DETAIL INVESTIGATION OF MICROSTRUCTURES AND MECHANICAL PROPERTIES OF INCONEL 617 SHEET OF FIBER LASER WELDING

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ABSTRACT

Inconel alloy 617 is used during the research, because it has high strength and oxidation resistance in a wide range of temperatures. It is used in combustion cans, transition liners in both aircraft and land-based gas turbines and medical engineering. Because of its resistance to high-temperature corrosion, the alloy is used for catalyst-grid. Inconel alloy 617 also offers attractive properties of components of power-generating plants, both fossils fuelled plants and nuclear power plants. In the present research, full penetration welding of 1.5 mm thick Inconel 617 plates in a butt configuration was performed by adopting a fiber laser welding machine. The influence of different welding conditions like welding speed, welding power on the heat affected zone (HAZ) morphology, metallurgy and mechanical properties was discussed in detail. Microstructures were assessed by optical microscope and by field emission scanning electron microscope (FE-SEM), while the mechanical behaviour was analysed in terms of Vickers micro-hardness is compared with different welding conditions specimen and base material. Microstructure at different welding parameters was inspected by FE-SEM. Hardness of the base metal is lower in comparison to the fusion zone due to rapid cooling.

Keywords: fiber laser welding, microstructure, field emission scanning electron microscope, microhardness.

1. INTRODUCTION

Inconel 617 is a Nickel base super alloy primarily a solid solution with exceptionally good engineering properties Because of its exceptional properties like high hot hardness, creep resistance, oxidation resistance and also provides resistant to both reducing and oxidizing media. This alloy is widely used in aerospace, power plants, chemical industry and nuclear industry [1], [2] and [3]. Components used for making with this alloy such as ducting, combustion cans, transition liners in both aircraft as well as land based gas turbines. Due to simultaneous presence of Chromium (Cr), Aluminium (Al) and Molybdenum (Mo) in the composition this alloy is extensively used in many oxidizing and reducing environments [4]. The Nickel base super alloys, mainly gain their high temperature strength in the austenite phase due to formation of dispersive γ'-Ni3(Ti, Al) and γ''-Ni3Nb inter- metallic particles in this phase[5]. Homam Naffakh Moosavy *et al.* has been investigated the designed precipitation- strengthened nickel-base super alloys using different welding parameters with heat input as a constant parameter [6]. Mankins *et al.* [7] investigated about the microstructure and phase stability and showed the major phase present in the alloy after exposure to the temperatures in the range 649^0C-1039^0C. The phase remained stable and precipitated as discrete particles at all temperatures. Kihara *et al.* [8] studied about the morphological changes of carbides and their effects on creep properties of Inconel 617 during creep at 1000^0C. They show that the grain boundaries started to displace towards the steady state creep region on which the carbides dissolved. Kimball *et al.* [9] investigated about the various effects of thermal aging on the microstructure and mechanical properties of this alloy.

Laser welding is one of the new joining technology that has received growing attention because of its exceptional features and potential and having many advantages as compared to conventional thermal joining processes. High scanning velocity, low heat affected zone, less distortion, high controllability and also having the ability of producing highly intensified heat source that makes it possible for highly precise welding [10]. Through this technique, high range of complex weld geometries and configurations can be obtained with optimum level of productivity, exceptional weld quality and flexibility. Due to its high level of energy density in small spot dimensions, there can be obtained a narrow bead width, high precision and low panel distortions. As compared to other available commercial lasers, fiber source laser presents low capital investment requirements with several remarkable advantages that can improve the quality of the seam with very high potential. Since the good beam quality fiber source coupled with high continuous wave powers that offer deep penetration welding as well as shallow conduction mode welding. As the low wavelength of the beam allows absorption by almost all the metals and alloys, these lasers can be useful in various kinds of materials [11] and [12]. Caiazzo *et al.* studied the effect of various parameters like laser power, welding speed and defocusing on Ti-6Al-4V plates in of thickness 3 mm square butt weld configuration in which a disk-laser source has been used [10]. The different welding techniques have been compared in previous studies [13, 14]. The influence of pulse energy and pulse duration on depth penetration of laser welded titanium alloy joints has been investigated Akaman *et al.* The influence of power output in the weld bead geometry was shown in the study [15]. Schneider *et al.* [16] a remarkable improvement of

