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Role of Laser Beam in Welding and Assembly: A Status Review

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Abstract

Laser Technology is gaining importance both in manufacturing / production industry.Metal joining by welding of similar and dissimilar metals is the most important process. Further, the effective utilization of metals also influences economic aspects, due to differences in chemical composition, coefficients of thermal expansion and thermal conductivity of base metals to be welded. Dissimilar metals are being welded in energy generating plants, chemical, nuclear and marine industries. Hence, design of the joints and their strength conditions are important. Thus, advanced process / techniques such as Laser / Laser Beam Welding (LBW) of metals is in forefront not only to achieve sound joint / assembly but also reliability. Therefore, a solemn attempt is made in the present paper to present a brief status review based on seventy two various contributions in terms of research / experimental studies, since the LBW possesses high speed, low heat input per unit volume and deep penetration. Hence, it is necessary to identify the effect on weld bead size, microstructure of the weld joint or assembly not only on the steels but also other metals. The paper also presents the importance of visual inspection and Non-Destructive Tests (NDT) which are being conducted on welds to ascertain the joint integrity and quality of the welded joints and on the assembly.

Keywords:Laser Beam, Welding, Heat Affecting Zone, Assembly, Joining, Alloy Steels,Quality, Reliability.

1. INTRODUCTION

Metal joining of similar metals is an important activity in industrial practice in general and that becomes a complex issue in joining of dissimilar metals. Wide range of welding methods / Techniques are available to choose a suitable one depending on the metals. Each process differs in respect of their capability to apply heat for fusion [1], protection of the weld pool and Heat Affected Zone (HAZ) of the metals to be welded [2]. However, selection of a particular process is dictated by the size and shape of the component to be manufactured, availability of consumables, machines, precision required and economy. Whatever may be the design process [3] of weld joint, it is to perform the intended function for designed life [4].

The Welding can be used for joining of any type of metal(s) with small HAZ and deep penetration with single pass. Nomenclature of the HAZ inLaser Beam Welding is shown in fig.1. Though many welding processes for thick and lengthy joints to obtain good mechanical properties are developed, there is a lacuna in respect of Bead Geometrical Parameters, Laser Beam Incident Angle, Laser Beam Off-Set, Distance between Work Pieces and Laser Beam Nozzle, Oscillating of Laser Beam. Further, Design of a joint depends on mechanical properties of Laser Welding, metallurgical characterization of the welding and such concepts of design require much more concentration [5]. The literature shows that the required sophistication, accuracy and seam quality of joints can be achieved through LBW with high speed, low heat input per unit volume, deep penetration, narrow HAZ and reduced tendency for cracking [6]. Accordingly, it is a common feature to bring-out the status of art in Engineering, Science and Technology of welding in terms of Literature Survey or Review in general and welding in particular, in the present paper.

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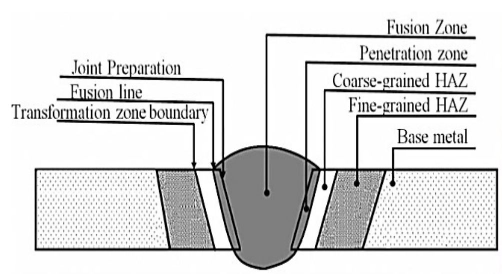

Fig.1: Nomenclature of zones in LBW

1.1. Objective of the Present Paper

An attempt is made in this paper to bring-out the various contributions of different authors in terms of research / experimental studies. The review is divided into: (i) Selection of metal / metal (s), (ii) LBW Process parameters considering (a) Laser Power,(b) Welding Speed, (c) Laser Beam Incident Angle, (d) Laser Beam Off-Set; (iii) Mechanical Properties, (iv) Laser in Assembly Joints and (iv) NDT.

2. SELECTION OF METAL (S)

Materials used in Aerospace, Aircraft, Automotive, Electronics, Power Plants, Chemical, Petrochemical industries, Nuclear, Marine applications, etc., [7] require high strength, toughness, ductility, weldability and durability of materials for usage directly or joining of two or more parts of different metals [8]. Usage of Steel and Steel Alloys are being mainly considered due to their good strength, weight and addition of other elements to the base metal. When all the said properties of the metals are possible with a single alloy [9] and metal or such alloy material can be chosen, so that, the metal properties better suited [10].

2.1. Alloy Steels

An enormous variety of distinct properties can be created for alloy steel by addition of the chemical elements on metals to increase hardness [11], strength [12] or chemical resistance

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[13]. Mechanical properties of metals alloy steels are shown in the Table-1. Main elements those used are Carbon, Nickel, Chromium, Vanadium, Silicon, Titanium, Magnesium, etc., depending on the requirement.

