A COMPARATIVE STUDY ON THE LASER, PLASMA AND TIG WELDING OF DUPLEX STAINLESS STEEL +

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Abstract:

The rule of laser, plasma, and TIG welding energy concentration, in the transformation behavior and hardness of duplex stainless steel weld metal was investigated. The significant findings were that the Nd-Yag pulsed laser welding changes the duplex ferritic-austenitic structure of fusion zone to a full ferritic structure after solidification, and increases its hardness above the average value of the duplex base metal with no evidence of HAZ. The plasma welding causes the development of dendritic duplex structure in the fusion zone and widman-statten duplex structure in the HAZ, besides reduce the hardness of welds to lower than that of laser samples. The TIG welding produce the larger duplex fusion zone and HAZ and more reduction in hardness in comparison with plasma welding. All these steep variations in structure and hardness accompanied with the three technologies mean that the three is a severe reduction in energy concentration from laser to plasma until TIG technologies.

دراسة مقارنة على لحام الليزر والبلازما و TIG للصلب المقاوم للصدا المزدوج

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المستخلص:

تم في هذا البحث دراسة تأثير تركيز طاقة لحام الليزر و البلازما و TIG في سلوك التحولات الطورية والصلادة في وصلات لحام الصلب المقاوم للصدأ المزدوج. وكانت اهم النتائج هي أن لحام الليزر Nd-YAG النبضي يحول التركيب المزدوج الفرايتي- اوستنايتي لمنطقة الانصهار الى تركيب فيرايتي تام بعد التجمد وتزيد صلادتها الى ما فوق المعدل للصلب المزدوج وكذلك عدم ظهور منطقة التأثر الحراري. يسبب لحام البلازما ظهور تركيب شجيري مزدوج في منطقة الانصهار وتركيب ودمن-ستاتن مزدوج في منطقة التأثر الحراري اضافة لانخفاض صلادة الملحومات الى اقل مما في عينات لحام الليزر. انتج لحام TIG منطقة انصهار وتأثر حراري اكبر مما سبق واكثر انخفاض في الصلادة بالمقارنة مع لحام البلازما. ان هذه التغيرات الحادة في التركيب والصلادة التي رافقت هذه الطرق الثلاثة تعني ان هنالك انخفاض كبير في تركيز الطاقة من الليزر الى البلازما الى لحام TIG .

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Introduction:

Energy concentration is one of the main characteristic which determines the welding parameter such as the maximum temperature, width of the fusion and adjacent zone, the thermal distortion value, and the structural changes [1] .

Advanced technologies such as laser, electron beam, and plasma have a high degree of energy concentration that qualifies them for the minute and special applications in the electronic, atomic, ceramic applications and the welding of thin sheets [2] .

During welding, the higher energy concentration means low energy consumption, a small welding volume, low thermal distortion, high maximum temperature, and high solidification and cooling rates [3]. Accordingly the mechanical and structural properties of the welds change the variation of energy concentration, or in other words, with technology type.

The Duplex Stainless Steel :

Duplex stainless steel contains a high content chromium (more than 22%) with a nickel content not enough to create an austenitic structure (less than 8%) . the main characteristic of duplex stainless steel is high yield strength which twice greater than that of austenitic type, but with a little decrease in elongation and impact strength [4,5] due to its high strength, it allowed to reduce the thickness of pipes, heat exchanger cylinders, containers and pressure vessels and to reduce the width of motor, gears, pumps and valves [6].

The Welding Microstructure of Stainless steel :

The origin of stainless steel weld microstructure can best be explained with the schematic Fe-Cr-Ni pseudo-binary diagram. It is also possible to predict the behavior of side range of Fe-Cr-Ni alloys upon cooling from solidification range. Composition on the Ni-rich side of the diagram solidifies as primary austenite, while those on the Cr-rich side generally solidifies as primary ferrite (although the primary phase of solidification also depend on somewhat on solidification rate [7,8].

Following the conventional welding, alloy AISI 304, 308, 316 and 312 contain duplex ($\gamma + \delta$) microstructure and solidify as primary ferritic mode [9, 10] at slow laser welding speed (low cooling rate), the same duplex structure were observed .However, for alloy 304, 308 and 316 which were not sufficiently enriched with Cr and depleted in Ni , as the welding speed increased, a decrease in ferrite content was observed, ultimately resulting in fully austenitic microstructure

at the highest welding speed. The observed fully austenitic microstructure at the high welding speeds or associated high cooling rates may be attributed to a change in the mode of solidification from primary ferritic to primary austenitic. Alloy which was sufficiently enriched in Cr and depleted in Ni, showed different type of structural dependence on the cooling rate. This alloy following the conventional welding may typically contain 40% ferrite after solidifying in the primary of the ferritic mode. However, during laser welding, as the welding speed increased, the ferritic content increased until fully microstructure was obtained at higher welding speeds.

