Laser welding of plastically deformed lean duplex stainless steel

I. Calliari, C. Gennari, E. Hurtado Delgado, A. F. Miranda Pérez, B. R. Rodriguez Vargas

Duplex stainless steels are preferred in industries where a combination of mechanical properties with higher corrosion resistance is required. Their excellent properties are due to the biphasic microstructure, however, when thermal cycles are applied can be highly affected by the formation of hazardous intermetallic phases decreasing their performance. Welding as beneficial can be detriment for joining stainless steels; moreover, some welding processes are limited for narrow thicknesses or the electrode can promote intermetallic phases. Laser welding is an advanced joining process that is currently replacing traditional fusion processes, besides it can be employed to join thin plates. The aim of this study is to observe the plates of 2304 DSS plastically deformed joined by pulsed laser welding varying the peak power in order to observe the microstructural modifications and penetration of the joint. The experiments were performed by fixing some laser welding parameters in order to observe only the influence of the peak power. Microstructural observations by means of optical and electron microscope were performed, within EDS analysis to identify possible intermetallic phases. Microhardness evaluation was performed observing variations mainly at the surface.

KEYWORDS: LASER WELDING, DSS, SEM, COLD WORKED, CHARACTERIZATION

INTRODUCTION

Industry demands materials with excellent performance, good mechanical properties and environmental resistive (1); Duplex stainless steels (DSS) fulfill these requirements, that is how are predominantly employed in pulp and paper, chemical tankers, pipelines, reactors plants and nuclear waste containers (2; 3). In corrosive conditions DSS proved to have higher resistance than conventional stainless steels, besides the approximately equal combination of both phases (ferrite and austenite) provides them of higher mechanical strength (4; 5). The yield strength achieves 450 MPa, and is excellent for applications were stress corrosion resistive materials are required. Additionally, referring to Lean Duplex Stainless (LDSS), it is almost Mo free and the nickel content is lower than 4% that is traduced on low-price stainless steel (6). DSS are in valuable demand of grades with excellent performances that were customized by more than 20 years of successful service applications (3).

In manufacturing, assembly for DSS became a challenge since some fusion welding processes significantly affects the phase balance, and in certain duplex grades strength the formation of deleterious phases (7). The processes more often employed are submerged arc welding (SAW), gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW) and laser beam welding (LBW). Laser is related as products with high quality, precision and greater speed, which is traduced in high productivity at several industrials applications. This process is eight times faster than Gas Tungsten Arc Welding (GTAW) (8). Many have reported investigations regarding LBW, fiber laser can be employed with proper parameters and shielding N2 gas as reported by R. Lai et al. (9). However, Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) industrial lasers confirmed reductions in the heat affected zone, improved weldability and narrow fusion zone (10). In these lasers, the energy is supplied by a laser diodes, the wavelength is shorter than fibers lasers,

I. Calliari, C. Gennari
Industrial Engineering Department (DII), University of Padua, Via Marzolo 9, Padua, Italy

E. Hurtado Delgado, A. F. Miranda Pérez, B. R. Rodriguez Vargas
Corporación Mexicana de Investigación en Materiales, Ciencia y Tecnología 790. Saltillo, México

which supports the laser for robotic purposes. Several studies agree with the increment of ferrite phase during joining (11), which can affect severely the corrosion resistance (12). In this study, cold rolled lean duplex stainless steel was joined by Nd: YAG laser welding in order to observe the microstructural effects after welding, with the purpose to increase the mechanical strength of the material.

EXPERIMENT

Lean duplex 2304 plates (254 Hv) of 5 mm thickness were cold rolled until achieve 40% of thickness reduction (Fig. 1), Then, welded by Nd:YAG micro-laser of 160 W model HTS LS P-160 using a 1064-nm wavelength, no clamping to the plates was carried out. Prior to laser welding, no polished with grit paper was needed since the surface was adequate for avoiding the reflectivity. However, the samples were cleaned with acetone to remove any grease and other contaminants.

