In-situ laser repair of steam turbine blades

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Abstract

Reliable and efficient power generation is a major global issue due to both political and environmental concerns. Nevertheless many critical components, particularly the blades of the low pressure (LP) side of power generating steam turbines, are subjected to failure due to severe erosion at the leading edges. Since taking machines off-line for maintenance and removal of damaged blade for repair is extremely expensive, increasing the service life of these critical components offers significant economic and political benefits. Conventional techniques to increase service life include brazing of an erosion shield at the leading edge of the turbine blades, open arc hardfacing, and cladding with erosion resistant materials using gas tungsten, manual metal or plasma transferred arc welding.

We have been investigating for the past few years the potential of laser cladding to deposit a high quality and erosion resistant protection shield on the leading edge of LP blades. Laser cladding offers unique advantages over the conventional techniques. The project to-date has demonstrated the feasibility of in-situ repair of turbine blades in trials conducted at a power station using a fibre delivered Laserline diode laser and a robot. A company, Hardwear Pty. Ltd., has been established to commercialise the technology.

Keywords: Steam turbines, diode laser, in-situ repair, laser cladding

1 Introduction

In the conventional generation of electricity from fossil fuelled Power Stations, a boiler is used to heat water to produce steam. This steam is superheated and then enters a turbine where the stored energy is used to turn the turbine shaft which then turns a generator. Superheated steam is very dry and causes no mechanical damage to the blades. In a typical boiler, the superheated steam enters the high pressure stage of the turbine at approximately 545^0C and 16.5 MPa pressure. The same steam is returned to the boiler through the hot reheat system, after which it enters the intermediate pressure stage of the turbine, again at approximately 545^0C but only at 4.5 MPa pressure. The steam then goes directly to the low pressure stage by which time the inlet temperature has dropped to approximately 215^0C and the outlet pressure is basically below atmospheric (5.7 KPa) as the steam enters the condenser.

As the steam exits the turbine, the pressure drop may be enough to start the condensation of water droplets. This is a function of the turbine design and the temperature/pressure relationship at the exit. In certain designs, the water droplets cause erosion of the leading edge of the last one or sometimes two rows of blades. The steam normally enters the stage in the centre and passes over the rows of blades in both directions as it leaves.

Fig 1. *Typical low pressure stage from a 200MW turbine showing the blades.*

Researchers [1 – 4] have investigated the potential of repairing erosion damaged turbine blades by laser cladding. We have achieved this, however, with the increased complexity of cladding blades while they are still attached to the low pressure rotor (total mass 27 tonnes) and while located at the power station - that is, in-situ. A 3 kW fibre delivered Laserline diode laser, Sulzer Metco powder feeder and Motoman robot where integrated to apply the laser clad to the LP turbine rotor suspended in a cradle as seen in **Fig 1**. The arrangement of the largest (last row) blades demonstrates the near vertical surfaces and restricted space in which the clad was applied.

2 Materials

The traditional material for all stages in steam turbines is a Martensitic stainless steel, UNS 42000. The reasons for this choice include good creep properties and an excellent combination of strength and toughness. Typical mechanical properties are 345 MPa yield strength, 650 MPa tensile strength and 25% elongation.

Water droplet erosion has been known for some time, and one of the methods the manufacturers have to overcome this used is to add a shield to the blades in the area where there is erosion. Of those materials tried as a shield, Stellite 6 has proved to be successful. Stellite 6 is a cobalt based material with nominally 28%Cr, 4.5%W, 1.2%C, 1%Mn, 3%Ni and 3%Fe. It is often used as pressed and sintered part and is attached to the blade using a silver brazing alloy. This has proven to extend the life of the blades considerably, but over time the shield also erodes as shown in **Fig 2**.

Consequently, blades need to be completely replaced or new shields need to be fitted. In either event, the blades have to be removed from the shaft.

Fig 2. Erosion of the blade.

The costs involved in replacing blades are substantial. Each blade is in the order of AU$5,000 to AU$10,000, and since there are 90 blades per row and two rows affected, blade replacement alone is some AUS $1M to AUS $2 M. Added to this is the production loss of approximately 30 days at AUS $100,000 to 200,000 per day and this is up to another AUS $3M to AUS $6M.

In 2001, the Cooperative Research Centre for Welded Structures and the Welding Technology Institute of Australia arranged funding from a group of Power Stations in Australia to develop a suite of research projects that could benefit the group. One of the research projects was to investigate the possibility of in-situ cladding without removing the blades from the shaft.

