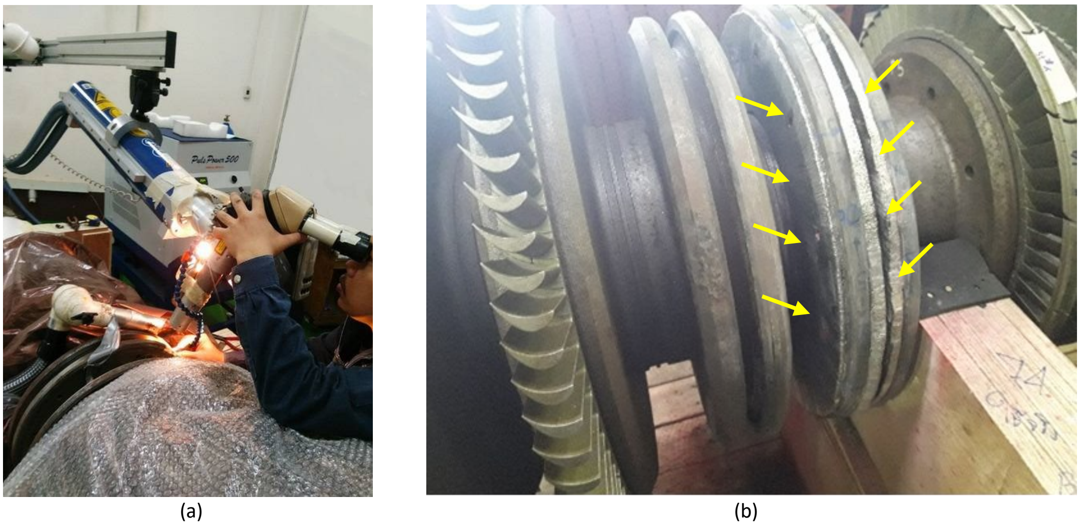

(a) (b)

Fig. 7. (a) Laser welding performed on the damaged areas of the rotor disk; (b) As welded surfaces after laser welding

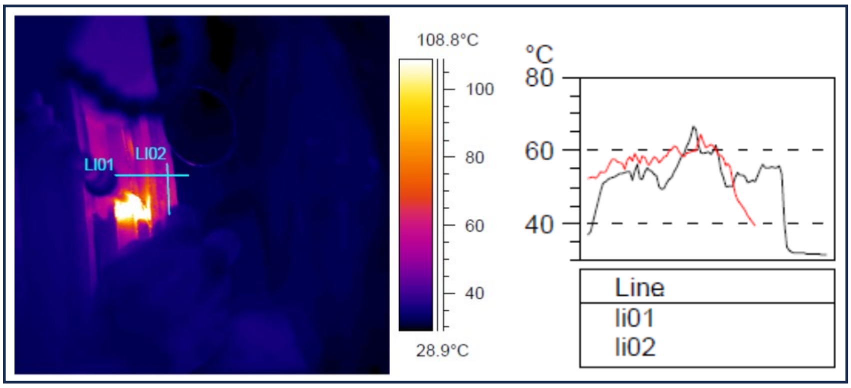


Fig. 8. Monitoring the temperature around the welded areas by thermography camera