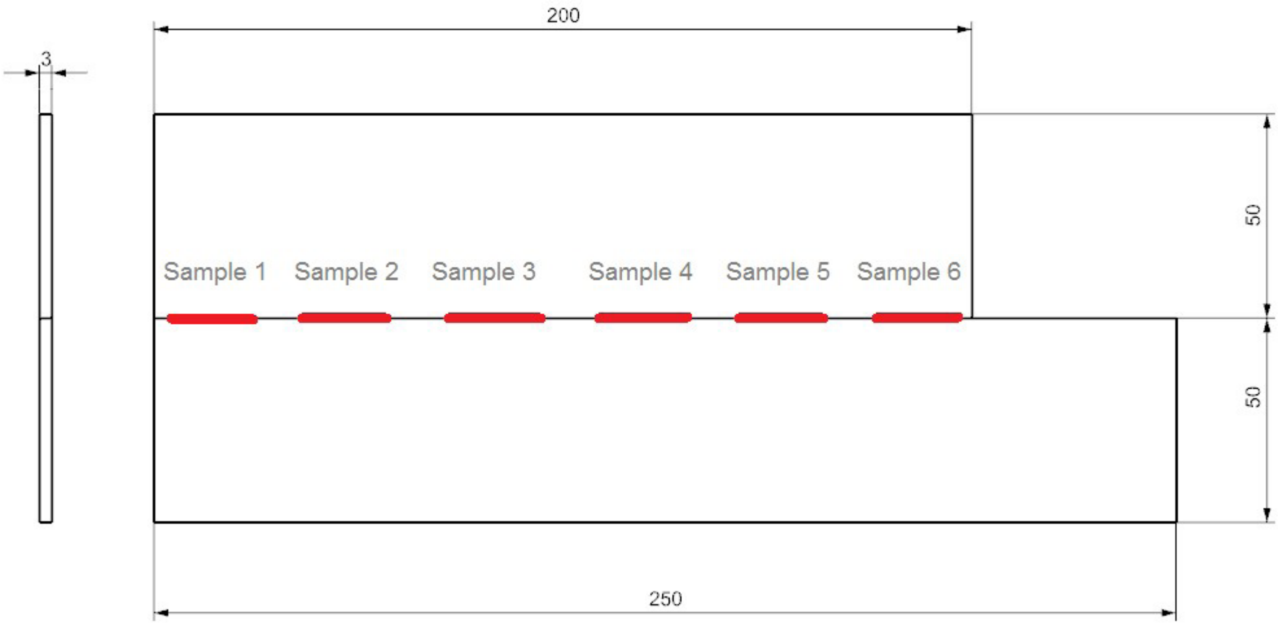

Fig. 1 - Schematic view of the performed laser welds

The micro-laser process was pulsed type, employing argon atmosphere (flow: 0.5 bar) in order to reduce metal oxidation and contamination. The welding speed was fixed at 0.2 mm/s, pulse width of 7 ms with a repetition rate of 5.5. The peak power was then modified as shown on Tab. 1, acting as the varied process parameter. The chemical composition of the base metal is presented on Tab. 2.

Tab. 1 - Pulsed laser parameter.

	Peak Power (W)	Heat input (J/mm)
Sample 1	136	680
Sample 2	128	640
Sample 3	120	600
Sample 4	112	560
Sample 5	144	720
Sample 6	152	760

Tab. 2 - Chemical composition (wt. %) of the LDSS 2304.

C	Si	Cu	Mn	Mo	Cr	Ni	S	P	N	Fe
0.02	0.48	0.29	1.37	0.36	23.5	5.02	0.014	0.031	0.10	Balance

Selected samples were cross-sectioned and prepared with the traditional metallographic procedure (grinded and polished), and then etched with Villella's (picric acid) for 15 seconds. For macroscopic examinations, a stereoscope was employed, and for microscopic analysis, the optical and scanning electron (TESCAN MIRA 3) microscopes were used. Semi-quantitative chemical analysis of the samples was obtained using a Quantax EDS Bruker detector. Hardness profile was fixed a 500 kgf using a Vickers indenter.

