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A Study on Behavior of Materials Under The Influence of Laser Joining

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Abstract

Laser welding will be an important welding process for different applications in aerospace , aircraft , automotive, electronics and other industries, due to its capabilities like minimum heat affected zone, welding of various thicknesses, adoptability to welding of various materials possessing widely varying physical properties like melting point, absorption, reflectivity etc. It utilizes laser source as a non contact heat generation technology to weld different materials so as to achieve welds of high quality narrow width and high penetration depths without the need of filler wires. It may be necessary to understand the effect of process parameters on the weldability of materials for successful welding. Laser welding popularly uses two types of lasers like CO_2 and Nd:YAG (neodymium doped yttrium – aluminium – garnet) with different powers. Nd:YAG lasers are used to weld materials of different thicknesses involving powers upto 5 kW. Whereas, CO_2 lasers are used for applications which involve higher powers upto 20 kW. Laser welding allows a direct transition from light energy into heat energy. This technique is involved with the process of laser - matter interaction in which various parameters such as pulse energy, pulse duration, spot size, welding speed, laser power, weld width, penetration depth, reflectivity, absorption coefficient, thermodynamic properties etc. are used for analysis. This paper presents a review of the different parameters including process as well as materials on the weldability of various materials like carbon steels, stainless steels, magnesium alloys, aluminium alloys, refractory materials such as vanadium, titanium, zirconium, tantalum etc. The selection of appropriate parameter for welding of specified material is discussed. The prominent weld defects common to the laser welding such as porosity, oxide inclusions, cracking, loss of alloying elements etc., are discussed as related to the microstructure as well as mechanical properties such as hardness, tensile strength and fatigue strength etc.

Key words: Aluminium alloys, magnesium alloys, carbon steels, stainless steels, vanadium alloys, laser welding.

Introduction

Basic Principles of Laser Welding

Laser welding of is a process that melts and joins metals by heating them with a laser beam. Laser beam can be produced either by a solid state laser or a gas laser. In either case, the laser beam can be focused to very small areas. If a 1 kW laser beam is focused to a spot of 200 microns in diameter, the power density (or the irradiance) is 1000 divide by the area of the spot (3.14 x 10^{-8} m^2) or 3.2 x 10^6 W/cm^2. This tremendous concentration of power is necessary for welding to occur (1). The focusing of the laser to a small area is achieved by optical means. In a solid-state laser, a single crystal is doped with small concentration of transition elements or rare earth elements. For instance, in Nd:YAG laser the crystal of yttrium – aluminium – garnet (YAG) is doped with neodymium (2). The electrons of the dopant element can be selectively excited to higher energy levels upon exposure to high intensity flash lamps. Lasing occurs when these excited electrons return to their normal energy state by emitting energy in the form of light.

Laser beams are just light beams, and metals are very good reflectors of light. This problem is compounded by the fact that the major industrial laser types emit infrared light, which metals reflect even better visible light. As a result most of the incoming power bounces right back at the source. This by the way can damage lenses or whatever else is back there. Since metals are also good conductors of heat, the power that does get into the work is rapidly dissipated away from the spot being heated. The only way lasers can weld metal is by applying so much power that the small fraction absorbed in the work is enough to melt it.

Modes of Laser Welding

Conduction welding

It is a laser welding process in which irradiance or power density will be kept low. Conduction welding will be done typically with Nd:YAG lasers rather than with CO_2 lasers. This is because of the fact that the solid metal absorbs much more Nd:YAG light than CO_2 light. For example, stainless steel absorbs about 25% of the incoming Nd:YAG light. Whereas, it absorbs only 5% of CO_2 light. When the metal melts, it absorbs about 50% of the light at either wave length. The absorbed power then doubles for Nd:YAG welding. Whereas, it increases by factor of 10 for CO_2 welding. The sudden change in absorption by an order of magnitude makes CO_2 conduction welding unstable. Once there is enough power to melt the surface, there is almost always enough to form a keyhole. With Nd:YAG laser, the absorbed power doubles upon melting, but this leaves a fairly large process window between melting and vaporization. When there is no vapor channel all the power will be absorbed on the surface of the weld. Sub-surface melting occurs by conduction and convection. The conduction welds are consequently semi-circular in cross section with aspect ratios of 1:2 or less. In conduction welding laser radiation does not penetrate into the material being welded. As a result, conduction welds are less susceptible to gas entrapment (porosity). During welding with keyhole welding an intermittent closer of the keyhole can result in porosity due to this, there may be porosity in the welds (3).