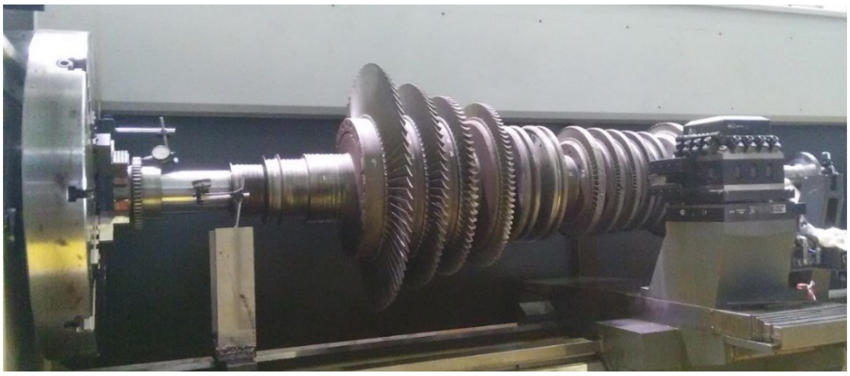


Fig. 9. Machining work after post weld heat treatment

3. Results and discussion

3.1 Non Destructive Testing

Aside from dimension checking, liquid penetrant testing was undertaken for examining the indications following laser welding. The result confirmed that no cracks were found on the welded areas as shown in Fig. 10. Moreover, the hardness result of the nickel based superalloy weldment after final machining was reported to be 374 HV in average significantly greater than the values on the tested specimen (238.4 and 248.0 HV) and rotor's base material (274 HV). Due to the effect of work hardening from plastic deformation and strain aging, the high level of hardness after machining superalloys is unavoidable and displays different behavior when compared with the interior surface well agreed with the work indicated in [7].

Fig. 10. Liquid penetrant testing on the welded areas

3.2 Rotor run out

To analyze geometrical unbalance of the rotor, run out measurement is one of the most important indicators to evaluate rotor distortion after refurbishment process especially in welding repair. The rotor was set up for radial run out check using a dial gauge. The maximum values from incoming inspection and after final machining were 0.15 mm and 0.09 mm, respectively as illustrated in Fig. 11. It was obvious that the effect of welding process on rotor distortion in this case was minimal as a result of low heat input. In addition, the run out of the rotor tended to be improved after refurbishment process. This could be concluded that the residual stress causing rotor bow after operation was reduced by applying heat treatment in vertical position.

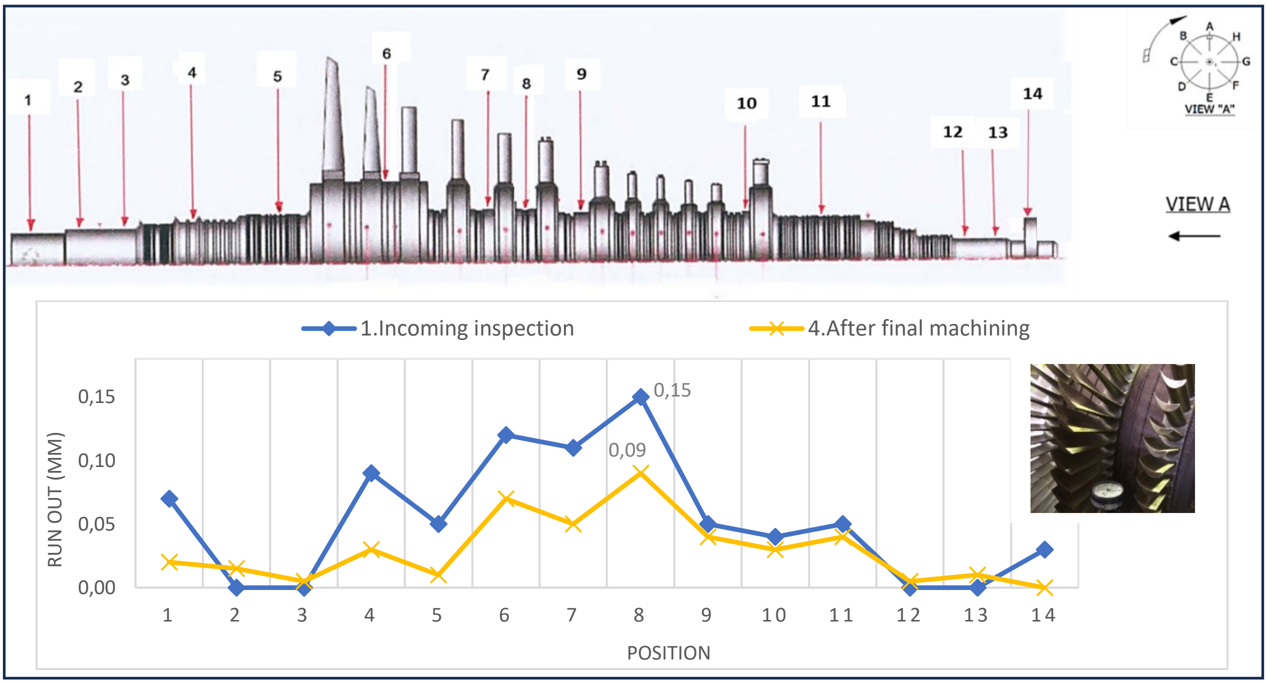
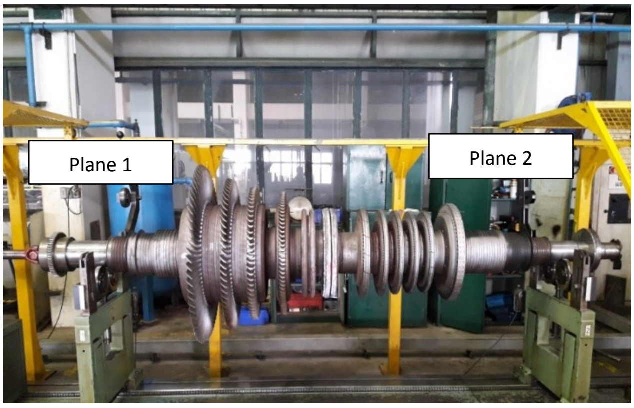


