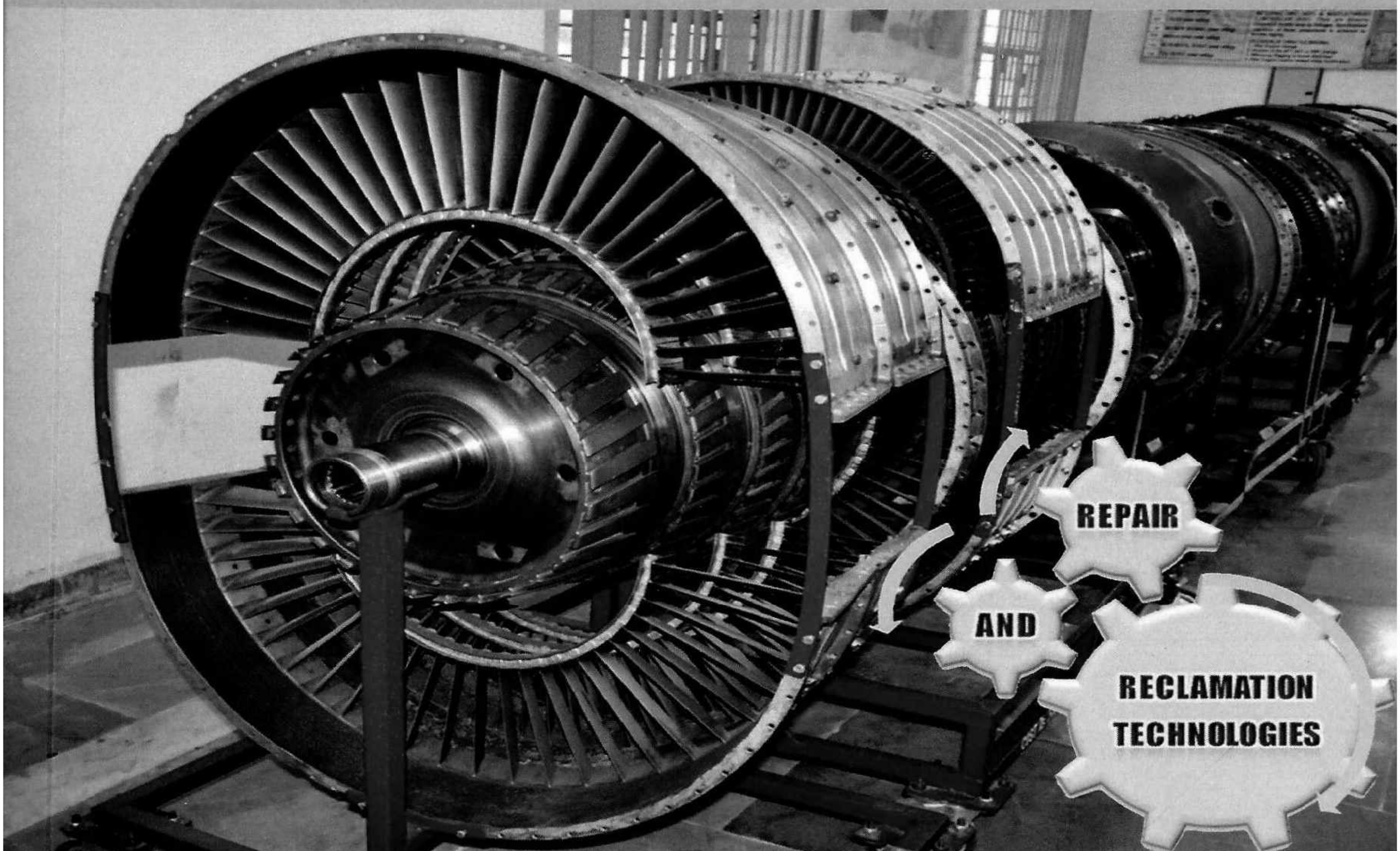
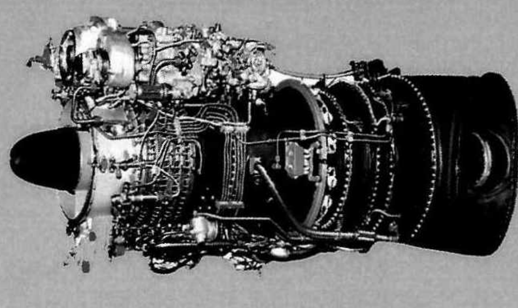
INTERNATIONAL SEMINAR