Table 1. Mechanical Properties of materials some Alloy Steels.

Alloy	Typical Mechanical Properties			
	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation (in 50 mm) %	Brinell Hardnes
AISI 4130	560	460	21.5	217
AISI 4140	655	415	25.70%	197
AISI 4330	860	690	15	250-325
AISI 4340	745	470	23	217

3. LASER WELDING PROCESS PARAMETERS

A variety of process parameters affect weld joint quality. The process parameters in LBW mainly include Laser Power [14], Welding Speed [15], Laser Beam Incident Angle, Laser Beam Off-Set, Shielding Gas Flow [16], Pulse Rate [17] and Focal Distance and Gap [18]. Thus it is to understand that the two main process parameters are laser power and weld speed affect the weld bead.

3.1. Laser Power

Laser Power output of Gas lasers is higher than the solid-state lasers. Reaching 25W power [19] and even fiber lasers are capable to develop a power upto 50 kW and are increasingly being used for robotic industrial welding [20]. The characteristics such as penetration depth [21], bead width [22], keyhole depth [23] and measurements [24] are found to be the function of the laser power. Accordingly, the increase in laser power directly increase the said characteristics [25]. Such power utilization in joining AISI Steels requires further more experimental studies.

3.2. Welding Speed

Welding speed significantly influences the size and depth to width ratio of fusion zone. A lower welding speed has resulted in a remarkable increase in the fusion zone size [26]. But the attenuation of beam energy by Plasma is less significant at low welding speed [27]. Further, it is relatively more exposed byLaser Beam onto the sample surface. Consequently, the depth to width ratio decreases with increase in the fusion zone [28]. Hence, blowholes are formed in the weld metal [29]. Viscosity of Magnesium becomes low during the increase in welding speed [54]; thereby, it causes a sagging of molten pool [31]. When the molten pool (with a low viscosity material) moves faster, it is characterized by turbulent flow. Furthermore, Magnesium presence results in violent fluid flow leading to collapse of the molten pool [32]. A better weld quality with addition of magnesium is achieved at a lower welding speed. Such conclusion is also supported by the findings [33]. Thus, the addition of various elements is found necessary to improve the properties of welding of steel alloys.

3.3. Laser Beam Incident Angle

Experimental results show that increase in laser incident angle directly influences the penetration depth and bead width but decreases bead length [34]. Shape and size of welded spot depend not only on the laser energy but also on the incident angle of Laser Beam. Depth of penetration, bead width and area of penetration are maximum at the beam angle of 90°. As the beam angle increases from 82° to 98° in anti-clockwise direction [35], the bead width and area of penetration decreased. But, there is no significant effect on depth of penetration.The Laser Beam incidence angle is shown in fig. 2.

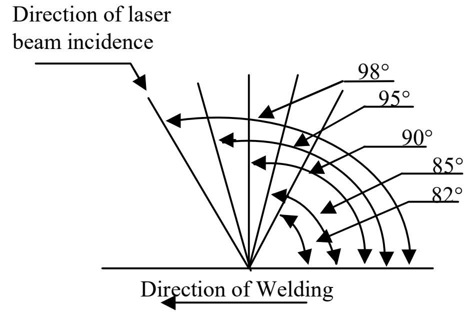

Fig. 2: Laser Welding Beam Incidence Angle

3.4. Laser Beam Off-Set

Laser Beam offset from 0.4 to 0.8 mm, first increases the tensile strength of joints and then reduces. In particular, at 0.6 mm laser offset, average tensile strength reaches a maximum of 185 MPa [36]. It is attributed to the defect-free joining of steel. If laser offset exceeds the optimum range (0.5 - 0.7 mm), defects like welding crack or incomplete fusion would occur at the interface [37]. Such a deviation phenomena show a rapid increase in hardness near the interface and it influences the coarse microstructure with elemental concentration [38]. Though, it is identified as elemental concentration but still there is a lacuna about the element which can influence the microstructure.

4. TYPES OF LASERS

Diode lasers of sufficiently with high power and power density are used for production of deep penetration welds. Regardless, the medium source of excitation, the photons are formed resulting in the Laser Beam. Out of available sources of media, the solid-state lasers such as Ruby, Nd:YAG and Gas lasers are widely used [39]. The first solid type uses one of the solid media [40]: consisting of Synthetic Ruby (Chromium in Aluminum Oxide), Neodymium in glass (Nd:Glass), and the most common type Neo-dymium in Yttrium Aluminum Garnet (Nd:YAG) [11]. Low power Nd:YAG lasers are used in the electronics industry [42]. Gas lasers use mixtures of gases such as Helium, Nitrogen, and Carbon dioxide (CO_2) as a medium. Such lasers are used for sheet welding at high weld speeds [43]. But the required speeds in solid state welding of AISI steels require further investigation to meet the sophistication and quality characteristics of the products.