Experimental Procedure:

In order to investigate the influence of welding technology type on determining the microstructure and the properties of duplex stainless steel weld metal and adjacent zones, TIG, plasma and laser welding technologies that differ in the concentration of energy, were applied in the different conditions (table 1).
A duplex stainless steel strip of thickness (3mm) were used in this study, the welding operation were conducted without of filler metal.
Different stage of grinding, polishing and etching (with 10 vol. HCI + 10 vol. HNO3 + 15 vol. Acetic acid etchant) were employed to prepare the welding sample surface for microstructure and hardness measurements.

Result and Discussions:

1- Laser Sample: the fusion zones appear as a single phase ferrite structure (white pool), whereas the base metal is a duplex deformed structure (fig. 1). In such composition and cooling rates, many investigations [9] have classified the fusion zone a fully ferritic type, since the high cooling rates accompanying laser welding prevent the transformation of primary solidification ferrite to austenite. Fig 2 shows a higher magnification micrograph of the fusion zone-base metal interface of one of the laser sample. Fig. 3 illustrate the variation in the Vickers hardness with distance which start from a 0.5 mm at the left hand of fusion zone –base metal interface until some distance in the base metal for single pulse welded samples . This figure shows that the fusion zone is harder than the base metal. This can be attributed to be high solidification and cooling rates resulting from the self quenching effect. On the other hand, the heat affected zone is approximately absent.

2- Plasma Samples: Fig .4 illustrates the micrograph of plasma welds. There is three zones: the fusion zones, the heat affected zones, and the base metal. The fusion zone is denderitic duplex structure, the heat affected zone is widman-statten austenite at the boundaries and inside the ferrite grains, and the base metal is normally lamellar duplex structure. The hardness-distance relationship (fig.5) shows that the hardness of fusion and heat affected zones are less than that of the laser samples. In comparison with the laser samples, the hardness reduction of welds, the occurrence of duplex structure in fusion zone, and the presence of clear heat affected zones confirm that the energy concentration of plasma welding is lower than that of laser welding.

3- TIG Sample: Fig (6) shows the micrograph of TIG welding sample. The three zones are also present, but the fusion and heat affected zones are much larger than that of plasma samples. Also the hardness relationship (fig. 7) shows that the hardness of both zones is less than that of plasma welding. All these effects confirm that the energy concentration of TIG welding is less than that of plasma and laser welding.

Conclusions:

From this investigation, it can be concluded that:-
1- The laser welding changes the duplex structure of fusion zone to a single phase ferrite and increases its hardness above the average value of the base metal.
2- The plasma welding cause s the development of dendritic duplex structure in the fusion zone and widman-statten structure in HAZ.

3- The TIG welding produces a much larger duplex fusion and heat affected zones and more reduction in hardness in comparison with plasma welding.

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Table (1) Welding conditions of three methods

Welding Methods	Energy Concentration J/mm^2	Joint Width mm	Welding type
Nd-YAG Laser welding	1500	0.5	Pulsed
Plasma Welding	180	5	Continuous
TIG Welding	20	10	Continuous