ON
EMERGING TRENDS IN REPAIR
&
RECLAMATION TECHNOLOGIES ON
AERO ENGINE PARTS





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3 Base Repair Depot

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METALLURGICAL INVESTIGATION ON THE EFFECT OF BZL WELDING OF LPTR BLADE SHROUDED TIPS OF AERO ENGINES

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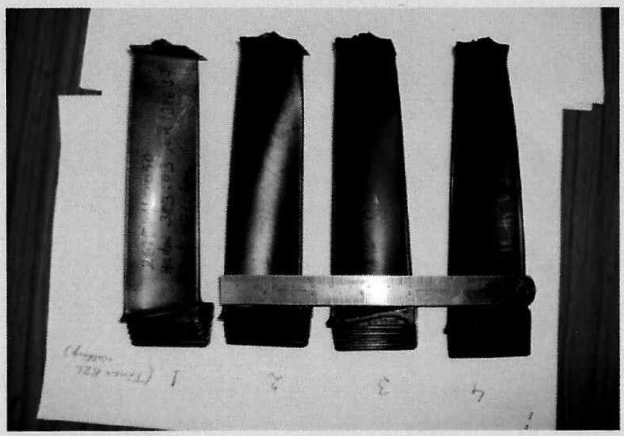
1. BZL welding and assembly procedure could be an area of concern for failure of LPTR blades of aero engines that might have caused number of accidents of aircrafts. So the present investigation is aimed to understand the effect of number of times BZL welding performed on microstructure and properties of the LPTR blades shrouded tips. Hence four numbers of LPTR blades of R-29 aero engine with different number of times BZL welding carried out were investigated and the results were presented. The increase in grain size of the LPTR blade tip was observed with number of times BZL welding was carried out. Rounding of γ' (gamma prime) phase is occurring with BZL weldings. The dissolution of γ' (gamma prime) phase near interface between base metal and weld metal is observed. However, there is not much appreciable change in hardness of the blade tips with number of times BZL weldings performed were observed. Moreover all the BZL welded blade tips have compressive residual stress.

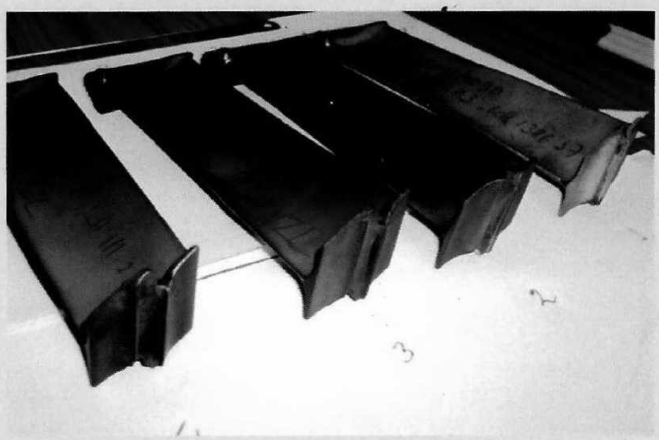
2. *Keywords: LPTR blades, BZL welding, Microstructure, Gamma prime phase and Residual stress*

INTRODUCTION

3. BZL welding and assembly procedure could be an area of concern for failure of LPTR blades of aero engines that might have caused number of accidents of aircrafts. BZL welding is carried out on the Z-notch at the tip of each LPTR blade, primarily to butt against respective portion (BZL welded tips) of neighbouring blades so as to dampen the vibration. BZL welding is meant for hard face coatings and undertaken during every OH processes of aero engine. BZL welding is carried out using TIG welding methodology and the local temperature (peak temperature) during welding process may be around 2000°C. The number of time the BZL welding has been carried out may have effect on the microstructure and properties of the LPTR blade tips. So the present investigation is aimed to understand the effect of number of times BZL welding performed on microstructure and properties of the LPTR blades shrouded tips. Four numbers of LPTR blades of R-29 aero engine with different number of times BZL welding carried out were examined to assess the effect of BZL welding on the grain structure of blade material



Photographs of the four LPTR blades on which 1, 2, 3 and 4 times BZL welding have been carried out respectively (Left to Right).



Photograph of Z-notch of tip shrouded portion of the LPTR blades where BZL welding have been carried out as marked by arrows

near welding portion.