process stability is achieved by optimizing the flow rate of shielding gas by suppressing the vapour plume. The underfill defect formation and mechanical properties for various welding regimes and specific heat inputs has been investigated by Squillace *et al.* [17].
In this present study, fibre laser welding of Inconel 617 alloy of 1.5 mm thin sheet was investigated. The investigation was done for the microstructure and the mechanical properties i.e. micro-hardness of the alloy in the weld zone by varying various parameters like welding speed and laser power.

2. EXPERIMENTAL SET UP

A 400 W Fiber laser was used to weld the Inconel alloy 617. The spot diameter of the laser beam was 0.25 mm with focal length 30 mm. The Nitrogen (N2) gas was used as a shielding gas. The pressure of the Nitrogen (N2) gas was 3.0bar.A schematic representation of a fiber laser setup shown in Figure-1.

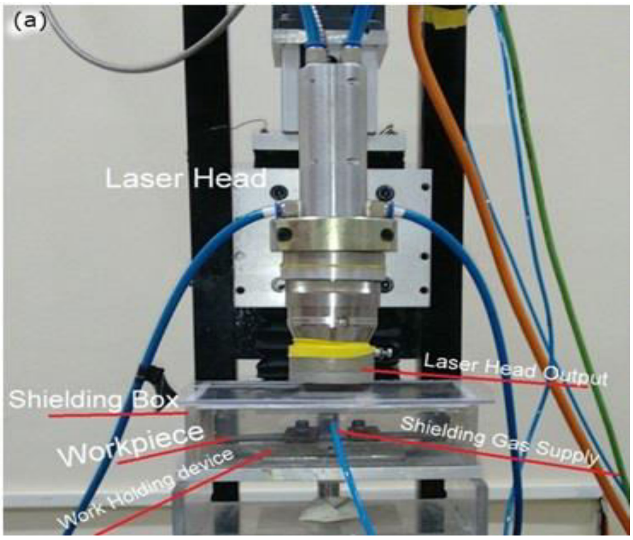

Figure-1. Setup of fiber laser welding.

In order to obtain the better laser welding quality, welding parameter like welding power, welding speed has been varied and rest of all welding parameters are kept constant.

3. EXPERIMENTAL PROCEDURE

Specification of fiber laser welding is given in Table-1 and schematic representation of cad model of fiber laser welding as shown in Figure-2.

Table-1. Laser system specification.

Laser system	Maximum output power	Emission wavelength	Focal Length	Focal point diameter
Fiber Laser welding	400 W	1070 nm	30 mm	0.25 mm

Table-2. Fixed parameters used in the present study.

Welding Parameters	Value
Beam diameter	(beam diameter 0.25 mm)
Wave length in nm	1070
Focal position	At the surface
Gas (N2) Pressure (bar)	3
Beam angle in degree	90
Focal length in mm	30.00 mm

In this present study the parent material Inconel 617 of 1.5 mm sheet is used. Sheet was further cut into the section of 80 mm × 25 mm × 1.5 mm. Welding is performed by the single pass full penetration by fiber laser welding with nitrogen gas as a shielding gas. The welding parameters like welding power, welding speed are varied.

For examination of microstructure at FZ (fusion zone), HAZ (heat affected zone) and BMZ (base metal zone) several specimen were prepared along the transverse cross-section of weldments. The specimen was prepared by grinding using 400, 800, 1200 and 1600 grit of SiC paper. Grinding time for each sample is 8 minutes each grit. Each sample is polished at 400 and 800 grit in clockwise direction and final polishing is done at 1200 and 1600 grit size in the opposite direction that of 400 and 800 grit.

