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PULSED WAVE ND:YAG LASER WELDING OF UNS S32750 SUPER DUPLEX STAINLESS STEEL

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ABSTRACT

This paper presents the microstructural and mechanical behavior of Nd:Yag laser welded super duplex stainless steel employed in chemical and petrochemical industries. Microstructural investigation was conducted using optical and scanning electron microscopies to confirm the presence of large ferrite grain with intra and inter-granular austenite. Ferrite content studies on the weld zone indicate no significant element partitioning between austenite and ferrite phases. Mechanical testing viz., Tensile strength and microhardness, were determined as per relevant standards and the results are presented.

Key words: *Super Duplex Stainless Steel, Pulsed Wave Laser Welding, Microstructure, Mechanical strength.*

1. Introduction

Super duplex stainless steels (SDSS) are high strength and corrosion resistant widely used in chemical and petrochemical industrial applications. UNS S32750 steel is employed in off-shore equipments used to store and process aggressive fluids [1]. While the superior mechanical properties of SDSS alloy is due to the equal distribution of ferrite (α) and austenite (γ) phases, the high pitting resistance equivalent is due to distribution of Cr, Mo, N content in the α and γ phases [2]. Though duplex stainless steel (DSS) and SDSS alloys are readily weldable, the heat input is the key factor in achieving the desired microstructures without the precipitation of sigma (σ), chi (χ) and secondary austenite (γ_2) deleterious phases [3]. Secondary austenite phase may also be independently formed by diffusion at high temperature and its characteristic low nitrogen content leads to poor mechanical and corrosion resistance than previously formed (γ) austenite [4]. Though welding of various grade steels by laser is reported by earlier researchers, the studies on the weldability of super duplex stainless steel UNS S32750 is limited and attempted herein using a 600 W Nd:Yag pulsed laser welding machine.

2. Experimental procedure

The chemical composition of the base metal UNS S32750 is presented in Table 1. 150 X 75 X 2 mm^3 dimension was used for butt joint configuration. JK 600/450 HP (Nd:YAG) of pulsed laser welding machine, with average power 600 W, maximum peak power 10 kW, maximum pulse energy 100 J, maximum pulse frequency 1000 Hz, pulse width range 0.2-20 ms was employed. The process is schematically shown in Fig. 1. The optimal parameter setting for maximum strength, after conducting the iterative runs, is listed in Table 2.

Macro and microstructure examinations were performed on the specimen extracted from the weldment and standard metallographic procedures were followed. The specimens were polished with 220 to 1200 # emery sheets and subsequently disc polished with 0-2 μm diamond paste. The mechanically polished samples were electrochemically etched with 10 % NaOH solution with 6V DC supply for 20 s. Tensile test was carried out as per ASTM: E8M-04 standard in a 100 kN servo controlled universal testing machine (UNITEK-94100; FIE). Vickers microhardness profiles of the welds were estimated using a microhardness tester (HMV-2T; Shimadza Pvt. Ltd) by applying a load of 500 g for 15 s, at equal interval of 0.5 mm, for each indentation

3. Results and Discussion

3.1 Macro and Microstructure analysis

The macrostructure of the weldment Figs. 2.a and 2.b reveal no evidence of macro level defects such as cracks and porosity. The weld bead is conical shaped and is completely penetrated through the thickness with proper fusion. The aspect ratio (depth to width) of the weld zone is 1.67, thus indicating that the mode of

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welding is 'keyhole mode' as reported by Chelladurai et al. [5].

Table 1. Chemical composition of base metal

Elements	**C**	**Mn**	**P**	**S**	**Si**	**Cr**	**Ni**	**Mo**	**N**	**Cu**	**Fe**
Wt %	0.02	0.71	0.02	0.002	0.5	25.2	6.5	3.7	0.3	0.8	Balance

Table 2. Optimal parameters in laser beam welding of UNS S32750 super duplex stainless steel

Parameter	**Values**
Welding speed (mm/min)	200
Pulse rate (Hz)	20
Pulse width (ms)	8.5
Pulse height (%)	35
Pulse energy (J)	28
Focus	On the surface
Shielding gas (l/min)	Argon (10)
Average power (W)	578

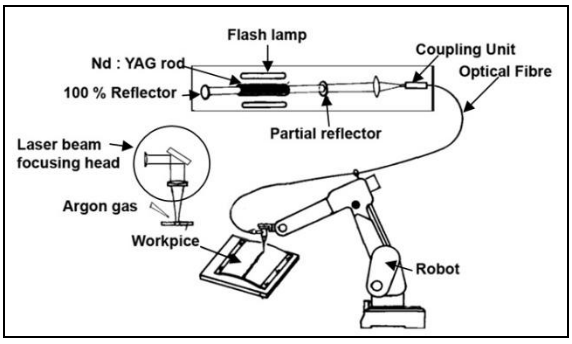

Fig.1 Schematic of laser welding.