EXPERIMENTAL AND RESULTS

4. **Materials.** The LPTR blades are shown in Figure 1, on which once, twice, thrice and four times BZL welding were carried out respectively (from left to right). Top side is the tip portion and bottom side is the root portion of the LPTR blades. The tip shrouded portions (Z-notch) of blades where BZL weldings were carried out is shown in Figure.

5. **Stress Measurement/Analysis.** Residual stresses are defined as stresses that remain in a component after fabrication/welding and are caused by incompatible internal permanent strains. It may be modified at every stage in the component life cycle. Welding generates residual stresses and typically produces large tensile stresses whose maximum reaches up to yield strength of materials being joined, balanced by lower compressive residual stresses elsewhere in the component. Tensile residual stresses may reduce the performance or cause failure of components and may increase the rate of damage accumulation by fatigue, creep or environmental degradation. Compressive residual stresses are generally beneficial, but cause a decrease in the buckling load. Attempts were made to measure the residual stress near the BZL welding tip after cutting the tip shroud portion cross sectionally as shown in Figure 3. However due to the surface complexity, the stress measurement was not very accurate. The residual stress was measured by X-ray diffraction method using X-ray stress analyser AST 3000 GR. The parameters used in the measurement are as mentioned above.

Method: $Sin^2\psi$ method

Radiation: Cr Kα

Crystallographic plane: (222) plane of austenite

Collimator diameter: 2mm

Exposure time : 15 sec

6. The measured value of residual stress is collated in table1 for different BZL weldings of the LPTR blade tips.

Table 1. Residual stress of the LPTR blade tips near BZL welding

Table 1. Residual stress of the LPTR blade tips near BZL welding

Blade No.	Number of times BZL welding done	Residual Stress (MPa)
Blade 1	Once	-263+43 (Compressive)
Blade 2	Twice	-411.4+32.8 (Compressive)
Blade 3	Thrice	-33.4+10.1 (Compressive)
Blade 4	Four times	-121.5+25.0 (Compressive)

Photograph of the tip shrouded portion which was cut cross-sectionally for residual stress measurement.

It is evident from the data that the nature of the residual stress is compressive in nature irrespective of number of times of BZL welding of the LPTR blade tips. All the results indicated that the BZL weldings have desirable compressive residual stress, but its variation is random.

7. **Composition analysis by EDS.**

In order to know the chemical composition of the base metal and the weld metal of the LPTR blade, EDS microanalysis was carried out on the base metal and on the weld metal. The EDS spectra and corresponding elemental analysis of the base metal and weld metal are shown in Figures 4 (a & b) and table 2.

8. It is evident from the EDS microanalysis that the LPTR blade and the BZL weld metal is made of Ni based super alloys. The composition of the LPTR blades conforms to Russian grade of Ni-based super alloy AP 220BD. However, the composition of weld metal could not be compared because of non-availability of standard composition.

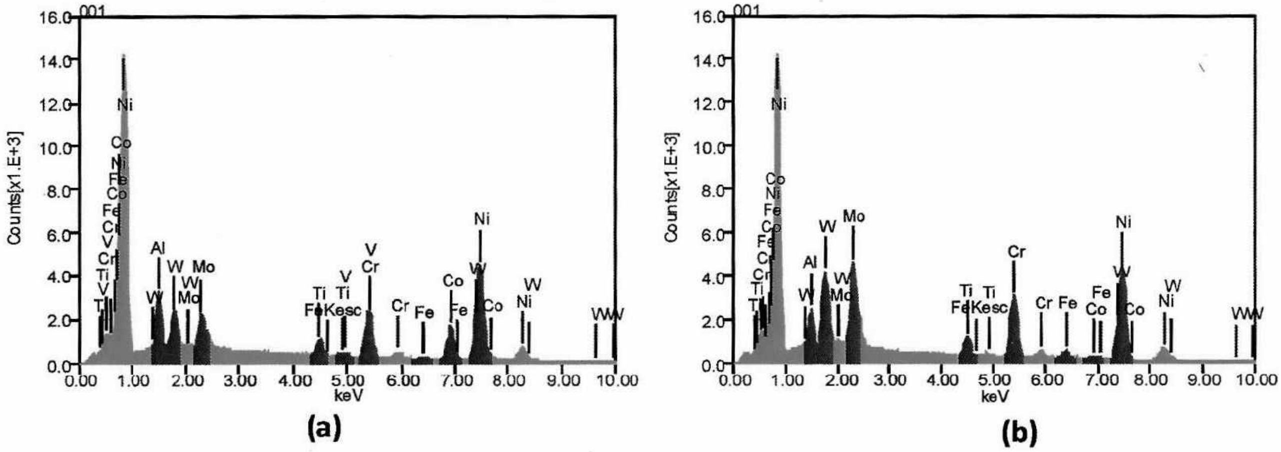


Fig.4 (a & b): EDS spectra of the (a) base metal and (b) weld metal

Table 2: EDS Composition analysis of base metal and weld metal and its comparison with standard.