RESULTS AND DISCUSSION

Microstructural characterization

The as-received material presented elongated grains that after deformation were slightly flattened. Macrographs of three representative samples are presented in Fig. 2. The joint with less peak power presents lower penetration compared to higher one, still when the heat input is increased the generated energy displace the plates and distortion is observed as in Fig. 2c. Grains size development varied in the selected samples, in pulsed laser welding the melting has two principal stages: at first the interaction of heat source which melts on one-step, and re-melting in order to achieve a hermetic seal produce by heat. Stress and distortion are produced due to a higher cooling rate which produce a rapidly solidification with solid-state transformation (10).

Fig. 2 – Weld cross sections of a) 128 W, b) 144 W) and c) 152 W of peak power samples.

Deformation by shrinkage is observed in Fig. 3, the heat generated in the process provokes a non-uniform expansion of the base metal within contraction for the heating and cooling cycle. Since the pulse in this process re-melts the material, physical properties of the base metal decreases while thermal expansion increases. In this case, the achieved mechanical strength due to cold rolled decreases since the heat input generated by the process softens the materials leading to crack initiation. Despite the low heat input values it generates distortion.

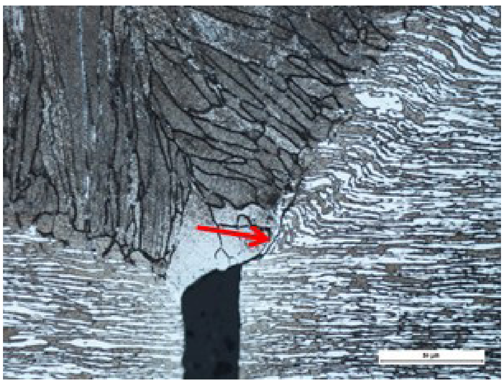

Fig. 3 – Initiation crack at joint 1 with 680 J/mm of heat input

During solidification, rapid cooling rate impinges the ferrite-austenite balance as observed in Fig. 4. Austenite is then decreased in volume, but is clearly grown as Grain Boundary Austenite (GBA); the transformation of this phase involves the formation along the ferrite grain boundaries of coarse ferrite grains that leads into a higher density austenite (7,13). As can be seen the heat affected zone is almost invisible since the cooling rate occurs rapidly.

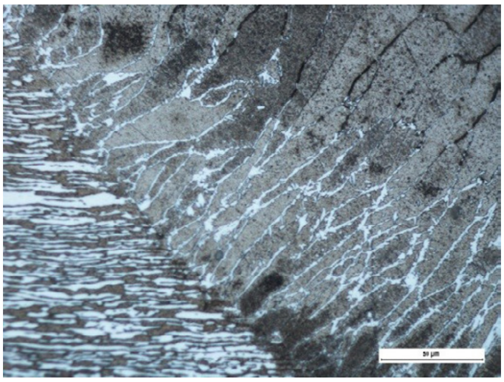

Fig. 4 – Welding interface in joint 6

The variation in the overlap factor produced by pulsed laser welding is reported in Fig. 5, layers were formed and epitaxial ferrite growth is presented at the first pulsed, sequentially at the second pulse the grain is dissolved, in some cases by the half, and grain texture is modified.

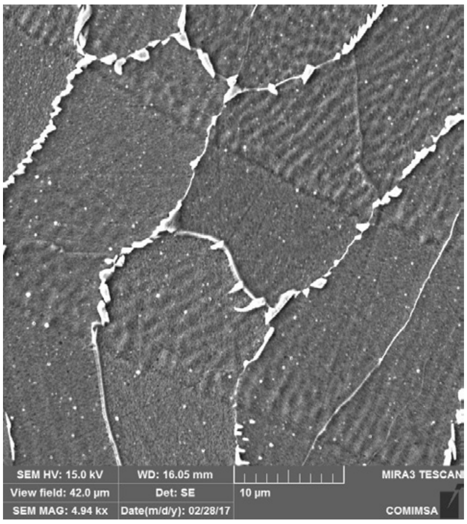

Fig. 5 – Scanning electron micrograph of the joint 5 at the fusion zone

Fusion line was selected for EDS analysis, in the macro view Cr and Ni distribution seems to be not affected by the process, however, the accumulation of Mn in the solid is confirmed by the map in Fig. 6. The Cr/Ni redistribution is evident in the fusion zone and the typical microstructure of banding disappears. In the electron micrograph, the heat-affected zone is undetectable.

