Laser Welding of Ultrafine Bainitic Steels

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ABSTRACT

Laser beam welding (LBW) is one of the advanced welding process which results in joining of materials with intense heat. The intense heat is produced using focused light source falling upon the metallic material's surfaces to be welded. The coherent laser beam is a known source of electromagnetic energy or light with single frequency which can be projected without diverging and also can be focused to an exact spot. The current investigation aims at establishing the parameters required for producing sound welds by fibre laser beam welding and identifying the evolution of microstructure in bainitic steel during similar welding of three mm thick plates. Sound welding was accomplished with laser power 3.5kW and at traverse speeds of 2000, 3000 and 4000 mm/min. The weld joints revealed base metal, weld zone and heat affected zones. The widths of weld zone and HAZ varied as a function of welding speed. Weld zone displayed hardness around 750-800 VHN. A sudden drop in hardness was observed across the heat affected zone, reaching a dip in the intercritical region of HAZ. Hardness in ICHAZ reached around 400-450VHN. The ICHAZ was more pronounced at 3000 mm/min. Microstructural changes were explored by optical microscopy techniques. The high hardness in fusion zone and low hardness in the intercritical structure was found to have correlation with prevailing microstructural features in the respective zones.

Keywords: Bainitic Steel; fibre laser welding; fusion zone; heat affected zone; intercritical structure; hardness.

1.0 INTRODUCTION

New carbide free-bainitic steels are gaining an increasing importance in automobile applications. The significant advantage of these steels is the desired combination of high tensile strength along with good ductility without employing complex heat treatment techniques or thermomechanical processes. The ultrafine bainitic plates of the microstructure are responsible for the achievement of strength. The presence of retained austenite along with bainitic plates controls the desired ductile behaviour. Conventional welding of bainitic steels offers challenges due to possible change in microstructure stability due to heat input [1].

The fibre laser welding offers advantages over traditional welding techniques due to its high power density, focused beam and fast cooling which is useful in reducing the softening of the heat affected zone. In this method, a coherent light beam produced by the laser beam is focused and reflected in the same path. The focused spot size is regulated by a choice of lenses and the distance from it to the base metal. The welding and cutting make use of sharp focuses spot. Heat treatment requires large spot. The laser beam generates large volume of concentrated energy that helps in welding; unfortunately, a few lasers are in real production and application nowadays. On the other hand, the laser of high-power density is extremely cost effective [2-7].

The significant parameters that direct the weldability aspects of Fibre Laser Welding are heat input during welding, Power of Laser beam, speed of beam. Among the aforementioned parameters, the change in speed is the important contributing parameter that dictates the phase transformations there by feasibility of welding. The wide application of Fibre Laser Welding in the fabrication of steels was delayed due to non-availability of a suitable fibre material. In the literature there have been fewer investigations exploring the feasibility of laser welding technique using various advanced steels [2, 3]. The present study was performed to explore the feasible parameters of fibre laser welding technique on ultrafine bainitic steel plates of 3mm thickness by Plate-to-Plate welding and secondly to establish the influence of beam velocity on the evolution of microstructural constituents, hardness, and tensile characteristics across heat affected regions during welding.

2.0 EXPERIMENTAL PROCEDURE

Ultrafine bainitic steel plates of 3 mm thick were laser welded. NdYAG fibre was used during this laser welding. A power of 3.5 kW and beam speeds of 2000, 3000, and 4000 mm/min (**Ref. Table 1**) were employed as welding parameters. Heat input per mm was calculated with the formula. During welding, the oxidation of surface is not uncommon. To prevent oxidation and produce clean and defect free welds, Argon gas shielding was used. The sound plate- to- plate weld obtained is indicated in **Fig. 1**.

Metallography was conducted on the samples that were cut by EDM machine. Primary polishing was done with emery papers. Final polishing was done with disc polishers using sub micron diamond pastes as abrasives. To reveal the microstructural constituents, Lepera reagent was used as etchant. Optical micrographs were obtained on base metal, Heat Affected Zone (HAZ) and weld zone regions. Microhardness profiling was undertaken from base metal to HAZ and to weld zone. Tensile samples were prepared (ASTM standards) and tested for determination of Yield strength, ultimate tensile strength and total elongation (**Fig. 2**).

Table 1 : Process parameters employed during Fibre Laser welding of bainitic steel

S. No.	Laser Power, kW	Laser Speed, mm/min.
1	3.5	2000
2	3.5	3000
3	3.5	4000

Fig. 1 : Plate –to–plate laser welded bainitic steel

Fig. 2 : Tensile samples from laser welds

3.0 RESULTS AND DISCUSSION

The elemental analysis of the considered ultrafine bainitic steel is indicated in **Table-2**. The UTS and total elongation values are found to be 1370 MPa and 21% respectively. The attainment of high strength combined with good deformability is due mainly to the existence of ultrafine bainitic plates (~130 nm in size) and increased dislocation density. These factors arise as a result of bainitic transformation. One of the transformation products of bainite includes carbon enriched retained austenite, which takes the credit for showing excellent ductility. The other product of transformation is carbide-free bainite that accounts for exhibition good strength. Sufficient window was maintained in the base material between bainitic starting (Bs) and martensitic starting (Ms) temperatures during thermal treatment of this steel. This has favoured formation of bainite rather than martensite thereby brittle nature was avoided.