Keyhole welding

In keyhole welding, the surface melts. Liquid metals absorb much more light than solid ones. So, the heat input suddenly increases. This raises the metals temperature above the boiling point, generating metal vapour. The pressure of this vapour opens a channel around the laser beam, forming what is called a keyhole (1).

A fully developed keyhole traps almost all the incident laser power and converts it into heat. Some of the light is absorbed by the vapour, while the rest bounces around inside the channel and delivers energy with each reflection. The keyhole allows lasers to produce welds that are deep and narrow, because power is delivered to the work through the vapour channel. The aspect ratio (depth/width) of keyhole laser welds can be as high as 8:1 but is more commonly around 4:1.

At power densities above 10^6 W/cm^2, the above events occur within micro-seconds in materials such as steel. Keyhole welding is a threshold process: When the irradiance is low, very little power is absorbed. Once the irradiance is high enough to form a keyhole, most of the power is absorbed by the work. Small power changes near the keyhole threshold will cause dramatic changes in the weld. Since aluminium alloys have high reflectivity and thermal diffusivity, it is difficult to generate a keyhole in laser penetration welding. This must be overcome by sufficient laser power and proper focusing, in order to achieve the required power density (2).

Literature Review

Laser Welding of Different Materials

Vanadium and its alloys

Vanadium – base alloys are potentially attractive for use as cladding in Liquid Metal Fast Breeder Reactors (LMFBR) and as the first wall structural material for fusion reactors. These alloys possess superior elevated temperature mechanical properties particularly creep strength and better resistance to fast neutron damage as compared to austenitic stainless steels. The excellent high temperature mechanical properties of vanadium alloys permit LMFBR operation at higher temperatures and to higher burn-ups than are possible with stainless steel cladding. However, weldability of these alloys in general must be demonstrated and laser welding must be developed specifically (4). Laser welding is considered to be as attractive process for the construction of a reactor due to its high penetrating power and greater flexibility for field and large component welding with acceptable atmospheric control. Welding of these alloys must be performed in an inert atmosphere to prevent O_2 and N_2 contamination. The use of a flexible containment chamber with an inert gas purge may avoid atmospheric contamination during welding (5, 6). It may also be possible to carry out on-site welding of large components by making use of an Environmental Control Box (ECB).

Deep penetration defect free and oxygen contamination free welds have been achieved under an optimum combination of pulse energy beam travel speed and focal length of lens. The key for such welds was found to be the stabilization of the keyhole and providing an escape path for the gas trapped in the molten weld pool (6).

Titanium and its alloys

Titanium alloys were successfully welded using a 2 KW CW CO_2 laser and him as a shielding gas above and Ar beneath (7). Titanium is a refractory metal which posses' high melting point .It is difficult to weld without using an inert gas shielding. Titanium and its alloys are used extensively for aerospace applications. Successful butt welding of a Titanium alloy (Ti-6Al-4V) using laser beam has been reported (7).

The x-ray analysis of welds has revealed the structure free of cracks, porosity and inclusions, which is better than the structure of the electron beam welds. Metallographic analysis, revealed that the parent metal matrix has a structure typical for annealed titanium. Some micrographs (SEM&TEM analyses) revealed a parallel martensite plate in the fusion zone, indicating the high cooling rates in these zones. The response of the micro hardness, across the welds on the variation of the laser power and transverse speed is shown in Figs. 1&2.