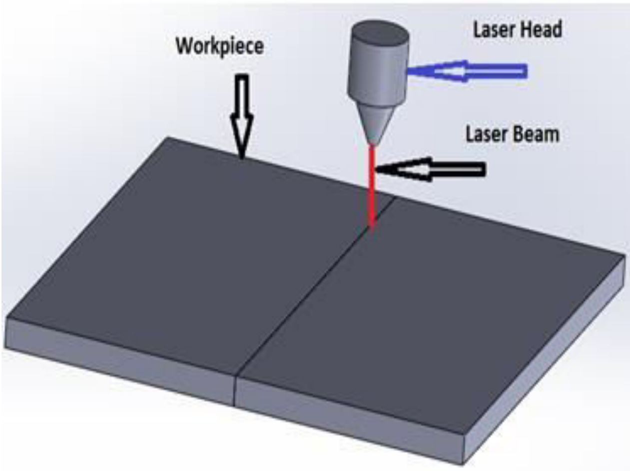

Figure-2. CAD model of laser welding.

The polished surface of the samples was etched at room temperature for 1.5 minute for OM (optical microscope) and 3 minutes for FE-SEM observations. Glyceregia reagent (15 ml Glycerol + 10 ml HCl + 5 ml HNO3) is used for OM and Aqua regia (20 ml HNO3 + 60 ml HCl Very strong) is used for FE-SEM.

Microhardness is measured at 200 micron of welding zones, heat affected zone and base material at load of 0.1 kg and for 10 second dwell time using vicker micro hardness tester.

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4. RESULT AND DISCUSSION

a) Microstructure analysis

The microstructure of the specimen were taken using field emission scanning electron microscopy (FESEM) at various zone i.e., weld zone, heat affected zone (HAZ) and base metal (BM). The uniform tree like structure was observed in Figure-3(a) and this tree like structure is known as dendrite structure in metallurgical term. The crystal of the material starts to minimize its areas where it has highest surface energy, therefore the structure become sharper as dendrite growth takes place more and more.

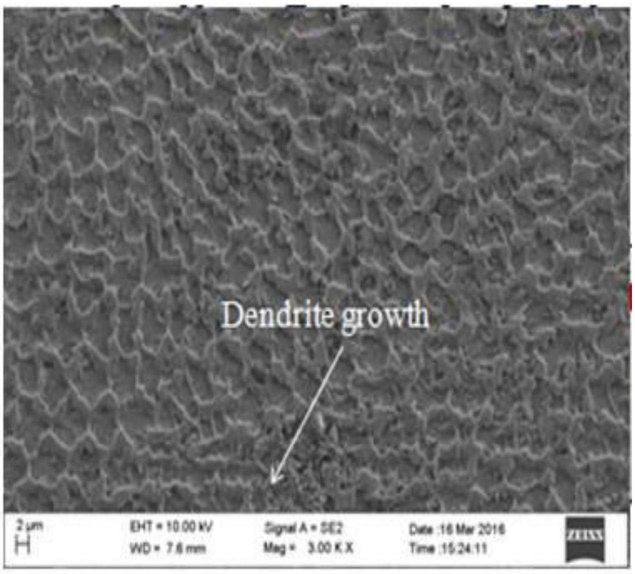

Figure-3(a). Microstructure of a fusion zone at 3000X by FESEM.

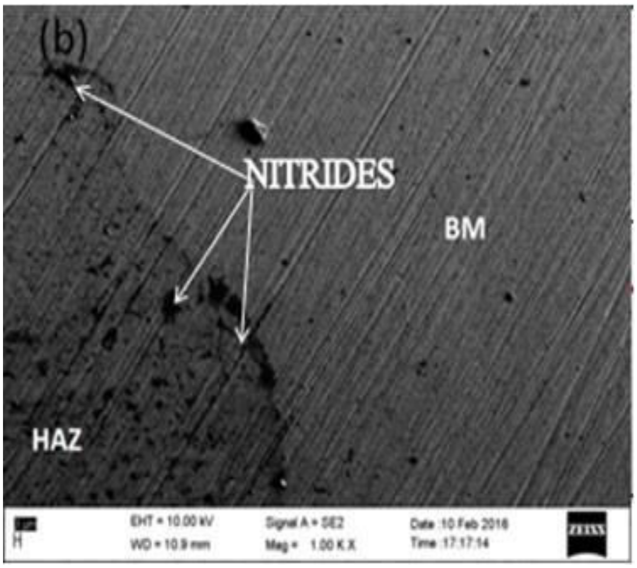

Figure-3(b). Combination of BM-HAZ by FESEM at 1000X.