3 Powder delivery

Cladding a surface that is not horizontal creates extra complexity due to the effects of gravity on the co-axial delivery of powder to the melt pool [5]. Here powder will bias towards the bottom of the co-axial delivery annulus resulting in an uneven distribution of powder across the melt pool and a potential for clogging of powder during delivery within the nozzle. Experimental results [5] show that with a biasing of powder flow a maximum tilt angle of approximately 20° from the vertical is possible before there are significant effects within the clad layer. This can be remedied by splitting up the powder flow prior to entry to the angled co-axial nozzle. This is a satisfactory method of overcoming the flow bias with acceptable clads at any angle but requires the use of several flexible powder feed tubes from the always vertical powder splitter to the variously inclined co-axial cladding heads. It also creates the added complexity of sustaining consistent powder flow along the individual flexible delivery lines.

An alternative is to divide the flow within the co-axial laser cladding head itself. In **Fig 3** the resultant flow of Stellite 6 powder and Argon gas from the nozzle is shown in two different designs. To allow entry between the blades and so allow cladding in-situ the nozzle was required to be compact. To effect this the cooling of the nozzle was placed further away from the nozzle itself and the nozzle was reduced to a minimal projected area with respect to the workpiece to reduce its exposure to reflected laser light and collateral heat. By limiting the laser power used to 2 kW at the workpiece and using standoff distances greater than 10 mm, high reliability clads of up to 1 mm thick with powder efficiencies typically around 60% were obtained. The cladding head was also constructed in a modular form to allow rapid replacement of components should failure occur and to facilitate rapid change to cladding conditions or powder. The cladding head was found to be remarkably robust in its performance being able to provide reliable clads over significant changes in nozzle-workpiece clearance, powder types and surfaces angled with respect to the incident laser beam. An international patent application on the nozzle design has been lodged.

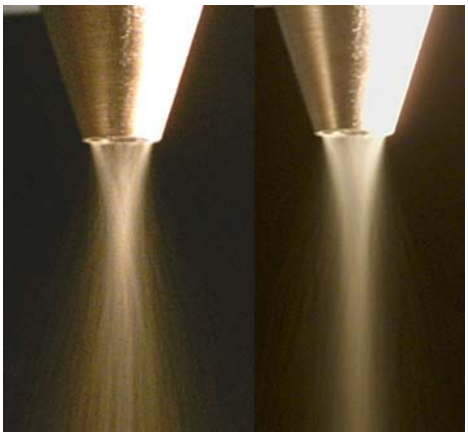

Fig 3. Powder flow from the nozzle.

4 Blade cladding

The blades were clad on the rear (trailing) surface near leading edge, the front surface and the top or leading edge after the original worn edge shields where removed. The sequence and direction of cladding used facilitated minimal distortion while providing a wide enough build up to facilitate the reconstruction of the leading edge. Finally, the blades where ground and the original profile of the blade restored. **Fig 4(a)** and **(b)** show the blades after cladding.

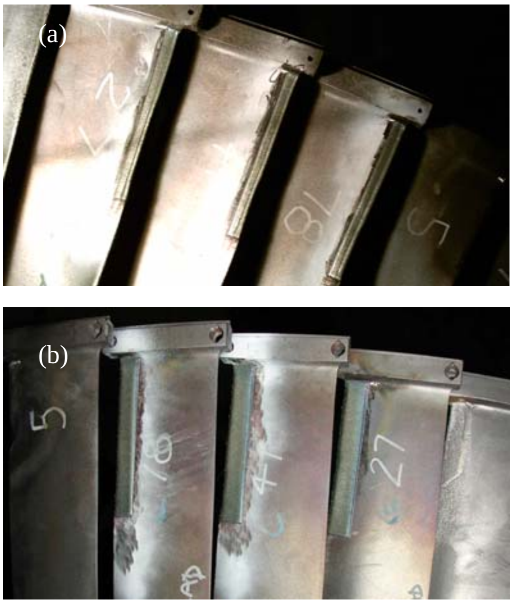

Fig 4. *Laser clad blades showing (a) front view and (b) rear view before processing to original profile.*

4.1 Blade Distortion

Of significant concern was the gross distortion of the blade that results from cladding on a thin surface. A typical sequence of distortion during cladding on a 100mm x 32 mm test coupon of blade material can be seen in **Fig 5**. Here the distortion is measured along the front edge. With each successive layer the distortion can be seen to change. By cladding the rear of the initially distorted surface, the distortion can be reduced and cladding on the leading edge does little to change the initial distortion. It can also be seen that the test coupons tend to return towards their original shape as the clad material is ground away.

