HYBRID LASER BEAM WELDING OF ALUMINIUM ALLOYS

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Abstract - *Hybrid Laser Beam Welding Technology is a combination of primary high quality laser source such as Nd-YAG with an additional secondary heat source like TIG. The extensive use of Aluminium Alloys as a sustainable form led to the development of Hybrid Laser Beam Welding of aluminium alloys. This study focusses on the common defects occurred while welding of aluminium alloys such as porosity, hot cracking, HAZ degradation and reflectivity.*

1 INTRODUCTION:

The demand for light weight material in construction and fabrication is on the rise to compensate both economical factors and industrial pollution norms [1]. Next to steel aluminium is the second most used structural material. The advantages of Aluminium alloys such as high strength to weight ratio, relative corrosive resistance and easy machinability made its application in construction and fabrication of aircrafts, transportation industry and power transmission [2]. Welding of aluminium alloys can be done using several different processes from fusion arc welding to solid state processes or brazing and soldering. The welding process creates a high temperature which alters the microstructure at welded areas which further creates a fusion zone associated with the molten metal and heat affected zone (also known as HAZ) which undergoes transformations metallurgically. This changes the mechanical behaviour of the material. In the process of welding of aluminium alloys, the metallurgical transformations can lead to softening of the material in the HAZ areas. Cracking and porosity also can occur. The process of fusion and solidification will also generate residual stresses which leads to distortion of the microstructure. These are very important in aluminium welding process due to the high thermal conductivity of aluminium and high linear expansion coefficient that leads to more fusion and heat affected zones [3].

Hybrid Laser beam welding can also be considered as an ecological process, since its emission level is considerably low, because of the efficient filtering systems that are applied by the modern welding equipment [4].

Heat source for Hybrid Laser Beam Welding includes a primary heat source as Laser power and secondary heat source either as an arc with consumable electrode or an arc with non-consumable electrode. The principle behind this process is that Nd-YAG lasers coupled with TIG generates a focused heat flux at a desired location which is sufficient enough to generate weld. The unique advantage of this process is that the deficiencies of each individual can be compensated by the other one. The reported improvement in the HLBW process over laser beam welding is the welding speed, weldable material thickness, gap bridging ability, the quality of welds with very low porosity and cracks, the efficiency and process stabilities [5].

Nd-YAG laser is chosen because it could be transmitted via optical fibres easily but in most case, for other lasers it is complex for transmission. The wavelength of Nd: YAG laser beam(1064nm) can be easily absorbed by the aluminium alloys which is one of the major advantage in HLBW. For the same weld penetration, the required power is lower for Nd: YAG laser than required for CO_2 laser.

1.1 PROPERTIES OF ALUMINIUM ALLOYS:

Aluminium(in pure state) is a relatively soft metal with yield strength of only 34.5 N/mm2 (5,000 lb/in2) and tensile strength of 90 N/mm2 (13,000 lb/in2). The development of variety of aluminium alloys, results in different strengths and changes ductility. Aluminium in its pure state has high resistance to corrosion and thus needs less protection than other metals. But on the other hand, some aluminium alloys, though contains aluminium, are distinctly more sensitive to corrosion due to the presence of some quantities of heavy metals such as copper, zinc or nickel for the development of high strength light alloys. Thus it results in the need for treatments to protect the surface. The presence of these heavy metals even in small quantities affects the alloy's resistance to corrosion, and thus high mechanical strength with good corrosion resistive alloys have proved largely incompatible. This makes us to ensure the development of good protective finishes for these alloys. The combination of aluminium with manganese and magnesium improved the resistance to corrosion. Al-Mn (3000 series) is one of the important alloy that can be Work Hardened to achieve desired strength. This is a general-purpose alloy for moderate-strength applications requiring good workability [6].