ELEMENT (Wt %)	*Al*	*Ti*	*V*	*Cr*	*Fe*	*Co*	*Mo*	*W*	*Ni*
Base metal	3.07	2.45	0.28	10.33	0.43	15.60	5.17	4.75	*Balance*
AP 220 BD	3.9-	2.2	0.2-	9-12	3	14-16	5-8	5-7	*Balance*
Weld metal	4.8 1.97	2.9 2.78	0.8 ---	14.40	max 2.93	0.95	13.39	6.92	*Balance*

Microstructure Analysis

9. **Microstructure /Grain size analysis by OM.** The grain size has a significant effect on the properties of a material. Hence to measure the grain size of the blades tip region at welding, an appropriate section was cut, mounted and polished using standard metallographic practice for microstructural analysis. The polished section was etched with glaceragia to reveal the microstructure. Figure 5 (a), (b), (c) and (d) are the microstructures of the four blades with once, twice, thrice and four times BZL weldings respectively. The interface between weld metal and base metal at the

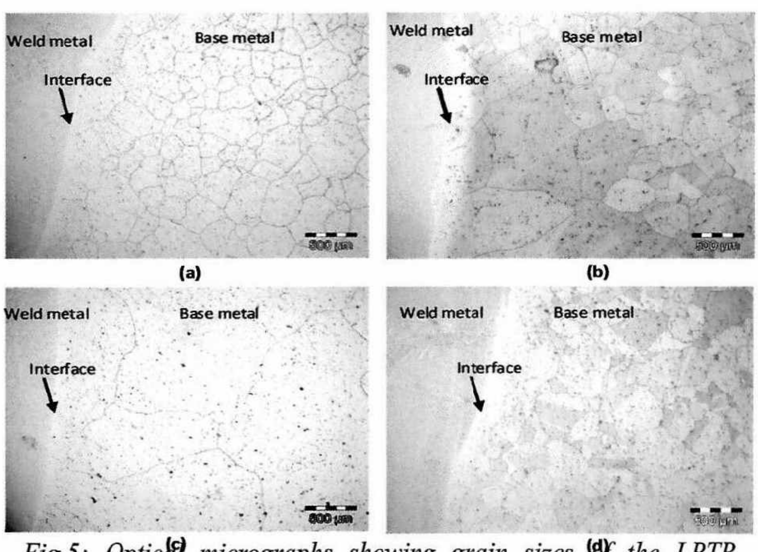


Fig.5: Optical micrographs showing grain sizes of the LPTR blades (a) for 1st BZL welding (b) 2nd times BZL welding (c) 3rd times BZL welding and (d) 4th time BZL welding

Z-notch of the blade is indicated by an arrow in Figure 5. The microstructures consist of typical equiaxed grains .The largest grain size near the weld zone for the 1st time, 2nd time, 3rd time and 4th times BZL welding is 550 µm, 800 µm, 1200 µm and 600 µm respectively. It is worthy to note that there is an increase in grain size from 1st to 3rd number of times BZL weldings of the LPTR blade tips. However there is no such change observed in grain size in case four times BZL welding as opposed to expectation. In order to understand further, micrograph was taken more on the welding portion as shown in Figure 6. The different layers of welding can be seen suggesting that the subsequent welding were done on the weld metal itself instead of on the base metal. Hence the heat of welding has not directly affected the base metal. Thus it could be explained that why in case of 4th time BZL welding there is not much increase in grain size of the base metal.