The main mechanisms that drive blade distortion are, firstly the differential of thermal expansion between the martensitic stainless steel (11.7 x 10^{-6} mm/mm/^{0}C) and Stellite 6 (15.5 x 10^{-6} mm/mm/^{0}C) which causes the blade to bend towards material with the greater thermal expansion during cooling and secondly the input of heat into the surface. To test this three different cladding conditions where used:

Condition 1: 2 layers of Stellite resulting in a total clad thickness of 1.4 mm

Condition 2: 3 layers of Stellite resulting in a total clad thickness of 1.5 mm

Condition 3: 3 layers of SS420 (a material similar to the substrate) resulting in a total clad thickness of 1.0 mm

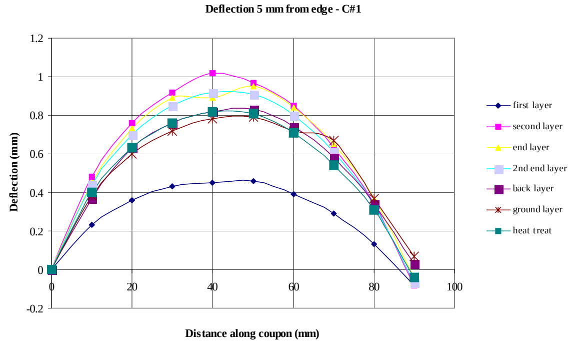

Fig 5. *Distortion of test coupons during multiple layer cladding of Stellite 6.*

After each layer of clad the test coupons where cooled to room temperature and measured for distortion by measuring the movement of the rear (unclad) surface. The distorted Stellite and stainless clad samples where then ground to a similar thickness. Finally all samples where tempered.

A comparison of the final distortion after tempering of the substrate is shown in **Fig 6**. Here the cladding began at the right hand side and finished on the left. It shows the there was no significant difference in distortion between 2 and 3 layers of Stellite clad, especially allowing for the 3 layer sample being slightly thicker after grinding. Therefore, the differential in co-efficient of expansion between the two materials is the principle driver of distortion. There is, however, also distortion of the SS420 clad sample towards the final section of clad. This sample shows distortion in the last section where the substrate becomes significantly hotter during cladding as the trailing edge of the test coupon is reached. Further, there is also an increased slope on the left hand side of the profile for the Stellite samples indicating that some distortion results from heat build-up. This indicates that:

1. Heat input should be kept to a minimum by using low laser powers and avoiding heat build-up at edges
2. Clad thickness should be kept to a minimum

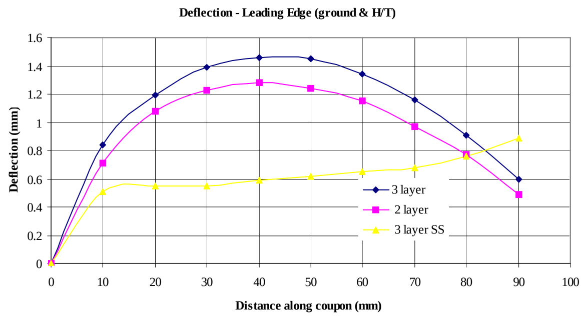

Fig 6. *Leading edge distortion during cladding.*

4.2 Clad layer quality

Apart from minimal blade distortion the quality of the clad layer itself needs to be maintained. It was shown in laboratory trials that with variation of the powder feed rate, laser power, clad increment and clad speed that the clad on the blade material which initially appeared of good quality was in fact porous or reduced in wear resistance between the clad tracks resulting in increased wear rates and surface flaws when ground. This results from insufficient energy to melt completely the clad track as a result of the high clad height to clad width ratio. The creation of high quality Stellite 6 clads are discussed more completely in [6].

Typically, intertrack porosity can be seen in cross-sections as a small regular pore at the clad to substrate interface or on occasion by a shallow surface flaw that appears at the surface during grinding. It is believed the surface flaw results from the failure of the weakened surface which is under tensile stress as a result of the differential co-efficients of expansion between the surface and substrate which lead to blade distortion. Stellite 6 clad tracks on the blades can also crack. Two modes of cracking appear, firstly cracks that appear within a clad track itself and secondly cracks that appear across the clad tracks. These crack types are shown in **Fig 7(a)** and **(b)**.

Cracking within the clad track such as that of Fig 7(a) occurs where dilution rates are greater than 50% and clad temperatures are excessive. Reducing the dilution by decreasing raster increment, reduction in laser power and/or change in scanning speed best controls this. Cracking across the clad tracks is believed to result from high stresses that result from differential contraction after cladding. The mechanism for this crack formation is still under investigation but cracks can be eliminated by reducing the clad length.