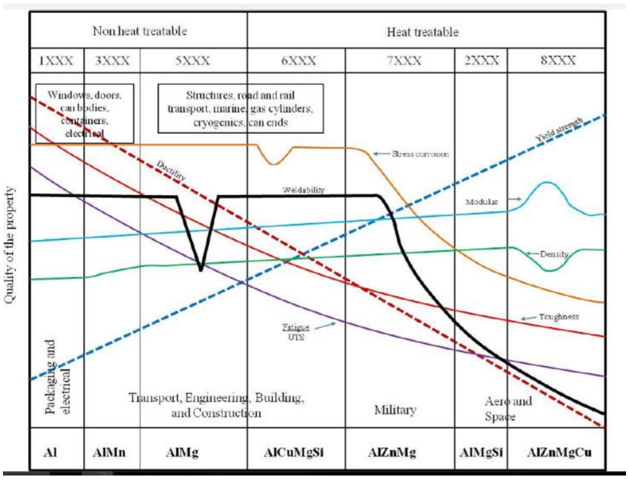

Fig-1: Properties of Aluminium Alloys

Aluminium and its alloys are grouped into cast aluminium and wrought aluminium alloys [7]. The wrought alloys are usually used in fabrication because of its high strength compared to cast alloys [8]. This paper focuses on wrought alloys. The wrought aluminium alloys are grouped into series based on the chemical composition. They are denoted by 4 digits where the first denotes the characteristic alloying element. They range from 1xxx to 9xxx series. For example, 99% pure aluminium belongs to 1xxx series while high strength aluminium (HSA) alloy like 7025 belongs to the 7xxx series.

Aluminium alloys weigh about 1/3 of copper and iron at equal volume. It is slightly heavier than magnesium and slightly lighter than titanium and it is a relatively weak metal. Alloying of aluminium can be done to attain high strength. Aluminium is resistant to corrosion due to the formation of its thin oxide layer on exposure to moisture. Aluminium conducts electricity, heat and reflects light and it is easy to fabricate. HSA alloys like the 2xxx, 7xxx, and 8xxx are becoming of high industrial interest because their yield strength is comparable to mild steel. However, the higher the yield strength the more difficult it is to weld (due to the chemical properties). Further relationship between the properties of aluminium alloys is presented in Figure.

1.2 COMMON DEFECTS ON WELDING ALUMINIUM ALLOYS

Welding of aluminium alloys is difficult in most cases due to their lower melting point(933K). It has become further more critical due to

1) Formation of oxide layer over welded surface on exposure to oxygen atmosphere.

2) High thermal expansion of aluminium due to development of internal residual stresses leading to weld cracks.

3) High shrinkage rate of aluminium during solidification processes that enhances cracking.

4) Solubility of hydrogen on the molten aluminium available during welding processes causes porosity.

5) Aluminium has high heat conducting capacity therefore higher heat inputs are required to achieve sound welds.

6) Further the high reflective nature of aluminium alloys disturbs the focusing of laser during HLBW.

2. WELDING PROCESS:

Common technologies in the laser focusing head includes the presence of closed loop systems, integrated actuators and sensors, self-learning and self-adapting systems. The combination of laser beam and arc can be of varying configurations which remarkably influence the weld performance (i.e.) focusing adjustment, change of intensity of beam and some other variations can be done to improve weld performance. It is very important to note that in hybrid laser beam welding, the primary heat source is laser while the secondary source can be of any arc process. The formation of weld pool is based on both the heat source types and relative position of the heat source to one another [9]. This arrangement plays an important role for the effectiveness and efficiency of the weld system as well as the welds. The heat source can be arranged to have a common or separated operation point as illustrated. In common operation point, the arc root and laser beam spot centre are in the same surface location of the work piece. Many hybrid laser-arc configurations use arc welding torch inclined to the laser beam along the weld direction or across. It is essential to note the position of the arc torch as it affects the position of focal point.

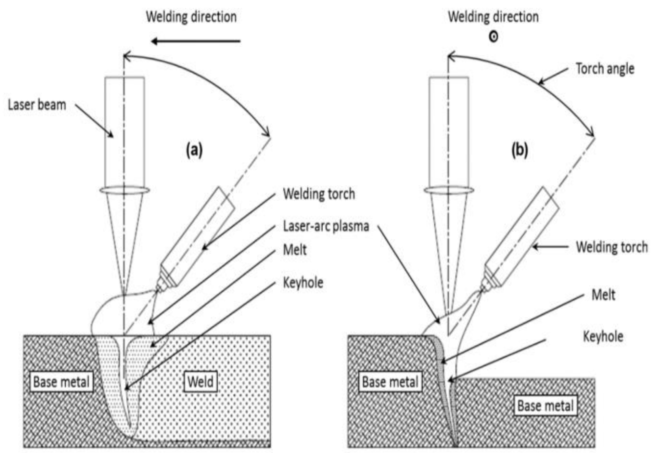

Fig-2: LOCATION OF ARC, SHIELDING GAS SUPPLY AND LASER TORCH

It is found that laser power is responsible for maximum attainable weld penetration depth and the arc processes were responsible for the adjustment of the weld seam width [10]. The same research group used the setup (as shown in in Fig. b) for tailored blank of two different plate thicknesses. The result showed that the configuration reduced the need for edge preparation increased molten material volume and generated a smooth zone transition between the plates because the arc burns the thicker plate's edge therefore improving weld appearance.