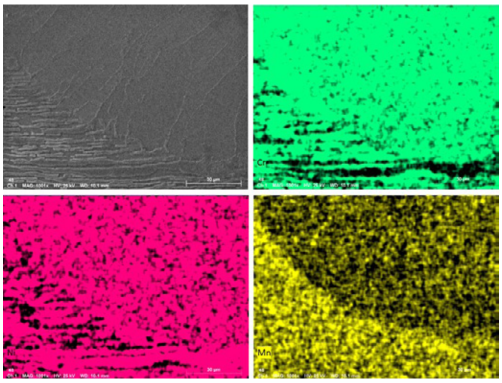

Fig. 6 – SEM micrograph and EDS maps at the interface (fusion zone and base metal)

Microhardness analysis

Fig. 7 presents the hardness profiles; initially the hardness value for the base metal (without plastic deformation) is 254 Hv, while the cold rolled material is about 370 Hv. The higher mechanical strength was marked even after welding, which means that LDSS maintain its mechanical properties in the weld. On the other hand, some fusion zones were affected by recovery since the material softens due to high heat input. Those grains in the fusion zone were not recrystallized, but were hardened by recovery during plastic deformation.

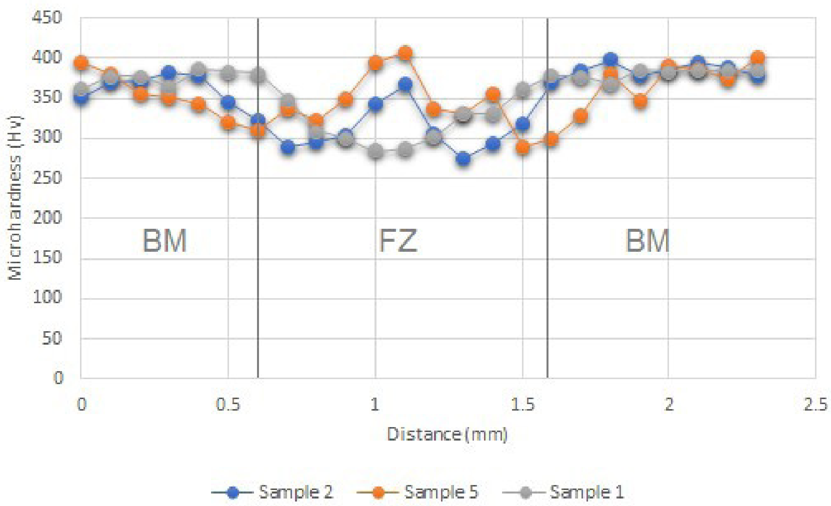

Fig. 7 – Hardness evaluation of 680 J/mm (sample 1), 640 J/mm (sample 2) and 720 J/mm (sample 5) heat input

CONCLUSIONS

In this investigation the microstructural features produced by plastic deformation and welding in LDSS were studied. By cold rolling, 40% of thickness reduction was achieved within approximately 370 Hv of hardened material. The main conclusions are summarized as follows:

• Increment of mechanical strength due to plastic deformation was obtained.

• Higher penetration by the laser welding process was achieved with a 720 J/mm heat input. Despite of low heat input, distortion was presented in some samples.

• The laser welding presents some advantages, such as, lack of intermetallics formation during weld, welding quality and absence of the heat affected zone maintaining their mechanical properties. Even though, the higher cooling rates softens the materials leading to shrinkage which ends as a crack.

• Ferrite phase was higher in the fusion zone compared to austenite, which is presented as a grain boundary austenite.

• During plastic deformation some grains were constrained of recrystallization, but presented recovery. After laser welding, which occurs so rapidly at high temperature, those grains were softened decreasing the hardness nearly the base metal-fusion zone interface.

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