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Review Paper on Fiber Laser Welding of Austenitic Stainless Steel

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ABSTRACT: This paper deals with the various investigations of austenitic stainless steel in fiber laser welding carried out by the various researchers. Across various industries including chemical, shipbuilding industries, and petrochemical austenitic stainless steel is used. Laser welding is a sophisticated, high speed and high precision joining process. Laser welding is a process of joining a plate where a laser beam is used as a heat source. So, this review paper systematically highlights the formation of welding porosity, microstructure, macrostructure, tensile strength, weld bead geometry, and the microhardness of weld fusion zones were compared and studied using different shielding gases, weld speed, defocusing distance, current, different gas flow rate and a spot diameter of austenitic stainless steel welding processes and conditions.

KEYWORDS: Fiber Laser Welding, austenitic stainless steel, parameters.

I. INTRODUCTION

Thick-plate welding is a common, key manufacturing process in the production of thick-section structures used in the ocean, nuclear power, and pipeline engineering. Laser beam welding (LBW) is a high-energy beam welding method, which is used because it has high flexibility, high energy density, low welding distortion, good quality of joints, and high welding efficiency. Therefore, LBW has huge potential for joining thick-section structures and has received a lot of attention from scholars. Some papers reported that deep-penetration welds could be obtained in stainless steel at high welding speeds. Welding of Austenitic stainless steel studies has been extensively carried out and is well documented. The investigation can be done on the mechanical, metallurgical, and corrosion properties changes that take place. For fiber laser welding the materials there are different parameters which are current, shielding gas, welding speed, defocusing distance, spot diameter, and gas flow rate used in welding. These parameters have to be studied for laser welding of austenitic stainless steel which parameters have to be chosen are important criteria for investigation.

The effect of fiber laser welding on mechanical, metallurgical, and corrosion properties have been the basic part of an investigation where using the optical microscope, x-ray radiographic test, Scanning Electron Microscope, Vickers microhardness, and tensile test. The preliminary literature review reveals that the studies on laser welding of austenitic stainless steel have been useful in many chemical industries, petrochemical, and shipbuilding industries.

II. RELATED WORK

LITERATURE REVIEW:

The various input parameters are Fiber laser welding current, spot diameter, Welding Speed, defocusing distance, different shielding gas and flow rate. The proper selection of input parameters results in proper welding of austenitic stainless steel. The different input parameter ranges used by the various researchers affects the microstructure and mechanical properties of the laser welding.

- C.Y. Cui et.al (2013) used 304 stainless steel plates with 3 and 6mm thickness are welded by a 6 KW high power fiber laser and Ar shielding gas. The microhardness, microstructure, and weld appearance of the weld

joint have been investigated. The cross-section of welded joints was mainly composed of fusion zones that have very small or no HAZ, because the welding speed and lower focused heat input during fiber laser welding. The generated higher cooling rate makes the grains surrounding the fusion zone have no time. The weld appearance also without macro-defects can be produced with laser power of 2 KW. And the full depth of penetration successfully obtained using tightly focused fiber laser welding. The microstructure in fusion zone were mainly columnar dendrites and equiaxed dendrites because, the weld was cooled fast, thereby producing a small temperature gradient and forming fine equiaxial dendritic crystals. The weld joint showed higher microhardness than the stainless steel base metal because the laser weld solidification is very fast so produce fine grain structure is achieve high hardness.