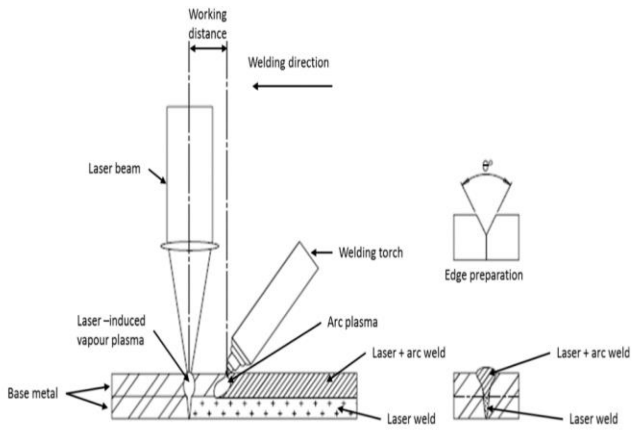

Fig-3: WELD WITH EDGE PREPERATIONS

A separated operation point arrangement can be of serial technique or parallel technique or a combination of both. The serial technique is a configuration in which the primary and secondary heat source has an acting point distance known as WORKING DISTANCE between them in horizontal and vertical direction along path. The arc source can follow or lead the laser beam. Leading arc source will allow preheating and thus increases laser heat source efficiency because of reduction in heat losses by conduction. It will also increase the weld seam quality due to the more stabilized keyhole. Leading arc also generates deeper welds since it is used at close working distances, and thus the laser beam strikes the deepest and narrowest part of the weld pool surface which is being suppressed by arc forces. In order to achieve deepest weld penetration, the focal point should be adjusted to hit at the lowest weld pool surface [11].

2.1 Nd:YAG - Neodymium Yttrium Aluminum Garnet:

Nd:YAG (Rod Laser) Pulse mode Laser (note: CW is superseded by CW Disk and Fibre lasers) uses a single Nd:YAG rod that is pumped using flash lamps to produce high peak and low average power for welding. E.g. a relatively low average power of 25W can provide up to 6kW of peak power. The correct high peak power/short pulse combination provides a good solution comprising efficient material coupling and precise energy input control. The considerations of Nd:YAG lasers are

(1) Fibre optic beam delivery

(2) Materials reflective to CO2 lasers wavelength can often be welded

(3) Easy beam alignment, beam sharing and beam switching

(4) Argon can be used for shielding gas (plasma suppression not required)

(5) Long and varied fibre lengths with no effect on process

(6) high peak power with high energy per pulse.

2.2 DEFECTS:

2.2.1 Hot cracking

The crack in aluminium welding occurs during weld metal solidification. It mechanically involves the splitting apart of liquid film because of the stresses and the strain that spring up due to solidification shrinkage and thermal contractions. The liquid film is related to the low melting eutectics. In situations where the difference between the alloys liquid film and the lowest meeting eutectic is large, the large solidification range makes the liquid film shrink more. In addition, it is more demanding to feed shrinkage over large distances. When the base of the dendrites solidifies fully and the shrinkage is culminated, feeding inter dendrites liquid to the shrinkage is then critical [12]. The loss of mechanical properties due to hot cracking while welding aluminium and its alloys is because of the failure that occurs in the liquated region (molten region) of the HAZ. The cracking susceptibility is purely based on the alloying elements. When the parent metal adjacent to the fusion zone is subjected to high heating rates, this brings into picture the problem of non-equilibrium in melting process. Micro-cracks can also arise in the liquated regions in the presence of hydrogen and/or sufficient strain. In additions, a change in composition of the weld regions, toughness can be seriously impaired following ageing. Precautions can be taken to control liquation and liquation cracking by controlling the grain size, the residual impurities, the degree of homogenization, and the alloy content.

2.2.2 Porosity

While welding of Aluminium Alloys two types of porosity are addressed: pore that are larger than 0.2mm which can be observed by Radiology are called macro pores. One the other hand the pores with diameter in micrometer range which can be observed only by Optical microscopy or SEM (Scanning Electron Microscope) are called micro pores.