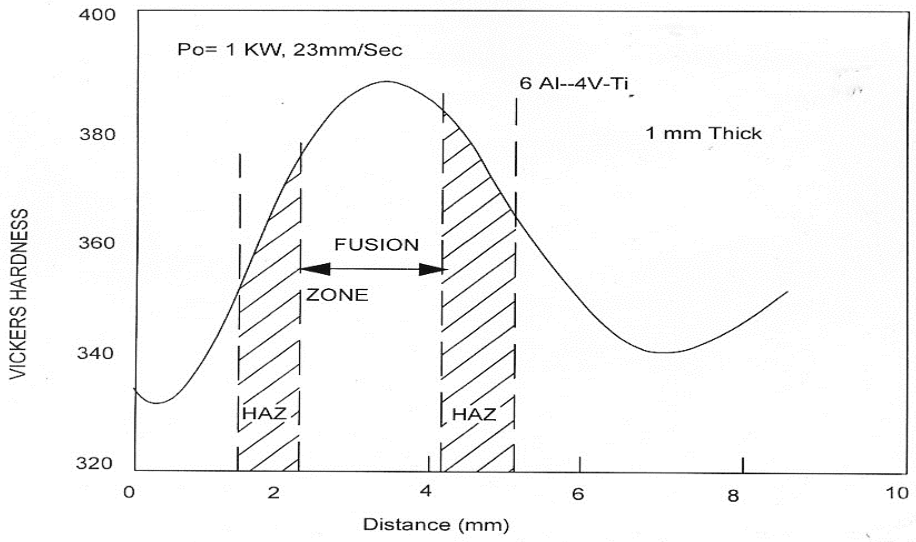

Fig.1. Microhardness transverse for 6Al-4V-Ti welds

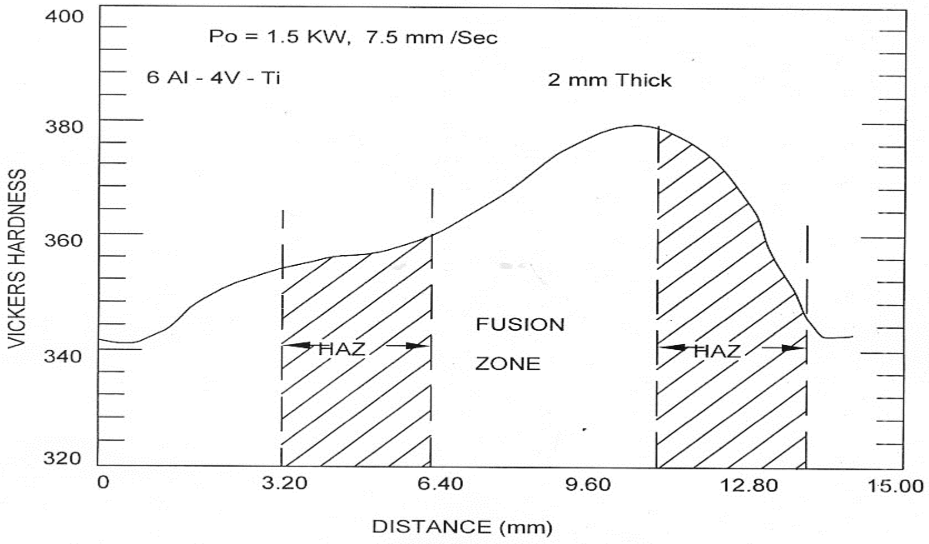

Fig.2. Microhardness transverse for 6Al-4V-Ti welds

The micro hardness for the weld zone is 380 to 385 VHN compared with 340 to 350 VHN for the parent matrix (7).The response of the ultimate tensile strength and percentage elongation on laser power and welding speed variation is shown in Figs. 3&4. It is evident that neither the welding speed nor the laser power variation affects the weld strength which is in agreement with the results found for other welding processes for titanium alloys(7).