The thickness of the substrate was also shown to affect the clad properties with thin substrates (< 2mm) resulting in higher dilution and thinner clads. This results in an uneven profile of clad as the various thicknesses of blade where encountered, consequently when cladding varying thickness of a turbine blade this must be taken into account.

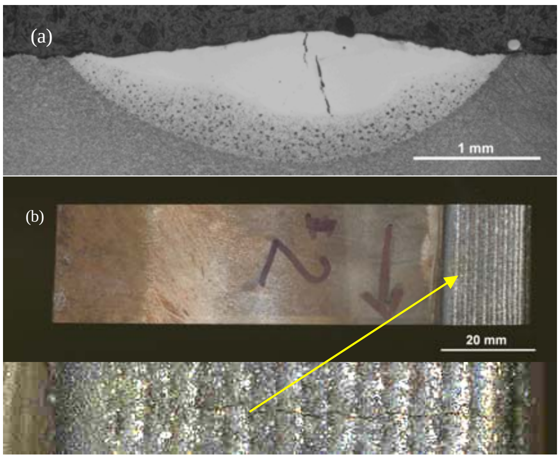

Fig 7. *Cracking of the Stellite 6 clad (a) within the clad track and (b) across the clad tracks.*

4.3 Field trials

One of the Power Stations supporting the research, TRUEnergy Torrens Island in Adelaide, Australia agreed to participate in a field trial, and made a low pressure section of a 200 MW turbine available. The field trials were carried out in September and October of 2004 and 2005 during a scheduled outage of the unit.

The objective was to clad a few blades in an initial trial and then run the unit for a few months followed by detailed inspection and a further trial.

During the first trial in 2004, the anticipated distortion proved to be a reality. Although it was of little significance to the blade performance and only in the order of 1.0 mm, it still warranted further investigation. This was addressed during further laboratory trials and in the 2005 trial the distortion was reduced to 0.3 mm. On some blades no distortion was observed. The robot programming was an issue in the 2004 trial, however, with only a small number of blades clad, time was not a feature. In the 2005 trial, modifications were made to the program which considerably improved the speed of processing each blade.

5 Conclusion

The laser cladding of Stellite 6 onto steam turbine blades has been achieved using a compact co-axial laser cladding head coupled to a fibre delivered diode laser. This head is arranged to facilitate even powder delivery at any angle of presentation and is modular in construction to facilitate quick repair or changing cladding conditions.

To successfully clad the blades requires minimizing the amount of material deposited and care with the substrate temperature especially where edges are involved. The elimination of cracks is achieved by reducing dilution, reducing the length of clad and optimizing cladding conditions. The clad layer was also shown to change as a result of the thickness of the substrate showing it also to be a parameter when cladding.

The September 2004 field trials showed that in-situ laser cladding of turbine blades is feasible and practical. This is the first time that such an application has been successfully demonstrated. In May 2005 the turbine was inspected and the laser repaired blades demonstrated good performance and no sign of damage. The October 2005 trial increased further the level of confidence in the technology through increased number of repaired blades and improved processing

A company, Hardwear Pty. Ltd. has now been established to commercialise the technology. The company is currently negotiating with a local operator its first commercial contract to be carried out in 2007.

Bibliography

[1] Brandt M., Harris J., Sun S., Dempster B., Alam N., and Bishop A. (2005), “In-Situ cladding of leading edge of LP turbine blades

using fibre delivered diode laser", ICALEO '05, Paper 1103.

[2] Peters T. and Jahnen W.(2002), "Steam Turbine leading edge repair by stellite laser cladding", Proceedings of EPRI '02, ST7.

[3] Shepeleva L., Medres B., Kaplan W.D., Bamburger M. and Weisheit A.(2000), " Laser cladding of turbine blades", Surface and Coating Technology 125 , pp. 45 – 48.

[4] Kathuria Y.P. (2000), "Some aspects of laser surface cladding in the turbine industry", Surface and Coatings Technology 132 pp. 262 – 269.

[5] Weisheit A., Backes G., Stromeyer R., Gasser A., Wissenbach R. and Poprawe R. (2001), "Powder injection: the key to reconditioning and generating components using laser cladding", Int. Congress on Advanced Mat'ls and Processes, pp 1-7.

[6] Sun S., Brandt M., Harris J. and Durandet Y.(2006), "Effect of increment and single track geometry on the formation of multi-track laser cladding", PICALO '06, to be published.

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