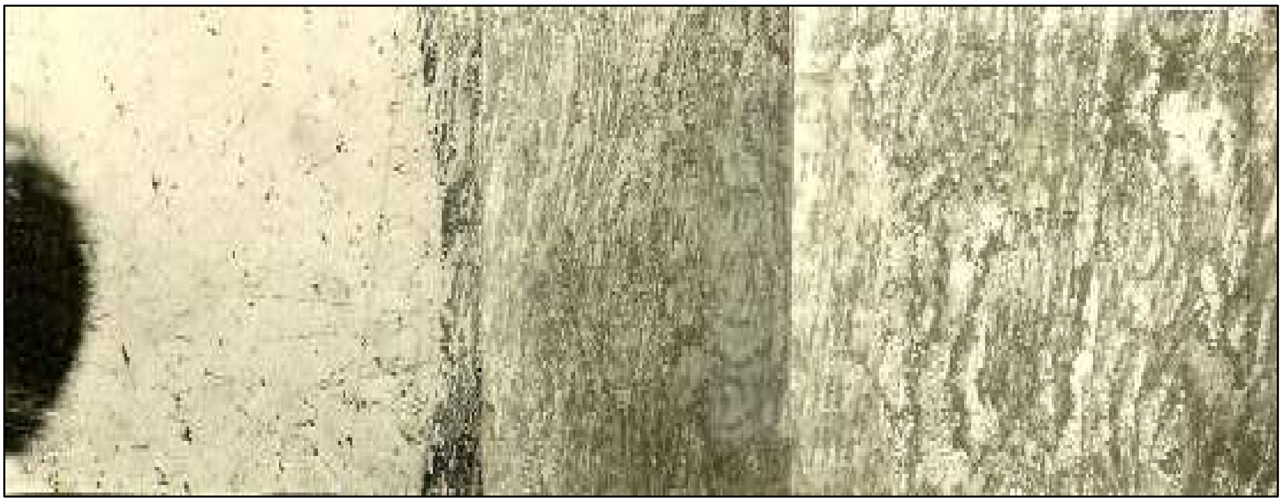

Figure (1) Weld joint of pulsed laser welding

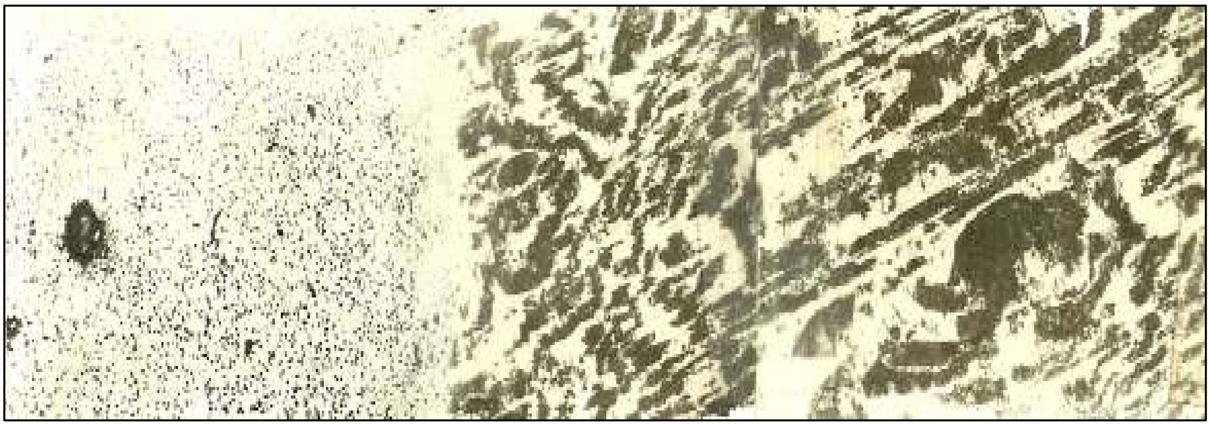

Figure (2) Interface between fusion zone and base metal in pulsed laser welding

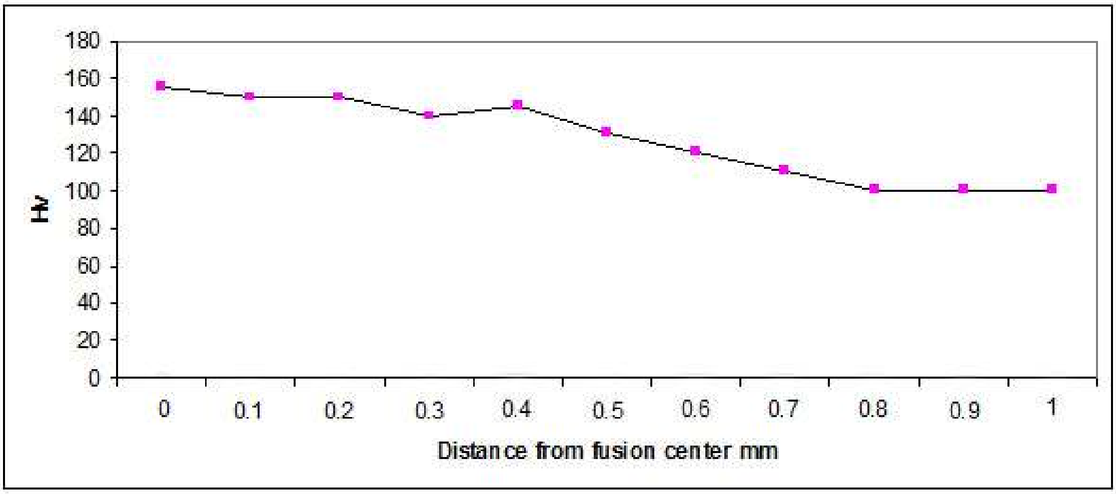

Figure (3) Hardness Variation through laser welding joint zones