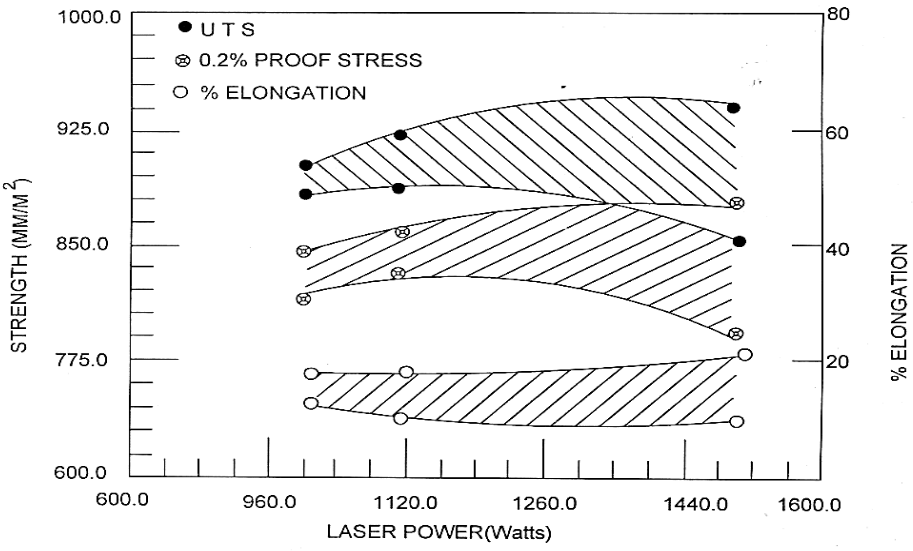

Fig.3. UTS, 0.2% proof stress and % elongation Versus power for Titanium welds

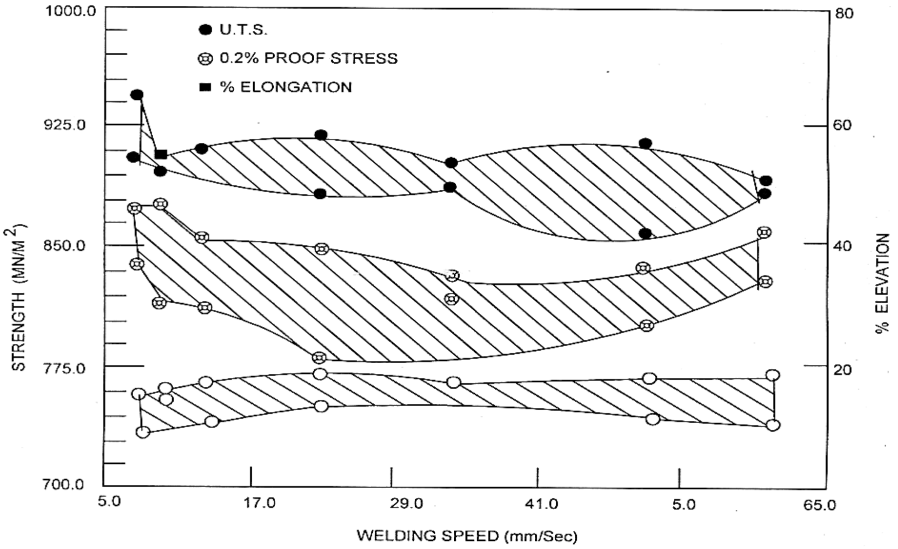

Fig.4. UTS, 0.2% proof stress and % elongation versus welding speed for Titanium welds

Zirconium and its alloys

These alloys are used extensively for nuclear power plant applications. Laser welding of zirconium has become a standard method for use in the nuclear fuel rod industry. Zirconium possesses similar properties to that of titanium it may be worth knowing that Zirconium may give weld properties similar to that of titanium (8).

Tantalum and its alloys

High quality welds of tantalum are essential as structural components for high temperature and nuclear applications (7).Very little published work is available on the welding aspects of Tantalum.

Carbon steels

Mechanical properties of the laser welded steels are usually identical to the base metal, and the weld itself is stronger than the base metal. The fast cooling rates in laser welding produce the fusion zone and HAZ considerably harder than the base metal. When steel with more than 0.3% of carbon is laser welded, it transforms to martensite. This produces a very hard and brittle weld, as well as hard heat affected zone (HAZ) next to the weld. High preheats are usually required to eliminate this problem (1).