Table-2 : Elemental Analysis of Ultrafine Bainitic Steel

Element	Weight %
Iron	95.42
Carbon	0.34
Manganese	1.80
Silicon	1.51
Others	0.96

The microstructure changes (base metal to Weld Zone) of three conditions are indicated in **Fig. 3**. The base metal microstructure clearly indicated the dark bainitic laths and bright retained austenite particles located along the boundaries of bainitic laths. The amount of retained austenite content in weld zone decreased in all welding conditions. The probable factor that contributes to the lowering of retained austenite content is its transformation to martensite due to rapid solidification occurring during welding. This was clearly evident through the formation of dendritic structure in the weld zone.

Fig. 4 depicts the Vickers hardness profile of different zones of the welds at all three welding conditions. Hardness of the Base Metal is about ~425 HV. Irrespective of the beam speed and heat input, weld zones displayed very high hardness. At 2000 mm/min. speed, the peak hardness in weld zone was ~725 HV. The hardness in weld zone increased with increase in beam speed and exhibited maximum of 800 HV at 4000 mm/min. speed. At HAZ, the hardness has come down to ~ 410 HV.

This increased hardness in weld zone is in qualitative conformity with the microhardness data obtained on some of the advanced high strength steels viz., ferritic-martensitic steels.

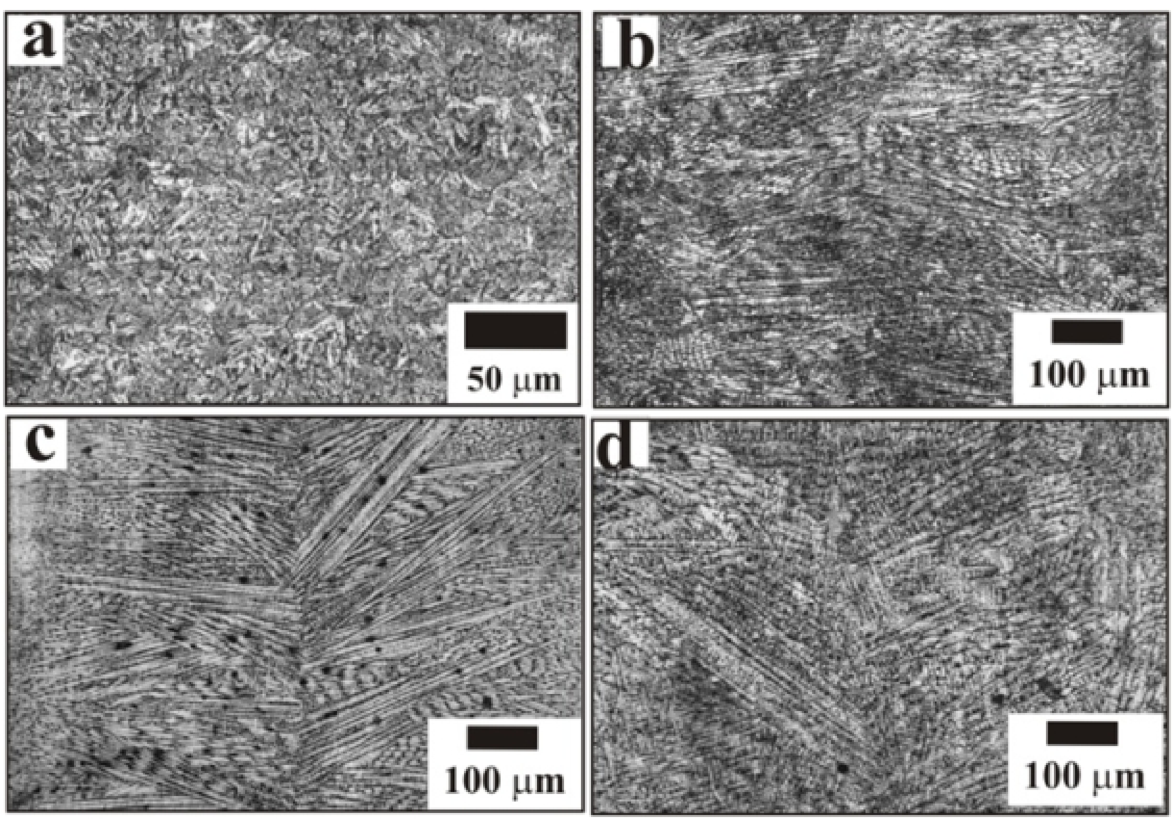
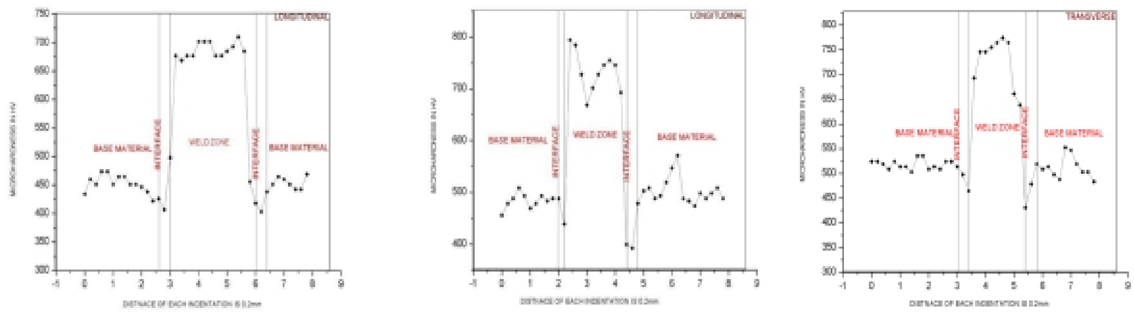