Fig. 11. Rotor run out results

3.3 Rotor mass unbalance

The residual mass unbalance of the rotor for 2 planes was checked on the low speed balancing machine having capacity of 3,200 kg as shown in Fig. 12. for incoming inspection, after final machining and after unbalance correction. This was the crucial process to confirm that the refurbished rotor will run without vibration problems in operating conditions to generate electricity of the power plant. The acceptance criteria of mass unbalance were followed the ISO 1940 Balance quality requirements for rotors in a constant (rigid) state — Part 1: Specification and verification of balance tolerances with the balance quality grade G1 for steam turbines. The results from Fig. 12. illustrated that the values from incoming inspection were significantly greater than the unbalance limits of the acceptance criteria because of the material loss in the damaged areas of the rotor disk from heavy rubbing. After repairing work, the mass unbalance correction by adding weight plugs on the rotor was performed and resulted in the minimal values of 2.5 g at 347° for Plane 1 and 2.88 g at 185° for Plane 2, which were below the acceptance limits.



	Mass unbalance	
	Plane 1	Plane 2
1.Incoming inspection	110 g at 297°	121 g at 305°
2.After final machining	72.4 g at 174°	88.4 g at 133°
3.After unbalance correction	2.5 g at 347°	2.88 g at 185°
Acceptance criteria (G1)	5.24 g	9.06 g

Fig. 12. Rotor mass unbalance checking and results

4. Conclusions

From this steam turbine rotor refurbishment project, the laser welding with the nickel based super alloy was introduced to restore the damaged areas for which the material was determined as a Cr-Mo steel. The concluding results were presented as follows,

- From liquid penetrant testing, there were no indications found after rotor refurbishment using laser welding process.
- The averaged hardness (374 HV) of the weldment from the super alloy filler metal was higher than that of the rotor’s base material Cr-Mo (274 HV), resulting from work hardening after machining.
- The maximum radial run out of the rotor after final machining (0.09 mm) was lower than the value from incoming inspection (0.15 mm), implying the minimal effect of laser welding on rotor distortion.
- The residual mass unbalances of the rotor after correction were in the acceptance criteria with quality grade G1.
- The refurbished rotor was reinstalled and operated in the power plant for electricity generation again.