Microstructural studies of the fusion zone revealed a continuous array of carbide precipitates surrounding the ferrite, whereas, in the stress relieved condition , the carbide particles are discrete, that is conglomerated.

The welding of carbon – rimmed steel with a 5kW CW CO_2 laser has shown that it is possible to achieve weld depths from 1 cm at a welding speed of 720 cm/min. The penetration depths of these welds are proportional to the power and exponentially depend on velocity (Figs. 5 and 6) (9). The variation of welding speed with laser power of tin-plated mild steel and tin-free steel is shown in Fig.7 (7). They have used a 2kW CW CO_2 laser to perform lap welds and bead on plate welds in 0.2 mm thick coated mild steel.

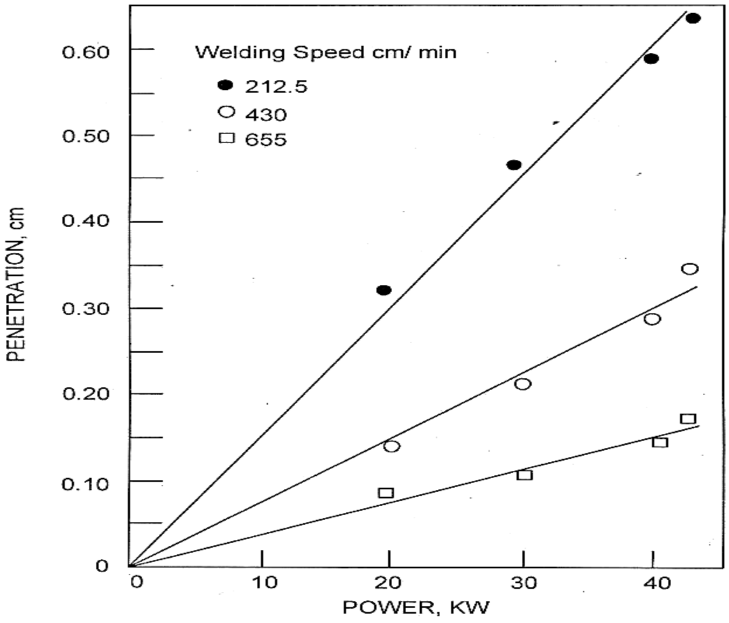

Fig. 5. Weld beam penetration as a function of laser power at various welding speeds

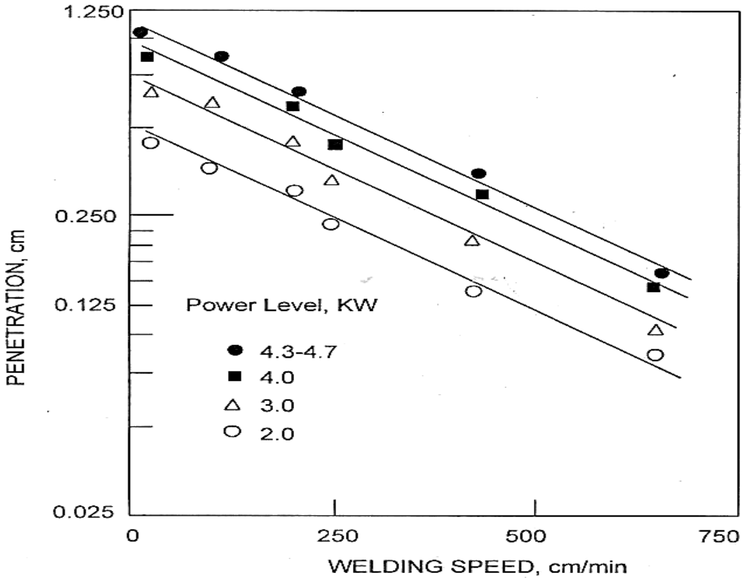

Fig.6. weld beam penetration as a funtion of welding speed at various power levels