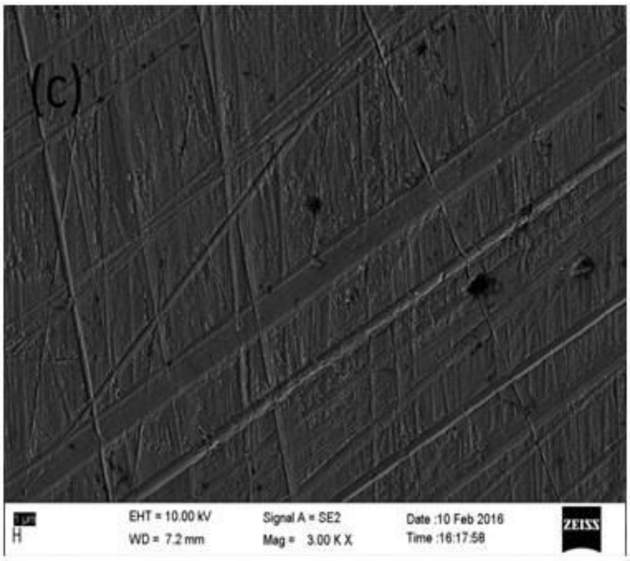

Figure-3(c). Base Metal at 3000X by FE-SEM.

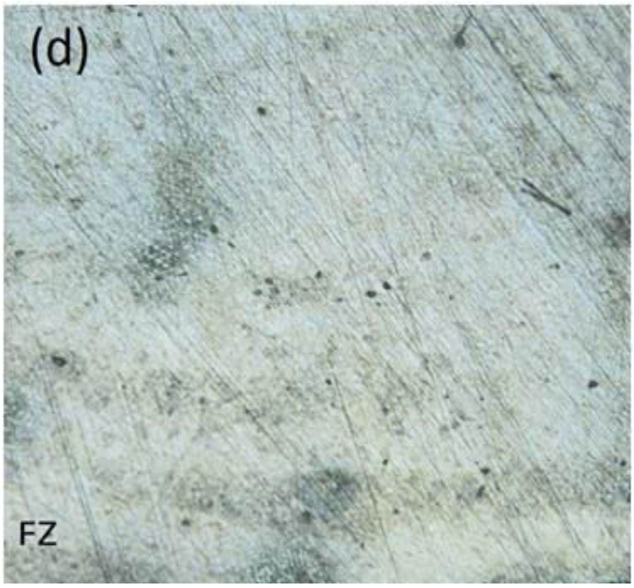

Figure-3(d). FZ at 100X by optical microscope (OP).

Figure-3(b) shows the difference in microstructure between the BM and HAZ. It indicates that there exist a partial melted region in HAZ and formation of nitrides took place on the surface as N2 was used as a shielding gas that reacts with the major elements at elevated temperature.

The microstructure in the weld zone is expected to be changed significantly at the temperature beyond the effective liquids temperature due to re-melting and solidification of metal in this zone. However the microstructure of fusion zone is much more complex due to the physical interaction between the heat source and the base metal. The microstructure in the base metal contains of a larger grain size in the heat affected zone due to heat distribution.

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Table-3. Chemical composition of the INCONEL 617 in base metal zone (% weight by EDAX analysis).

Elem ents	Al	S	Cr	Mo	Co	C	Ni
Atom ic %	1.31	0.06	22.77	9.22	12.99	0.09	51.78

Table-4. The chemical composition of the particle in the FZ of the sample 3 by EDAX analysis (at welding power 320 W and welding speed 80 mm/min).