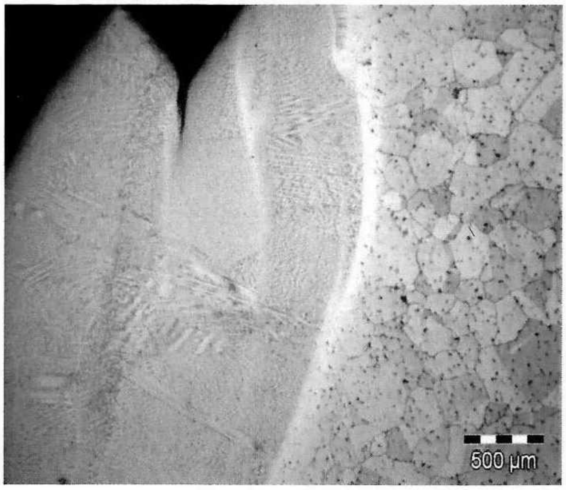
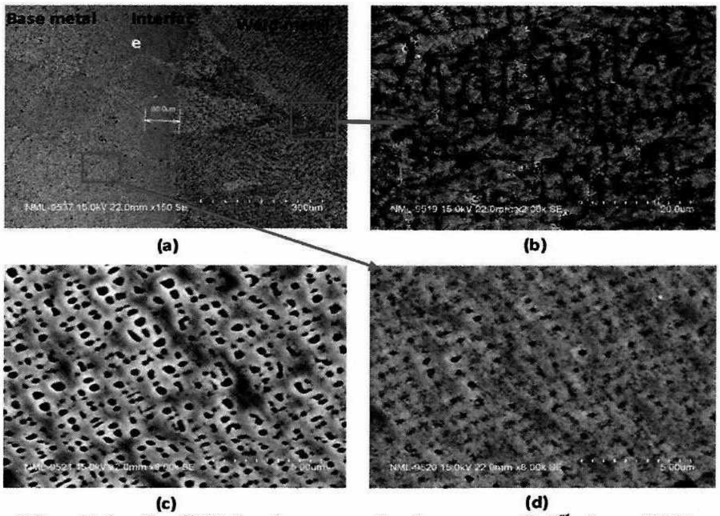


Fig.6: Optical photograph showing BZL welding layers in case of 4th time BZL welding

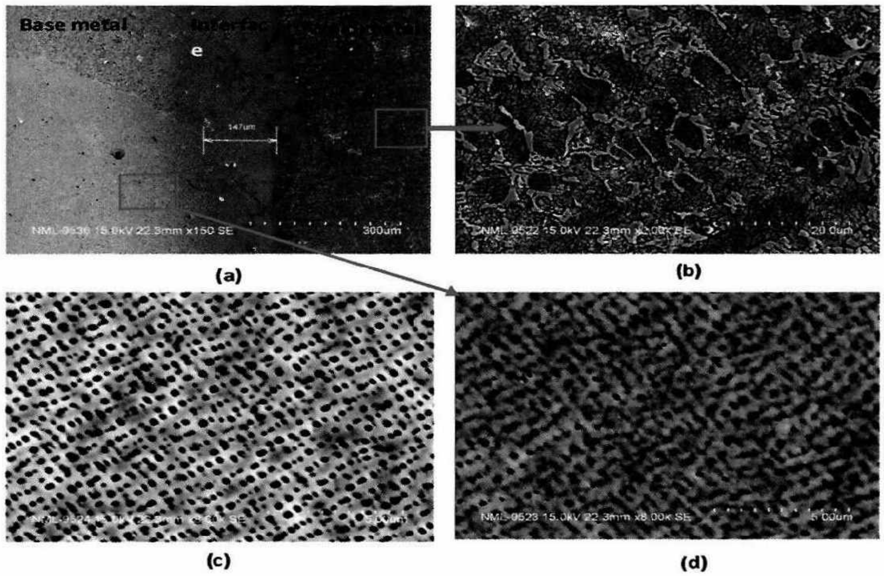
10. **<u>Microstructure/ γ′ (gamma prime) analysis by SEM.</u>** In order to understand the thermal effect on the gamma prime (γ′) precipated phase of the base metal by the number of times BZL weldings done on the LPTR blade tips, the etched samples were observed under the scanning electron microscopy (SEM). The effect of 1st time BZL welding of the LPTR blade shrouded tip is discussed herein. The Figure 7 (a) is low magnification image showing the microstructure of base metal (left region) weld metal (right region) and interface (middle region). The interface width is approximately 86 µm. Figure 7 (b) shows the microstructure of the weld metal at higher magnification. It is a cast dendrite microstructure with second phase precipitated at the interdendrite boundaries, typical of solidification structure. Figure 7(c) shows the microstructure of base metal away from the interface zone with precipitates of gamma prime phase in gamma matrix. The gamma prime phase contributes to strength to the base gamma (γ) phase matrix. The precipitation of gamma prime (γ′) phase appeared as rounded cuboids. The gamma prime dissolution near the interface region can be seen in Figure 7 (d) which is caused by higher temperature compared to adjacent base-metal.