2.2.2.1 PROCESS OF PORE FORMATION:

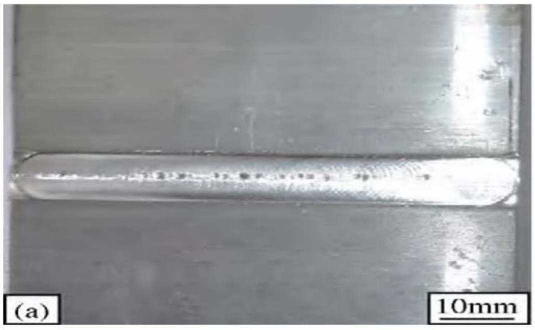

Fig-4(a): Top view of weld (800mm/min)

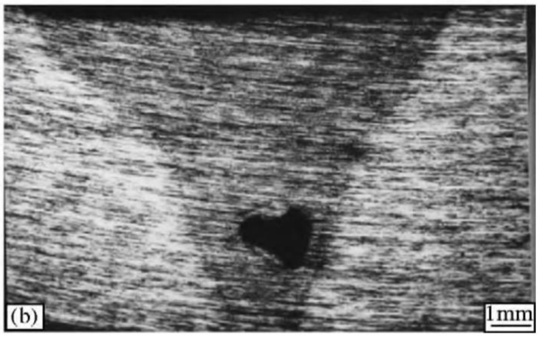

Fig-4(b) : Cross-section of weld(800mm/min)

This is the top face of the Aluminium treated by milling machine, here lots of pores are found explicitly in the weld metal and most of them takes the center of the metal resembling a line. The diameter of the pores obtained here is greater than 0.5mm most of which are obtained under these weld portions. One of the main characteristic nature of HLBW is high welding speed and high cooling rate, so it is often difficult to difficult to avoid these pores induced by hydrogen [13].

In extreme temperatures, during arc welding, aluminium approaches its boiling point on the surface of weld pool. At this time aluminium undergoes two order magnitude changes in hydrogen solubility. The changes tend to occur as it cools from initial high temperature till the onset of solidification; the activeness of hydrogen for aluminium is due to the temperature in the melted weld pool. Dissolution of hydrogen in aluminium is governed by factors of high temperature equilibrium and the fast mixing of the pool due to the electromagnetic forces. The weld pool therefore has high gas content relative to the surface temperature [14]. This effect is generated in aluminium because the arc weld region is under high heat and the pores can be supersaturated as that gas pore formation is possible without the aid of solidification. When the weld starts to cool, there is not enough time for the entrapped gas to move to move to the liquids surface and escape from the weld pool. The entrapped gases are the pores in aluminium welds [15] [16]. The source of porosity is usually due to the entrapment of various gases in the weld, the type of filler wire used, and the weld pools cooling rate. There are numerous possibilities of gas entering the weld pool (shielding gas, air product of turbulent arc action and even dissolved hydrogen). Hydrogen or water is the source of porosity. Hydrogen is the typical source of porosity in aluminium welding; other sources include oxygen, and other gases in the surrounding air. Porosity affects the mechanical properties of aluminium welds. The degrading effect on the tensile strength and ductility depends on the size and distribution of the pores. Elongation drops immediately as porosity level increases, tensile ductility drops by as much as 50% from its highest level when the porosity is about 4% of the volume. At same porosity level, tensile strength is observed to be very tolerant and yield strength is slightly reduced [17]. In aluminium alloys, zinc vapour is generated at the faying surface during HLBW which generates gas inclusion causing porosity aluminium has high boiling temperature of 2050 degree Celsius and then cleaning zinc in the weld region mechanically or using arc heat to volatize zinc ahead of the pool helps to reduce the possibility of porosity.

2.2.2.2 REMEDY FOR PORE ELIMINATION:

1)SURFACE COLOR OF WELD CONTRAST

The colour of weld whose laser beam was shielded by gas shows silvery white or straw yellow, while the weld colour without shieling seems dark. As a result of adding shielding gas, the molten pool is shielded enough and the reactive degree between air and molten pool decreases, during the welding processes the molten pool seems bright and the keyhole is continuous. Apart from this adding shielding gases improves the absorption rate of materials.

2)ADDING LASER CO-AXIAL SHIELDING GAS

The direction of adding shielding gas prevents the Arc from can prevent the Arc from rooting into the laser impinging spot, which leads to a part of Arc instability. Only when the arc current is great enough and stiffness of the arc is strong enough the arc can be rooted to the Laser impinge spot. It is found that there are various threshold values under various welding conditions. Using the co-axial shielding gas high current is required to generate high quality joints. But the advantage of HLBW lies in low current and high welding speed. In this sense the application of this welding process is limited.

3)ADDING LASER SHIELDING GAS

Adding Laser lateral shielding gas, two angles need to be taken into account. One of these angles lies between nozzle and laser beam and the other between nozzle and metal torch. Further the flux of shielding gas is also important. By these techniques we can get bright and continuous welds and thus the pores are being restrained [18].