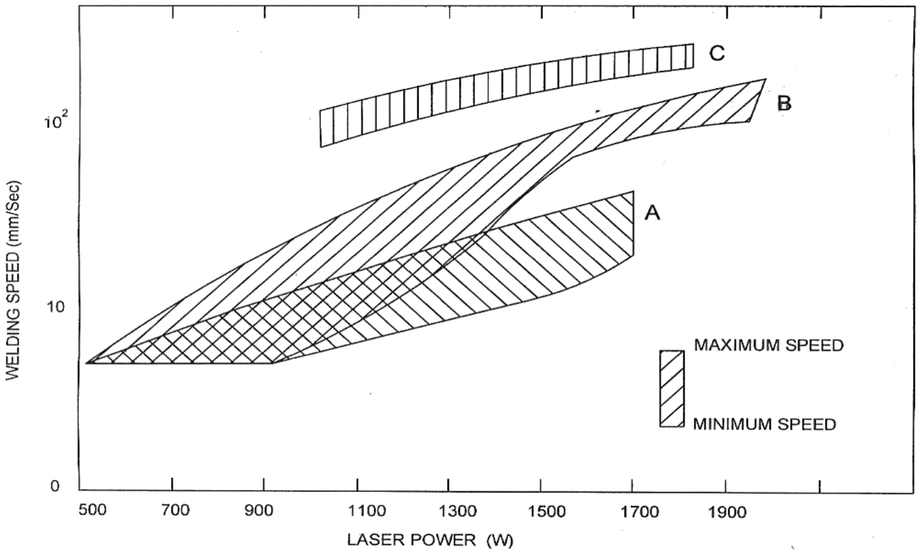

Fig.7. The variation of welding speed with laser power
A. Lap - welded 0.2 mm thick tin plate,
B. Bead on plate welds on 0.2 mm thick plate
C. Lap - welded 0.4 mm thick tin - free steel

Centerline cracking was found in both the single, and dual-beam laser welds of 1045 steel plate which is a medium carbon steel with a carbon content of 0.45%(10) when welded with CO_2 laser at a power of 6kW and a welding speed of 2.5m/min. This type of solidification cracking is usually found in most of the medium/high-carbon steel and some alloyed steels. In a 6kW CO_2 laser, the beam was split into two equal power beams and the dual beams were located in tandem i.e. one beam follows another. 0ne of the possible benefits of using the dual-beam laser was to decrease cooling rates in laser welding of high–carbon steels (10). The dual-beam process resulted in lower cooling rates, reduced hardness and a smaller volume percentage of martensite in the 4140 steel welds when compared to single-beam laser welds. Similar results were obtained in welding thin, high-carbon steel sheet using two combined pulsed Nd:YAG lasers.

Stainless steels

Lasers welds being small cool very rapidly. If short(less than 5 millisecond) duration spot welds are made on stainless steel, they can crack because of the high cooling rate. Increasing the pulse duration to 10 milliseconds or longer usually cures this (1). The rapid cooling rate of the laser welds has important benefits too. There is very little chance for sensitization of stainless steel, and many metals have better mechanical properties when they are rapidly solidified (1).

Austenitic stainless steels are important engineering materials in energy systems. The main problem in the production of fully austenitic stainless steel welds during solidification of these steels is the tendency towards hot cracking. The tendency to hot cracking of fully austenite steels is minimized by modifying the compositions of the weld filler material. Such compositional modifications may result in the deposition of 3-5% delta- ferrite in the as –

welded microstructure. Although ferrite prevents hot cracking during welding but may embrittle the steel due to sigma phase formation during service after prolonged exposure of these welds to high temperatures. The presence of delta-ferrite also reduces the corrosion resistance of austenitic stainless steels.