Fig. 3 : Microstructure variation of (a) base material and weld zones of at 3.5 kW beam power and respective beam speeds of (b) 2000 mm/min. (c) 3000 mm/min. and (d) 4000 mm/min.

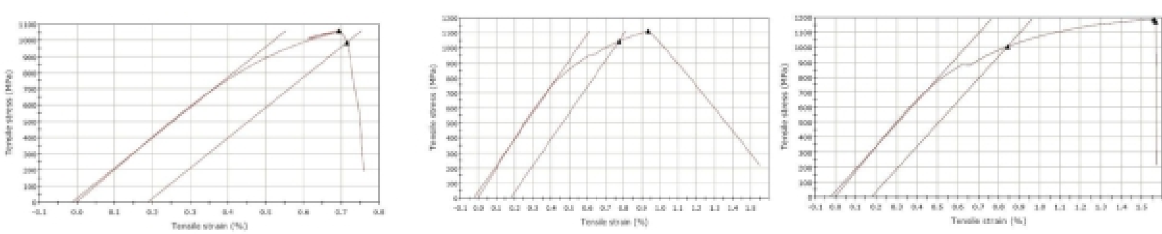


(a) (b) (c)

Fig. 4 : Microhardness profile of Base Metal, Interface (HAZ) and Weld Zones with Laser Power of 3.5 kW and at speeds of (a) 2000 mm/min. (b) 3000 mm/min. and (c) 4000 mm/min.

An abrupt decrease in the microhardness was observed in HAZ. Proceeding towards the weld zone, the increment in microhardness was witnessed from base metal to the weld zone. The hardness variation in the weld zone is dictated by various challenging factors. The transformation products of retained austenite in the weld zone i.e., martensite, dislocation density increase and the residual stresses present could be the contributory elements that may give rise to this higher hardness. Optimum heat treatments after welding are needed to lower the hardness of weld zone. The temperatures of optimum post weld heat treatments are recommended to be lesser than those of employed for down cooling during processing of the base bainitic steel.

The tensile behaviour of the Laser welded samples at three different conditions is indicated in **Fig. 5**. **Table 3** indicates the tensile characteristics of these samples welded employing three different process parameters. It was learnt that the difference between UTS and Yield Strengths decreased as the speed of the beam increased or heat input decreased. The maximum elongation was 1.7% at 2000 mm/min. against that of 21% in unwelded condition.



(a) (b) (c)

Fig. 5 : Tensile behaviour of the Fibre Laser Welded bainitic steel at 3.5 kW beam power and (a) 2000 mm/min. (b) 3000 mm/min. and (c) 4000 mm/min. laser speeds

Table 3 : Tensile characteristics of welded samples

Welding parameters	0.2% Yield trength, MPa	UTS, MPa	Elongation (%)
3.5 kW Laser Power and 2000 mm/min. Laser Speed	960	1117	1.7
3.5 kW Laser Power and 3000 mm/min. Laser Speed	1036	1120	0.64
3.5 kW Laser Power and 4000 mm/min. Laser Speed	1043	1075	1.1

The increase in the Yield Strength and decrease in elongation with increase in speed of the beam can be attributed to the decrease in the amount of retained austenite due to gradual decrease in the heat input while welding.

4.0 CONCLUSIONS

The ultrafine bainitic steel developed in recent times was subjected to Fibre Laser Welding. A beam power of 3.5 kW and traversing speeds of 2000, 3000, and 4000 mm/min. were employed as welding parameters. Defect-free plate-to-plate welds were successfully obtained. The weld joint was composed of Base Metal, Heat Affected Zone, and weld zone. The microstructures of these distinct zones were analyzed. The microhardness, and tensile properties were determined and correlated with the microstructures and heat inputs during welding. At all these welding conditions, it was found that the microstructure variation has not been so noticeable. Microhardness values variation starting from the BM region to the HAZ region and the weld zone indicated an increase due to the strengthening effect owing to presence of phases that result from retained austenite, existence of high dislocation density and residual stresses. All the welded samples exhibited similar tensile behaviour irrespective of the condition in which they were welded. These conclusions clearly specify that Fibre Laser Welding can be recommended as a manufacturing technique of advanced high strength steels like bainitic steels.

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