Elem ents	Al	S	Cr	Mo	Co	C	Ni
Atom ic %	1.09	1.98	22.19	8.89	12.19	2.42	51.2 4

Table-4 shows the chemical composition (weight %) achieved in the FZ indicated in the picture presented in Figure-5. The amount of sulphur in the FZ was about 1.98 % and carbon content is increased 0.06 5 to 2.42 % rest of all the composition is almost same so there is no loss of alloy element.

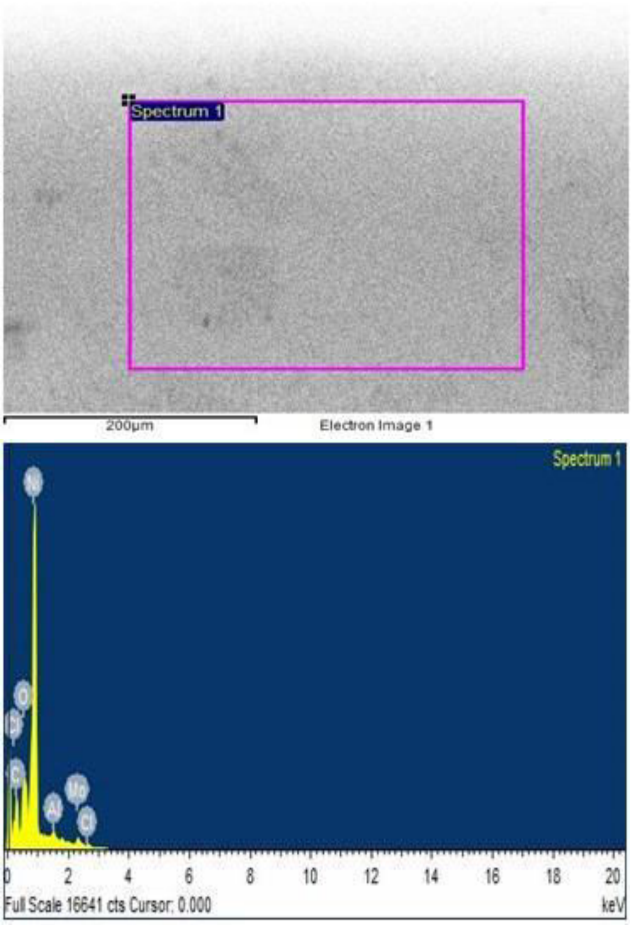

Figure-4. FESEM photomicrograph and EDAX spectrum of the particles marked via square area in the base metal.

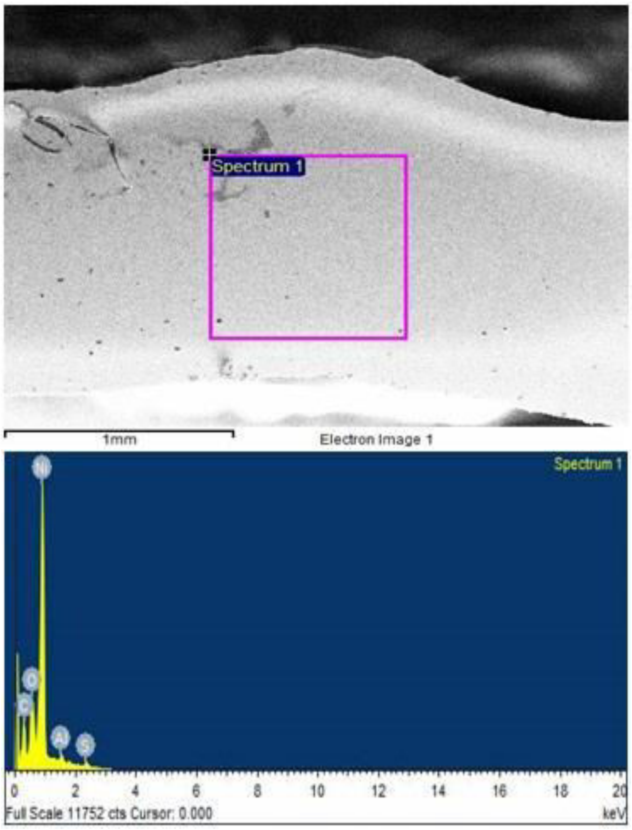

Figure-5. FESEM photomicrograph and EDAX spectrum of the particles marked via square area in the Fusion Zone of sample 4 (at welding power 300 W and welding speed 90 mm/min).

b) Microhardness

The hardness distributions of the welded cross-sections have been analysed using a vicker micro-hardness tester with a load of 100 g. The micro-hardness test has been carried out at 200 micron on the surface beginning on the base metal to fusion zone to base metal. As a result, the hardness is found maximum at the centre of the weld zone and the melted and cooled material is remarkable as compared to the base metal due to its high cooling rate.