- Junhao Suna, B et.al (2017) used Different shielding gases (Ar, N₂, no gas) to eliminate the porosity in the high-power fiber laser welds of 304L stainless steel in this study. The mechanism to reduce the porosity was revealed in detail. Many pores were retained in the 304L stainless steel laser welds made in Ar and almost no pores were found in the laser welds made in N₂ or no shielding gas. The nitrogen content in weld metal increased by 3.4×10^{-5} wt%. The nitrogen dissolution time into the melt pool was 30 μ s. The nitrogen retention time of the melt pool was 1.1 s. The laser welds became uncontinuous with large and periodic welding scales, especially when a low welding speed of 0.8 m/min was used. Many spatters, which varied from less than 1 mm³, to more than 20 mm³, were produced during the welding process. The spatters were caused by the unstable weld pool.
- Mingjun Zhang et.al (2014) used stainless steel plates 12 mm thick were welded autogenously using a 10 kW fiber laser. The effect of the processing parameters on the weld appearance is investigated, and the optimal parameters are determined. The microstructure and mechanical properties of the joint are investigated. The columnar and equiaxed grains are fine, extending from the fusion boundary to the center of the weld bead and consequently yielding a higher bonding strength. This is attributed to the rapid solidification during the laser welding process, especially deep penetration laser welding, which typically has a larger thermal gradient and higher cooling rate. The shielding gas (Ar, He, N₂) effect of the processing parameters on the weld bead geometry was examined, achieving a good full penetration joint. The type of top shielding gas influences the weld depth. Ar and N₂ compared to He have a high depth of penetration and low porosity because He have high ionization potential energy and its quenching in the plasma that reason laser beam easily transfers the keyhole and at the same time He is produced undercut.
- Seiji Katayama et.al (2010) investigate the mechanism of weld penetration and the phenomena in CO₂, YAG, or fiber laser welding, a variety of researches have been performed concerning laser-induced plume behavior, the interaction between a laser beam and its induced plume/plasma, melt flows, keyhole behavior and bubble generation in the molten pool leading to the porosity formation in the weld fusion zones. Ar or N₂ gas plasma are easily formed to absorb laser irradiation energy. Almost no pores were found in the laser welds made in N₂ or He shielding gas. Many pores were retained in the 304L stainless steel laser welds made in Ar. The dissolution of N₂ bubbles in the liquid melt pool led to the elimination of the pores in the 304L laser welds. Bubbles are formed in an inert gas such as Ar and He, but bubbles are hardly seen in N₂. Ar and He gas is generally detected in the pores. So, Ar or He gas is involved in an unstable keyhole at lower welding speeds, but a harmful influence of N₂ is reduced by reacting with Cr vapors in the keyhole or being included due to high solubility in the molten pool. N₂ gas is regarded as a proper shielding gas in YAG, disk, or fiber laser welding of austenitic stainless steels.
- S.K. Wua et.al (2018) used fiber laser and a CO₂ laser for conducting laser welding tests on austenitic stainless steel (SUS301L) plates with a thickness of 2 mm. Welds produced under different gas shielding (Ar, N₂) conditions were compared systematically in terms of macro-appearance, microstructure, micro-hardness, and tensile strength performance. The welding center was cooled rapidly, thereby producing a small temperature gradient and forming fine equiaxial dendritic crystals. By contrast, the temperature gradient is steep around the fusion line and therefore the crystalline grains grow towards the weld center along the perpendicular direction of the fusion line, during which columnar crystals are formed. The N₂ solubility of CO₂ laser welding in weld joints is slightly higher than that of fiber laser welding. The N that was absorbed by the interface of the molten pool mainly was concentrated around the surface of the weld and was present in the form CrN, CrN, and FeN. Accordingly, under different protective conditions with different percentages of N₂,

the welds using different welding conditions exhibit no significant differences in shape, micro-structures, average N content, mechanical properties, and microhardness of the weld or corrosion morphology on the weld surface.

- Khalid M et.al (2009) used fiber laser weldability of 5 mm thick AISI 304 austenitic stainless steel plate, and therefore bead-on-plate welding was exploited on Type 304 stainless steel plates with different laser powers, welding speeds, defocusing distances with different types of shielding gas and their effects on the weld zone shapes and final solidification microstructure. The amount of spatters and instability of weld bead increased at high welding speeds, while at low speed (6 m/min) full penetration welds and stable beads were obtained, Depth to width ratio changed with the change in laser power, welding speed, and defocused distance, depending on the heat input is determined by the heat transport mode in the molten pool. This ratio is obtained for changing of the molten pool from conduction mode to keyhole mode. The microstructure of all laser welds was always austenitic with a small amount of delta ferrite. Except welding with nitrogen as shielding gas, the welding conditions have no significant effect on the hardness distribution, in the case of using N₂ as a shielding gas instates of argon, the hardness slightly decreased, it could be due to the decrease of the ferrite content in the fusion zone.
- Ganesh S et.al (2014) used austenitic stainless steel AISI 304L plates of 0.2 mm thickness, to study the effect of process parameters i.e. Laser power(50-85W), welding speed(4-10mm/s), focal position(1-3μm), and constant flow rate(20l/min) Ar shielding gas for butt welding by using 100 W fiber lasers. By observing the above results we can say that weld strength is directly proportional to laser power (P) and inversely proportional to welding speed (S). As laser power increases weld strength increases, also weld width will increase, As welding speed increase weld strength decreases, also weld width will decrease, Also increase in focal position cause decrease in weld strength. The value of Laser power, welding speed, and focal position for achieving maximum weld strength are found to be 80 W, 4mm/s respectively. This is an experiment where the maximum weld strength of 1077.2 MPa is obtained.
- Shichun Li et.al (2018) the influences of CO₂ shielding gas on weld appearance and weld formation during 10 kW high power fiber laser welding of 304 stainless steel. The formation of welding porosity, differences of metallographic structure, and the hardness of weld fusion zones were compared and studied using different shielding gases(Ar, Ar+CO₂, CO₂). The porosity in weld joints was observed during Ar and Ar + CO₂ shielded welding processes. But not observed in the CO₂ shielded weld joints. The highest average microhardness was obtained from the Ar + CO₂ shielded weld joint, while the lowest was obtained from the CO₂ shielded weld joint, among the three kinds of weld joint studied. Levels of C, Si, and Mn in the CO₂ shielded weld joint would be decreased, because they were oxidized to form oxide inclusions, and thus, the quench hardening tendency was reduced and the impact toughness was increased during CO₂ shielded welding. Lots of oxide inclusions were observed in the CO₂ shielded weld joint compared with the base metal. The proportion of CO₂ in the shielding gas also had an important influence on the metallographic structure and even the elementary composition.
- Ghusoon Ridha Mohammed et.al (2017) investigated fiber laser welding to join two dissimilar metals plates (AISI 304 and AISI 2205) of 2 mm thickness. The joined metals were characterized for the tensile test, microhardness, macrostructure, microstructure, using an optical microscope (OM). The weld depth and width were found to increase proportionally to the laser power. A linear increase in the weld depth and width was observed at varied peak power rates. The weld depth was significantly influenced by the increase in peak power when compared to the weld width. The mechanical properties of the produced DSS-ASS joints were better when compared to that of the base metals due to the small HAZ that resulted from the laser welding and the advantageous effect of rapid solidification in the fusion zone. And the hardness is a high weld metal zone compared to the base metal of ASS and DSS. Chromium and manganese were observed to have the highest presence, indicating a higher tensile strength in the fractured joint when compared to the base material (AISI 2205 and AISI 304). This was noted in the three samples a maximum percentage of Cr was observed which might be due to the increased tensile strength of the joint.
- Y. Kawahito et.al (2009) investigate the weld penetration and defects formation conditions were investigated in the bead on plate welding of type 304 austenitic stainless steel plates at several welding speeds using a 10 kW fiber laser beam with four kinds of laser spot diameters. To understand the formation processes of typical welding defects, laser-induced plume behavior, melt flows and keyhole behavior in the molten pool were