2.2.3 Heat affected zone degradation

The HAZ is created beside the fusion zone and it results in the degradation of the parent materials caused by modification of the microstructure by devoted temperature. The nature of the HAZ is dependent on the diffusion in the region and the heat input. Due to the thermal dependency of the metallurgical transmogrification, the degradation depends on the type of welding process and parameters. Preheating parent metal before weld and using high heat input increases the HAZ region and the degradation level. The HAZ degradation may be limited by using multi pass welding, avoiding preheating, and by controlling the inter pass temperature [19].

3 CONCLUSIONS:

Aluminium has become an important structural material and has found its applications starting from kitchen utensils to aerospace vehicles. The usage of Hybrid Laser Beam Welding increases the weld speed and improves weld penetration thereby increasing productivity and weld quality. However, porosity formation cannot be effectively avoided in actual HLBW but by adding a shielding gas unit which might be costly we can possibly control pores formation and so this can be applied where the application of weld quality needs to be extremely high such as aerospace applications. Similarly welding Aluminium Alloys by HLBW also has disadvantages like high reflectivity and this can be minimized by tilting the laser head to required degree of deviation but, this affects weld penetration and so this technique can be utilized in automation welding.

REFERENCES:

[1] G. Kopp and E. Beeh // Materials Science Forum 638 (2010) 437.

[2] F. Ostermann, Anwendungstechnologie aluminium (Springer Verlag), 2007.

[3] Laser Welding of Structural Aluminium L. Quintino, R. Miranda, U. Dilthey, D. Iordachescu, M. Banasik and S. Stano.

[4] I. Pires et al, 2006.

[5] F.BEYER, B.BRENNER, and S.NOWOTNY, "OVERVIEW OF HYBRID TECHNOLOGY"' proceedings of the 2nd Int. WLT-Conference on lasers in Manufacturing, Munich, June 2003.

[6] The Surface Treatment and Finishing of Aluminum and Its Alloys, 6th Edition P.G. Sheasby and R. Pinner.

[7] G. Mathers, The welding of aluminium and its alloys (Woodhead Publishing Cambridge, England, 2002) & R.D. Joseph, Aluminium and aluminium alloys (J. R. Davis & Associates, ASM International, 1993).

[8] S.R. Yeomans // Aust. Weld. J. 35 (1990).

[9] A. Mahrle and E. Beyer // Journal of laser applications 18 (2006) 169.

[10] E. Beyer, R. Imhoff, C. Maier, J. Neuenhahn, K. Behler and U. Dilthey // Laser Materials Processing 2500 (1994) 183.

[11] T. Sugino, S. Tsukamoto, T. Nakamura and G. Arakane, In: Proceedings of the 24th International Conf. on Applications of Lasers and Electro-Optics (2005), p. 10]

[12] F.C. Campbell, Manufacturing technology for aerospace structural materials (Elsevier, Amsterdam -San Diego, 2006).

[13] Pore formation during hybrid laser beam welding with inert gas atmosphere by Liming Liu, Gang Song, Guoli Liang, Jifeng Wang & State key Laboratory of material Surface modification by Laser, Ion, and Electric Beams, Department of Material Engineering, Dalian University of Technology, Dalian 116024, China; July 20, 2004.

[14] F.C. Campbell, Manufacturing technology for aerospace structural materials (Elsevier, Amsterdam -San Diego, 2006)].

[15] ASM International Handbook Committee, ASM handbook. Volume 6: Welding, brazing, and soldering (ASM International, Ohio, USA, 1993.

[16] G.S. Ba Ruizhang, Welding of Aluminum Lithium Alloy with a High Power Continuous Wave Nd3:YAG Laser 2004; IIW Doc. IV-866-04 (accessed 2012).

[17] F.C. Campbell, Manufacturing technology for aerospace structural materials (Elsevier, Amsterdam -San Diego, 2006).

[18] Gang Song, Guoli Liang, Jifeng Wang State Key Laboratory of material Surface modification by Laser, Ion, and Electric Beams, Department of Material Engineering, Dalian University of Technology, Dalian 116024, China; July 20, 2004.

[19] OVERVIEW OF LASER SYSTEMS AND OPTICS APPLICABLE TO HYBRID LASER WELDING OF ALUMINIUM ALLOYS, Muyiwa Olabode, Paul Kah and Antti Salminen, Lappeenranta University of Technology, Lappeenranta, Finland; January 27: 2015.