When variable welding speeds such as 13min/sec, 25mm/sec, and 63mm/sec are used in the welding of AISI 308,310 and 312 stainless steels by employing CO_2 laser of 9-kW power different microstructures like austenite, austenite and delta - ferrite may get deposited in the as – welded condition upon the solidification of liquid melts to room temperature under nearly all the conditions (11). Hot cracking was not found although laser welded type 308 steel was free of ferrite .Where as in the case of laser welded 310 stainless steel, evidence was found for hot cracking. The as- welded micro structures showed only austenite. Metallographic tests have shown that solidification cracking appears in all the welds on type 310 stainless steel, initiated probably by the liquation cracks in the HAZ. Defects of this type occur in the steel welded autogenously by other processes, for example TIG. The results show that the filler wire should be used in welding of type 310 stainless steel.

The micro structural changes in the type 312 steel laser welds were caused by the rapid solidification process (11). The bottom of the welds, where solidification and cooling rates are the highest, appears to be fully ferritic at all three speeds. In the top region where the solidification rates are lower, the structures were duplex in (gama + delta) nature (12).

Aluminium and its alloys

Aluminium alloys are leading candidates for many applications in automobile and aerospace industries because of their inherently low density and superior corrosion resistance compared to steels, greater design flexibility due to ease of forming and diversity of forming processes compared to reinforced plastics, aesthetic appeal, and 100% recyclability (13). Other than these advantages, weight is the key of these alloys to fuel savings because a 10% reduction of weight yields a 6 – 8% improvement in fuel economy (13). An approximately 40% Body –in-weight savings can be expected with aluminium and its alloys compared to steel because the density of aluminium alloys is 1/3 that of steel (13).

Problems during Laser Welding of Aluminium Alloys

Lasers use light for welding. So lasers have problems with reflective materials such as aluminium or copper. Aluminium which has more commercial welding applications than copper, presents several metallurgical difficulties. Regardless of the welding process, most aluminium alloys must be welded with a filler metal having a different composition than its base metal to keep the welds from cracking (1). With lasers it is very difficult to use filler wires. The material being welded must be clean. This is true for all welding but more important for laser welding. Any non-metalic contaminants get ejected from the keyhole producing spatter, under cuts porosity and lens damage. Alluminium due to its high reflectivity requires relatively high power density in order to be able to create a keyhole, which is approximately of the order of 10^6 – 10^7 W/cm^2. Power densities of this magnitude are easily achieved with commercially available CO_2 lasers (2).

Hydrogen Porosity

Hydrogen is very soluble in aluminium and its alloys. The solubility of oxygen in aluminium alloys at the weld pool temperatures is very small. Hence it is unlikely that the porosity in aluminium alloys is due to dissolved oxygen (14). Most gas porosities that occur in aluminium alloys are attributed to hydrogen. The solubility of hydrogen in liquid aluminium is an exponential function of temperature. That is the reason why it is not possible to overcome the problems due to porosity. In laser welding the problems associated with the hydrogen porosity are still severe. Such problems have been ascribed to high solidification rates of laser welding for high energy density welding processes. The solidification rates are of the order of 10^5 to 10^{6O}C/Sec which are very high as compared to the solidification rates of conventional welding processes (~ of the order of 10^2 to 10^{30}C/Sec) (15). As a result, it is not possible for the diffusion or floatation of the trapped hydrogen (2). The hydrogen levels in molten aluminium normally vary from 0.10 to 0.40 mL/100g. It is worth noting that for a part to pass aerospace quality, the gas contents have to be less than 0.06 mL/100g. The formation and growth of hydrogen porosity can be prevented by selecting a critical welding speed during welding. Also, another way to reduce hydrogen porosity is to increase power density, because it keeps the keyhole stable, increases the solidification time, allowing the hydrogen to escape (16). The hydrogen porosity also depends on the alloy composition. The rate of hydrogen porosity shows a tendency to rise considerably, as the magnesium content increases. This happens because magnesium in aluminium alloys raises the hydrogen solubility in the molten pool and hence the segregation of magnesium enhances the segregation of hydrogen during solidification. In other words, aluminium alloys containing a large amount of magnesium will have higher hydrogen solubility in the liquid phase than pure aluminum, since magnesium itself has a higher solubility than aluminium.