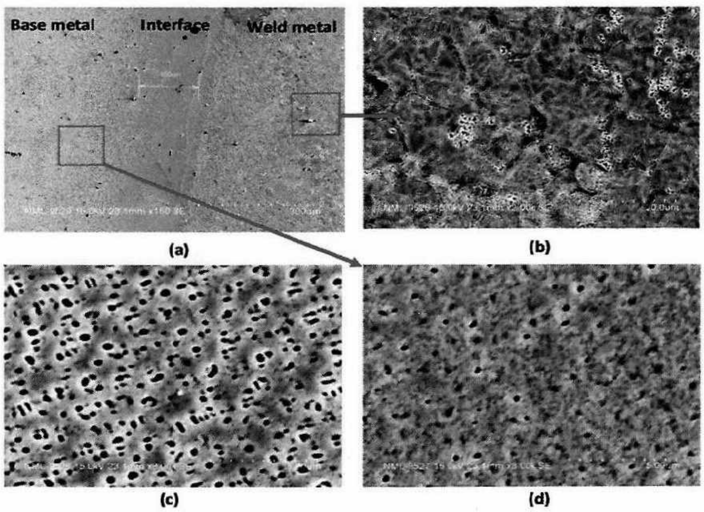
Figs 7 (a-d): SEM micrographs in case of 1st time BZL welding of the LPTR blade shrouded tip show (a) at low magnification (b) microstructure of BZL weld metal,(c) precipitation of γ′ phase in γ matrix of the LPTR blade tip and (d) dissolution of γ′ phase near the weld interface

11. The effect of twice number of BZL welding of the LPTR blade shrouded tip is discussed and compared. The Figure 8 (a) is low magnification image showing the microstructure of base metal (left region) weld metal (right region) and interface (middle region). The interface width is approximately 147 µm. Figure 8 (b) shows the microstructure of the weld metal at higher

magnification. It is a cast dendrite microstructure with second phase precipitated at the interdendrite boundaries. Figure 8 (c) shows the microstructure of LPTR blade tip away from the interface zone with precipitates of gamma prime (γ') phase in gamma (γ) matrix. The precipitation of gamma prime (γ') phase is spherical in shape as compared to cuboids in unaffected zone. The precipitates are finer and more uniformly distributed than in case of single time BZL welding of the blade tip. The gamma prime dissolution near the interface region can be seen in Figure 8 (d).



Figs 8 (a-d): SEM micrographs in case of 2^{nd} times BZL welding of the LPTR blade shrouded tip show (a) at low magnification (b) microstructure of BZL weld metal,(c) precipitation of γ' phase in γ matrix of the LPTR blade tip and (d) dissolution of γ' phase near the weld interface .



Figs 9(a-d): SEM micrographs in case of three times BZL welding of the LPTR blade shrouded tip show (a) at low magnification (b) microstructure of BZL weld metal,(c) precipitation of γ' phase in γ matrix of the LPTR blade tip and (d) dissolution of γ' phase near the weld interface .

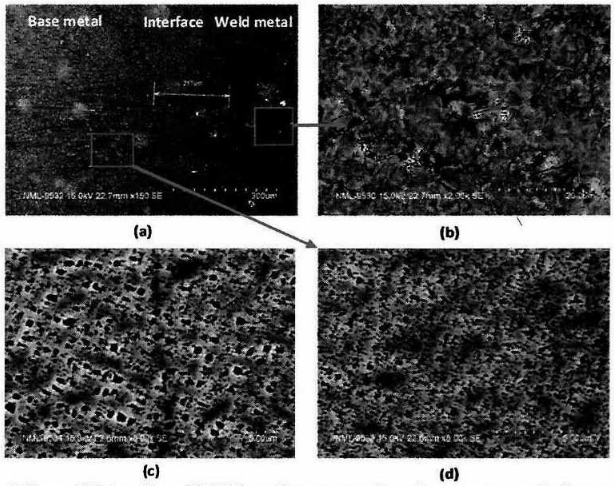
12. The effect of three times BZL welding of the LPTR blade shrouded tip is discussed and compared herein. The Figure 9 (a) is low magnification image showing the microstructure of base metal (left region) weld metal (right region) and interface (middle region). The interface width is approximately 150 µm. Figure 9 (b) shows the microstructure of the weld metal at higher magnification. It is a cast dendrite microstructure with second phase precipitated at the interdendrite boundaries. Figure 9 (c) shows the microstructure of LPTR blade tip away from the interface zone with precipitates of gamma prime (γ') phase in gamma (γ) matrix. The precipitation of gamma prime (γ') phase is spherical in shape. The gamma prime dissolution near the interface region can be seen in Figure 9 (d).