The optical microstructure of base alloy (Fig. 3.a) consists of approximately equal amounts of ferrite and austenite phases. The grain boundaries are easily distinguishable and sharp with the absence of any deleterious phases. The austenite phase is embedded into the ferrite matrix and elongated in the rolling direction. Epitaxial and columnar grain growths are observed at the upper segment of the weldment whereas, equiaxed grains are formed at the bottom of the weldment (Fig.3.b). The microstructure of heat affected zone (HAZ) show elongated α (ferrite) and γ (austenite) phases distributed in the ratio of 55:45 (as measured on six locations and averaged). Mirakhorli et al. [6] reported that the cooling rate in pulsed laser welding of DSS is so high and thereby the formation of austenite from ferrite grain boundaries is higher in some regions of weld. This leads to the presence of grain boundary allotriomorphs as in Fig.3.c. The formation of Widmänstatten structure (Fig.3.d) is a result of faster cooling, and which occurs at higher temperature. On the other hand the intra granular austenite particles precipitate in a lower temperature and require a greater driving force as concluded by Muthupandi et al. [3].

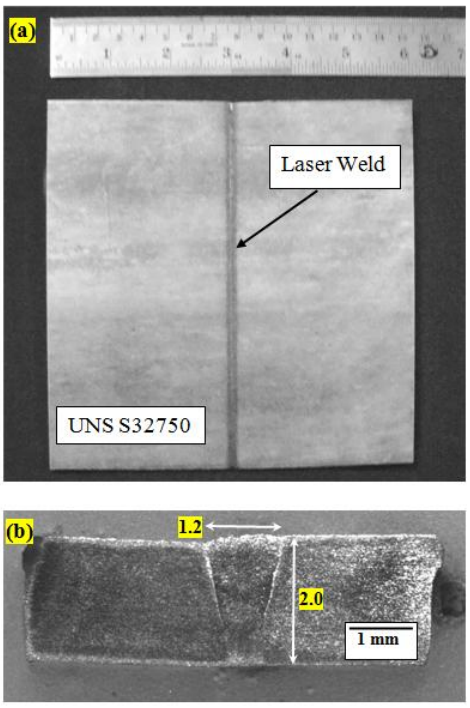

Fig 2. (a) Weld sample, (b) macro structure

3.2 Mechanical characterization

The mechanical properties of weld area were assessed by conducting microhardness and tensile test at room temperature and are described in the subsequent section.

3.2.1 Microhardness

Vickers micro hardness tests were conducted, in longitudinal and transverse direction of the cross-section of the weldments and the results are shown in Fig.4. The results portray clearly that the weld hardness (300 Hv) is lower than that of parent metal (320 Hv). The average hardness observed in the transverse direction of the weld zone is 315 Hv. Although the laser beam weld zone corroborated the presence of appropriate proportion of ferrite and austenite content and with the absence of secondary phases, there is a considerable reduction in hardness.

This could be due to the fact that the austenite grain size is much smaller as found as inter and intra-granular forms.

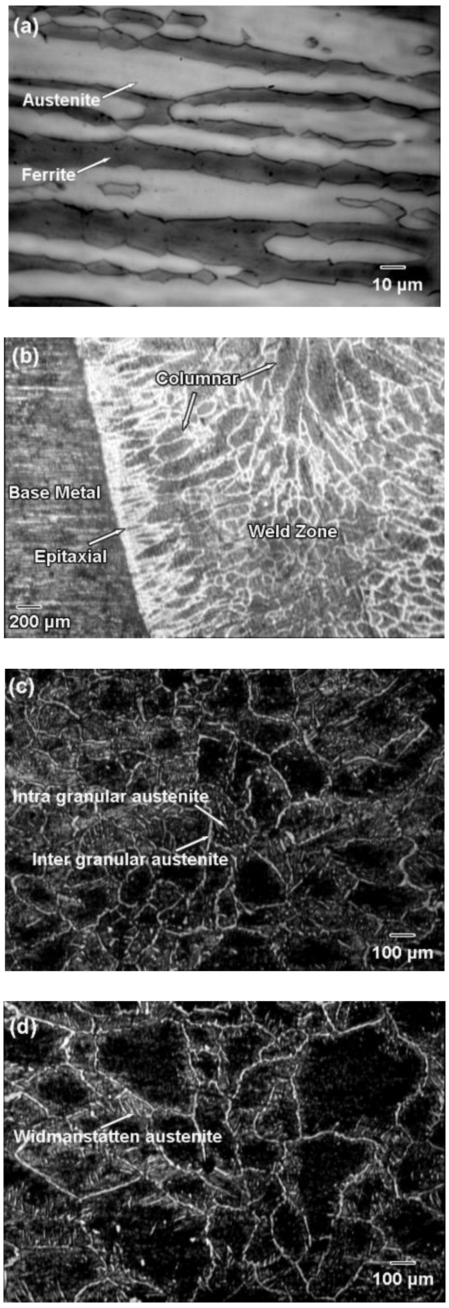

Fig. 3 Microstructure formation (a) Base metal, (b) interface (c) bottom, (d) top of the weld.