Applying laser welding in power plant part repair could be an effective solution for maintenance services, especially when strict dimensional acceptance criteria are the main priority. However, a higher power laser output unit or other welding processes should be considered as the alternatives for increasing deposition rate to reduce overall outage duration. For further suggestions, the study in mechanical property evaluation including fatigue and creep strength as well as microstructural analysis should be done to confirm the quality of weld in repairing high valuable power plant parts and equipment.

The following project for steam turbine casing repair as shown in Fig. 13. was an outstanding work to figure out how to solve the leakage problem of the contact surfaces between upper and lower casing. In this case, the fiber laser source with a power output of 1,200 W was utilized to overlay the nickel based super alloy on a Cr-Mo steel with the weld thickness of

5 mm. After completing welding process, face milling operation was arranged to obtain finish size dimensions of the casings. For NDT, there were no indications examined by liquid penetrant test. The machined surfaces of the casings were investigated using surface roughness measurements. The laser tracker and 3D scanner, coordinate measuring devices, played a significant role in investigating casing geometry. An example of the result for upper casing in Fig. 14. revealed improved flatness and parallelism after reconditioning, enhancing the contact surface between lower and upper casing without leakage issues.

Fig. 13. Steam turbine casing repair using laser welding

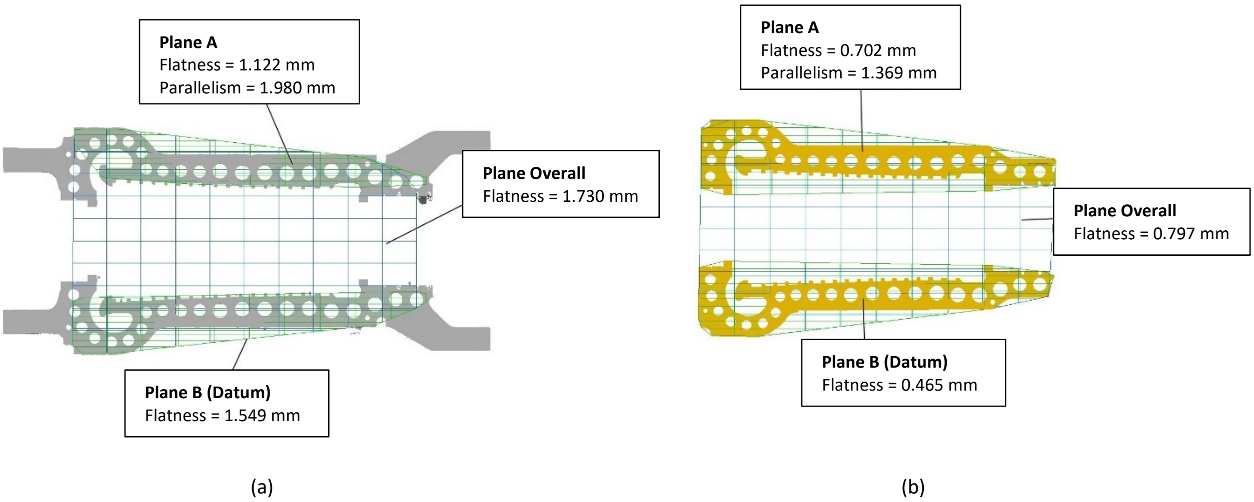


Fig. 14. Flatness and parallelism results for upper casing (a) Before repair; (b) After repair

Another remarkable implementation of laser wire welding involved repairing the stator blades of turbine nozzle by filling up a nickel alloy filler material on martensitic stainless steel blades, restoring surfaces damaged by erosion and corrosion during operation. A 900 W laser welding machine was applied in this case, and the subsequent activities for grinding work along with NDT verification were done without the evidence of cracks on the repaired blades as shown in Fig. 15. The reconditioned part was then assembled in the power plant and run with acceptable vibration and efficiency levels.

(a) (b) (c)

Fig. 15. (a) Eroded and corroded blades of turbine nozzle; (b) Laser welding repair; (c) Repaired blades after grinding and liquid penetrant testing

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