Figure (4) Weld joint of Plasma welding

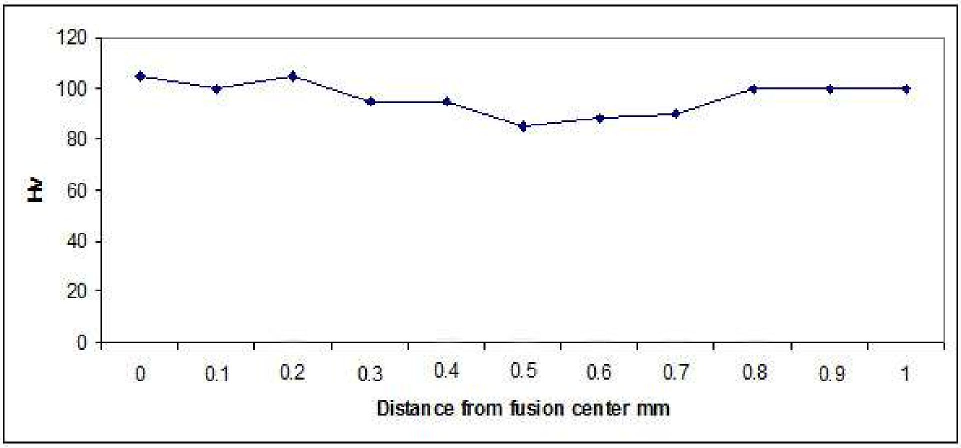

Figure (5) Hardness Variation through Plasma welding joint zones

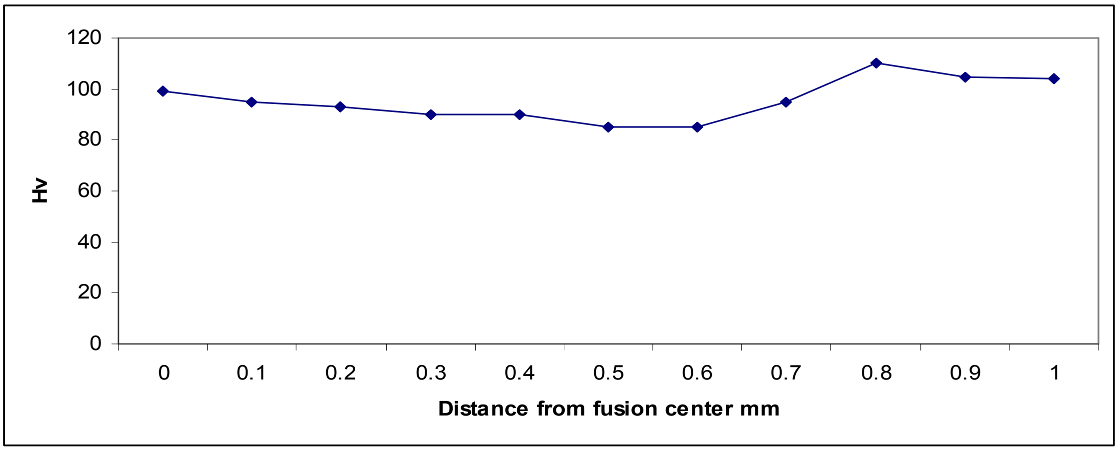

Figure (7) Hardness Variation through TIG welding joint zones

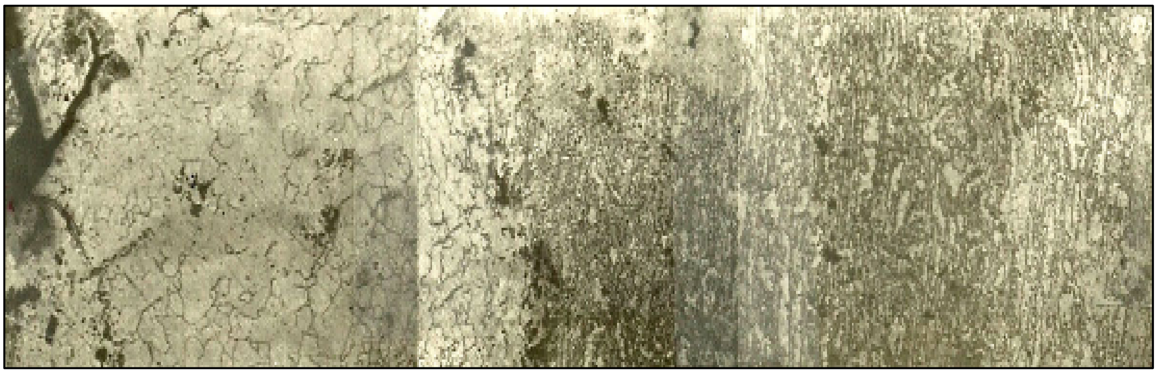

Figure (6) Weld joint of TIG welding