Ramkumar et al. [7], from his studies on the weld strength and impact toughness of SDSS in a multipass welding, stated laser beam welding resulted in narrow beads through single pass whereas other multi-pass welding processes viz., gas tungsten arc welding, shielded metal arc welding, result in reheated weld zones which in turn accounts for higher residual stresses.

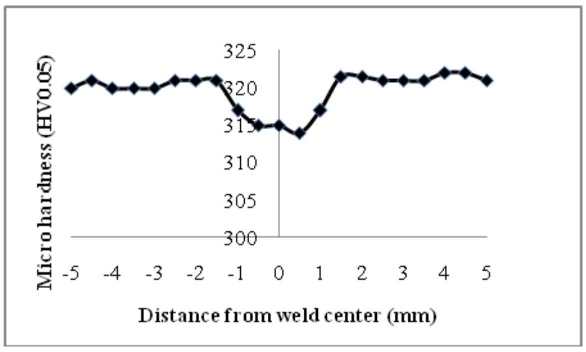

Fig. 4 Microhardness profile

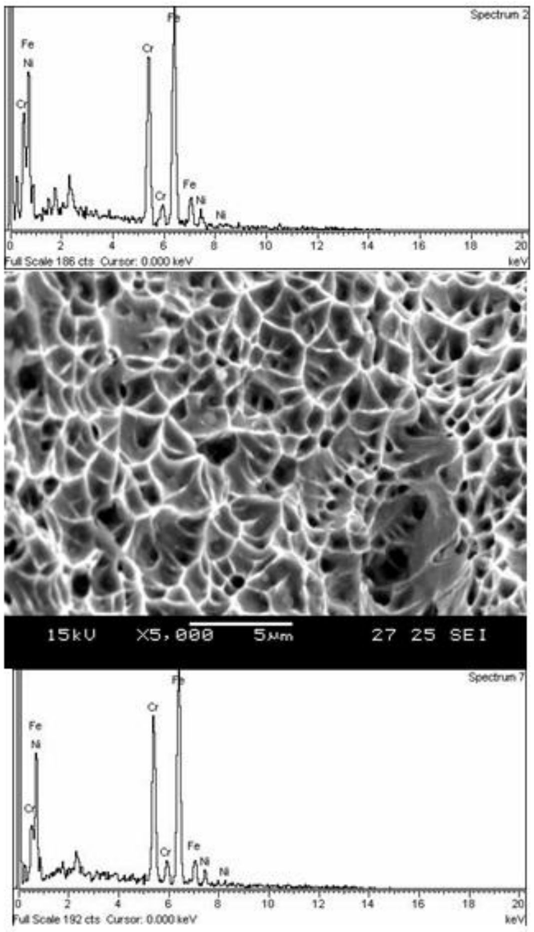

Fig. 5 SEM/EDAX point analysis of weld zone.

It could also be seen from the micro-structure studies that there were no cracks evident in the SDSS laser welds, to confirm that the residual stresses are minimal or totally absent in the weld zones produced by laser beam welding process.

3.2.2 Tensile test

Tensile test was conducted to determine the joint strength and plasticity of the weld joint at room temperature. The average tensile strength of the pulsed laser weldment is observed to be 885 MPa. The strength of the laser welds is lower than that of the base metal (957 MPa) and failure takes place at the weld zone. The tensile strength of the weld joint is reduced by 7.5% than base metal due to the higher ferrite phase and presence of stabilizing elements viz., Ni, Cr and Fe in the weld zone.

4. SEM/EDAX analysis

The tensile fractograph and EDAX of weld zone (Fig.5) show elongated dimples, a characteristic ductile fracture mode. EDAX analysis performed at the failure zone reveals the presence of γ-phase (27.78 wt% Cr, 58.00 wt% Fe, 7.43 wt% Ni) and α-phase (31.95 wt% Cr, 62.38 wt% Fe, 5.67 wt% Ni) confirming duplex microstructure

5. Conclusion

The present study analyses the laser beam welding of super duplex stainless steel. The joints were evaluated for metallurgical and mechanical properties. The following are the conclusions from this study.

1. Defect free full penetration weld of UNS S32750 super-duplex stainless steel could be obtained from laser beam welding on employing the established process parameters.
2. Microstructure of the laser beam weld zone contains coarser ferrite morphology with the presence of inter and intra-granular austenite.
3. The distribution of the ferrite and austenite phases in weld zone is 55:45 in favour of ferrite.
4. Microhardness of the weld zone is found to be lower than the parent metal.
5. Tensile strength of the weld is 7.5% lower than base metal.
6. EDAX analysis confirms the presence of stabilizing elements viz., Cr, Ni and Fe in austenite and ferrite phase of weld zone, and which enhances the strength of weldment.

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