13. The effect of four times BZL welding of the LPTR blade shrouded tip is discussed and compared. The Figure 10 (a) is low magnification image showing the microstructure of base metal (left region) weld metal (right region) and interface (middle region). The interface width is approximately 217 µm. Figure 10(b) shows the microstructure of the weld metal at higher magnification. It is a cast dendrite microstructure with second phase precipitated at the interdendrite boundaries. Figure 10(c) shows the microstructure of LPTR blade tip away from the interface zone with precipitates of gamma prime (γ')

phase in gamma (γ) matrix. The precipitation of gamma prime (γ') phase appears to be cuboids. Moreover, this region contains lager primary gamma prime (γ') and finer secondary gamma prime (γ') precipitates akin to virgin microstructure. The gamma prime dissolution near the interface region can be seen in Figure 10(d).

Number of BZL	Interface width (pm)
welding	86
II	147
III	150
IV	217

It is observed from the above results that the interface width is increasing with number of times BZL welding performed.



Figs 10(a-d): SEM micrographs in case of four times BZL welding of the LPTR blade shrouded tip show (a) at low magnification(b) microstructure of BZL weld metal, (c) precipitation of γ' phase in γ atrix of the LPTR blade tip and (d) dissolution of γ' phase near the weld interface

15. **<u>Hardness Measurement.</u>** Vickers hardness measurements were done on BZL weld metal and on the LPTR blade tips to see any variation on the hardness with number of times BZL welding were carried out on the LPTR blades. The hardness was measured at 1mm away and 2 mm away from the interface between weld metal and base metal. The hardness was measured at 30 kg load .The hardness values were collated in the table 4.

16. It is evident from the hardness values that the hardness value of weld metal is very high (i.e. >600HV) compared to base metal of LPTR blade (i.e. < 400 HV).

Table 4: Hardness of LPTR blade with number of times BZL welding were carried out

Number of time BZL welding	Hardness of blade at 1mm away from interface (HV)	Hardness of blade at 2mm away from	Hardness of the weld metal (HV)
1st time BZL welding	3.56	interface (HV)	607.8
2nd times BZL welding	380.4	397.4	698.4
3rd times BZL welding	370.7	356.4	616.8
4th times BZL welding	373.9	367.6	614.6

17. It is worthy to note that there is not much difference in hardness values of the LPTR blades with respect to number of times BZL welding were performed except for second times BZL welding. The hardness value of weld metal for second times BZL welding is also higher compared to other weld metals of rest of the BZL weldings.

Discussions

18. The effect of BZL welding on the microstructure of LPTR blade shrouded tips has been investigated and the results are discussed. It is important to note that the number of BZL welding operations yielded compressive residual stress at the blade tip. The increase in grain size of the blades is due to the heating effect during the BZL welding. The rounding of γ' (gamma prime) phase from cuboids shape as generally observed in virgin materials, is due to the heating effect during BZL welding. The increase in interface width is due to the interdiffusion of atoms of base metal and weld metal by the heat generated during BZL weldings. The higher hardness near the interface is due to the higher hardness of the weld metal which is contributed by the presence of higher content of molybdenum element in the weld metal.

CONCLUSION

19. (a) All the BZL welded LPTR blades have compressive stress on the tips.
(b) There is increase in the grain size of the LPTR blade shrouded tips due to number of times BZL welding performed.
(c) Rounding of γ' (gamma prime) phase occurring due to heating effect during BZL weldings.
(d) Dissolution of γ' (gamma prime) phase near interface is occurring due to heating effect during BZL welding.
(e) There is no appreciable variation in hardness of the blades iresespective of number of times BZL weldings carried out.

Acknowledgement

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Reference

2. Technical report no: NML/MST/IAF/1.13/111/2010 dated Dec. 2010, CSIR-NML, Jamshedpur archive.

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