observed with high-speed video cameras and X-ray transmission real-time imaging system. Moreover, the high-quality welding procedures were developed by reducing spattering, underfilling, humping, and porosity based on the essential understanding of the welding phenomena. Under filling was prevented in the forward welding at 20° along the welding direction, where spatter generation caused by a strong shear stream of a laser-induced plume was greatly reduced by controlling the direction of plume blowing out of a keyhole inlet. The humping formation was dependent upon several dynamic or static factors, such as melt volume, melt flow, solidification, and surface tension. The keyhole behavior was stabilized using a nitrogen shielding gas, which led to the porosity prevention owing to the absorption of nitrogen in a melt around the keyhole, because the Ar is not dissolved in metal. Concerning porosity, X-ray transmission in situ observation images that bubbles leading to pores were formed.

- Kawahito Yousuke et.al (2007) investigated partial penetration bead-on-plate welding was used on Type 304 stainless steel with a 6 kW high-power fiber laser under several conditions, such as four levels of laser power densities and several welding speeds. Moreover, the typical welding processes were observed with a high-speed video camera or X-ray transmission real-time imaging system in order to clarify the welding phenomena and the mechanisms of welding defects. The effect of laser power density on the formation of sound welds with the high-power fiber laser was investigated with four different laser beams of 130, 200, 360 and 560 μm in spot diameter, and their welding phenomena were explained with high-speed video cameras and X-ray transmission real-time imaging system during bead-on-plate welding of SUS304 plates with 6 kW fiber laser. The welds showed a keyhole type of penetration at any diameters and the maximum penetration of 11 mm depth was obtained at 130 μm spot diameter at 0.6 m/min welding speed.
- Chao Fang et.al (2020) This paper, a 20 kW fiber laser is used to systematically study the experimental phenomena and rule of laser welding on thick sections of austenitic stainless steel. The welding phenomena of the bead-on-plate welding of 40mm thick plates, butt-welding of 20mm thick plates, and butt-welding of 30mm thick plates in 1G and 2G welding positions are studied. Typical formation for each butt-weld, defined by the appearance of the topside and backside, is studied along with the formation mechanism. A 30mm thick plate was successfully butt-welded in the 2G welding position, and the microstructure and mechanical properties of this welding joint are discussed. The weld joint of 30mm thick plates has a full austenite microstructure, displaying columnar and cellular grains growing in a direction perpendicular to the weld boundary from the two sides to meet equiaxed grains at the weld centerline.
- Jingjing Yang et.al (2019) used 3mm thick 304 stainless steel plates to explore the feasibility of joining SLMed parts by laser welding in the present study. The comparison on microstructure and performance between the laser-welded joints and SLMed base plates was conducted. Also the effect of SLMed anisotropy on microstructure, weldability microhardness, and mechanical properties during welding was evaluated. As compared with the SLMed based metal joint exhibit a coarser dendrite structure, lower microhardness 220HV and area reduction 27.6%, and tensile properties 750Mpa. The laser welding along the building directions of the SLMed base plate can induce a slightly finer dendritic structure and high tensile properties.

III. CONCLUSION

Due to limited literature review on fiber laser welding of Austenitic stainless steel, this paper investigates on welding of austenitic stainless steel by fiber laser. By observing the results from above literature, Vickers microhardness, microstructure, macrostructure, tensile strength, porosity formation of use different shielding gases, weld bead geometry and corrosion properties of the welded sample can be evaluated. We can use the austenitic stainless steel weld joint in chemical, petrochemical, shipbuilding, nuclear power, and pipeline engineering industries.

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