5. MECHANICAL PROPERTIES

Mechanical properties of weldments are ascertained by conducting various mechanical tests consisting hardness testing, tensile testing and impact testing [44]. Tensile and impact tests are normally performed on samples at room temperature.

5.1. Tensile Testing

Specimens are prepared as per ASTM Standards for testing, normally at room temperature. Testing of the specimen shows the penetration depth of the laser welding which is directly proportional to the tensile strength [45]. Thus the welding power and speed influence more on the tensile strength [46].

5.2. Impact Testing

Charpy V-Notch impact tests are normally being conducted on the sub-sized samples as per ASTM Standards. The notches are made in weld center in such a way that the failure occurred only within the fusion zones [47].

5.3. Hardness Testing

Tests of weldments reveal that the hardness in HAZ of welded joints slightly decreases due to grain growth in fusion zone of weld metals [48]and hence no significant difference in hardness of weld metals. But, formation of Martensitic Structure in HAZ increases its hardness [49]. It is also to note that as the HAZ increases, the hardness results in the higher hardness in the weld fusion zone but with lower toughness [50]. Many contributions so for concentrated on tensile test, impact test and hardness test but the test on shear stress during applications of dynamic load is necessary.

6. LASER IN ASSEBLY JOINTS

Multiple beams can be created by optical division of a single layer to assemble a plurality of beam splitters and mirrors by twin spot Laser Welding, [51]. Both right hand and left hand door assemblies are achieved by Remote Laser Welding (RLW) technique and proved that RLW is better than RSW and SPR joining methods in terms of floor space and process costs, [52]. Then, the Gold Nano rod tips are melted with interparticle gap obtained from plasmonic response so as to achieve Femtosecond LaserControl tip-to-tip assembly and welding, [53]. Automotive Gears are produced from 16MnCr5 Alloy Steel and assembled by CO_2 (Laser made by RofinCinar Laser Mixture) and also achieved the weld depth, [54]. Laser pulses of the order of 1030-nm with the second glass in optical contact and non-optical contacts are achieved through assembly mechanism based on the internal modification with three glass substrates, [55], Sound weld beads and proper morphology are achieved by the long pulse Laser of Nd: YAG material in the welding of Titanium thin sheets, [56]. Though the process of the Weld Pool geometry of KPIs is affected by the process variables but the CO_2 Laser helps in the joining of Mild Steels, [57]. A car body is produced by Laser welding withoutjigs in a single weld and introduced mobility components for assembly in assembling automobile parts, and could achieve 25 times than conventional production, [58].

7. NON-DISTRUCTIVE TEST (NDT)

Selection of the NDT method is usually suggested by NDT laboratories [59] which know the NDT methods [60]; their feasibility and the necessity [61] in detecting the defects [62]. Therefore, the properties of materials and characteristics of a welding process have to be first established for the types of defects. It also requires the part of a structure which may undergo the highest stresses [63]. Widely used conventional NDT methods today are the visual inspection, magnetic particle testing, liquid penetrantion testing, ultrasonic testing and radiography [64]. Visual, magnetic particle and liquid penetrant testing are useful in detecting surface imperfections such as cracks, gaps, inconsistent weld bead profiles, undercut and concave or convex welds [65]. Ultrasonic and Radiography are used to discover sub-surface flaws [66].

Radiography (X-ray) utilizes X-rays [67] or radioactive isotopes to determine the internal strength of welds [68]. Magnetic Particle Testing (MPT) identifies the defects (such as cracks) at or near the surface of weldments [69]. Liquid Penetrate Testing (LPT) widely used to locate leaks in welds of Austenitic Steels and Non-Ferrous metals [70]. Ultrasonic Testing (UT) with high-frequency sound waves is applied to detect the surface and subsurface defects in metals with measurement [71]. The important aspect of the UT is to detect the flaws of too small which can not to be seen by any other methods [72].It is established that NDT / X-Ray a great role in welded joints of Martensite Steels and High Carbon Steels. But NDT is limiting in the welded joints.

8. CONCLUSIONS

Present day industries are doing their level best to meet competitive manufacturing in the world, so as to satisfying the customer demand of the goods in service with sophistication, quality and reliability. Therefore, the researchers and eminent manufacturing engineers could do something through LBW but still the global market is dominating. Thus, the LBW capabilities are being explored to join the similar and dissimilar metals in general and AISI Stainless Steels in particular. In the process, a solemn attempt is made in the present paper to highlightsthe contributions of various authors are reviewedbrieflyand presented. Such a review helps concentrate on newinnovative ideas in LBW process.

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