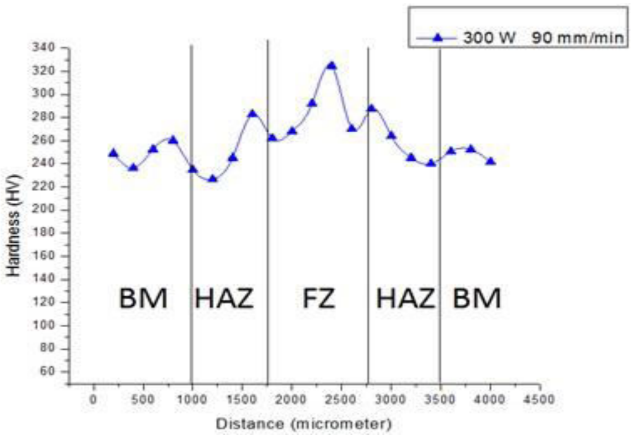

Figure-6. Microhardness of sample 2 (300W 90mm/min).

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The hardness values of the fiber laser welded FZ under different heat inputs are depicted in figure-6. The maximum hardness of FZ increases from 260.1 HV to 324.2 HV as the power decreases from 340W to 300W and the difference in the hardness value is 70HV between the fusion zone and the base metal. In heat affected zone, heat arises from the fusion zone so the hardness in the HAZ and the base metal is lower than the fusion zone and the difference is 32 HV. A study is performed by Wenjie Ren (2015) using Fiber laser welding and CO2 Laser welding techniques on Inconel 617 the hardness value of fusion zone was 259.4 and 240.1 HV respectively [18].

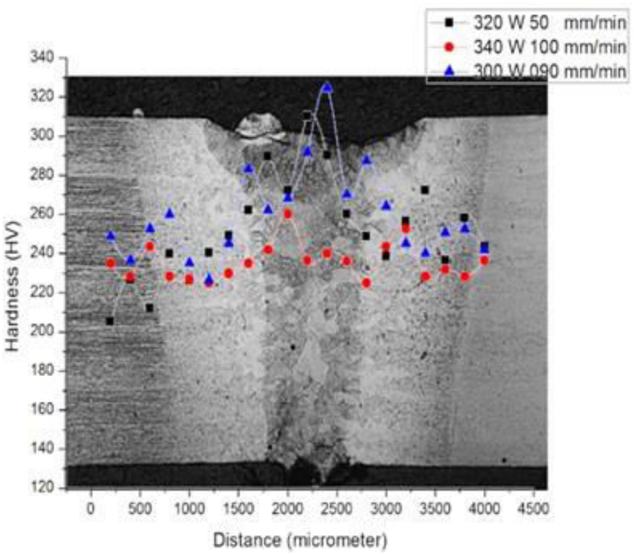

Figure-7. Microhardness at different zone of weldment.

5. CONCLUSIONS

Thin Inconel 617 alloy sheets with thickness 1.5mm were welded using a 400 W fiber laser machine. The effects on the microstructure and the microhardness in the weld zone of Inconel 617 alloy after being welded by fiber laser source were studied and the following key observations were found:

- After EDAX analysis it is observed that the carbon and Sulphur content has been increased significantly in the weld zone.
- Due to rapid cooling rate in this welding process the microhardness in the FZ is found to be higher than the microhardness in the HAZ and the BM.
- There is no solidification cracks were found in the fusion zone but some overheated point in HAZ was found.
- Whereas the decrease in average power decreases the heat input to the target increasing the hardness value.

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