Porosity caused by the collapse of unstable keyholes

The aluminium alloys are susceptible to the formation of random blow holes while laser welding even with the proper control of the material surface preparation, shielding gas and material composition (17). Keyhole instability and the coupling of the laser beam into the metal are suspected to cause these random blowholes. These blow holes have irregular or tubular form and are large enough to be visible with X-ray analysis (18). The blow holes are usually located in the keyhole path, where as hydrogen pores are more or less equally distributed. The number of cavities that form during solidification is strongly influenced by laser welding processing parameters such as power per unit welding depth focusability and wavelength. It is likely that the stability is increased with the shorter wavelength lasers (Nd:YAG). It has also been observed that the highest level of porosity is concentrated in the regions where an unstable keyhole is formed. They are mainly composed of metal vapor but will condense at room temperature. The way to reduce this type of porosity is to keep the keyhole stable, but this can be achieved by welding at high speeds and the addition of filler wire. Also the use of high power continuous wave (CW) can improve the stability of keyhole (19).

Porosity resulting from entrapment of gases by surface turbulence

The turbulent motion in a weld pool is supposed to be extensively known in laser welding. The entrapped gas by surface turbulence may be metal vapor, shielding gas, air or any combination of the above mentioned gasses.

Porosity due to Shrinkage

Any other type of porosity that occurs during solidification is due to shrinkage resulting from the lack of liquid metal feeding.

Oxide inclusions

Oxides are one of the main types of inclusions in aluminium alloys. During keyhole laser welding some oxide particles may occur in keyhole laser because the shielding gas cannot be truly pure (20). The surface of liquid metal in the weld pools may also be partly oxidized to form oxide films because of the entrapment of air or shielding gas into the pools. Depending on the Mg contents in aluminium alloys, oxides such as Al_2O_3, Al_2MgO_4, MgO or their combination may occur when the aluminium alloys contain a trace of magnesium a mixed oxide $MgAl_2O_3$ (spinal) may form where the Mg content of the alloy exceeds approximately 2%, the liquid oxidizes rapidly to form MgO.

Loss of Alloying Elements

The low fusion point alloying elements in aluminium such as lithium, zinc, magnesium vaporizes during laser welding. This is due to the higher power density used in laser welding process and higher equilibrium vapour pressure of these elements than aluminium. Selective vaporization occurs in both the modes of laser welding namely conduction mode and keyhole mode or penetration welding. The mechanism of vaporization can be divided into three stages. The first stage involves transportation of vaporization elements from the bulk to the surface of the weld pool. The second stage involves vaporization from the liquid vapour interface. Finally, vaporized elements are transported to the surrounding gas phases (19). This also causes void on the top of the weld called under fill.

The loss of alloying elements can be minimized by controlling the beam power density distribution during continuous wave (CW) laser welding, which influences the temperature of the molten pool. Another way of reducing this loss is through the use of filler metal which is used as an auxiliary source of material to fill the gap.

Hot Cracking

Aluminium alloys exhibit a strong propensity for welding crack formation because of their large solidification temperature range, high coefficient of thermal expansion and large solidification shrinkage. The restrained contraction of a weld during cooling sets up tensile stresses in the joint which may cause cracking. There are two types of hot cracking: Solidification cracking and liquation cracking. Solidification cracking usually occurs in the weld Fusion Zone (FZ) during solidification where as cracking that takes place in the Partially Metal Zone (PMZ) due to tearing of the liquidate is called liquation cracking (14).

Solidification cracking occurs at high temperatures above the solidus under circumstances where the material has low ductility and is under high contraction stresses (14). Solidification cracking can be identified based on the fracture surface. The special features on the fracture surface are i) The fractured surface is always dendritic in nature ii) Fracture usually occurs at the grain boundaries iii) The crack tip is dull iv) The fractured surface is usually covered with oxides if the crack reaches the specimen surface where it can be expose to oxygen, otherwise it has a silvery colour characteristics of an unoxidized metal (14). The low melting point grain boundary films may also be present in the HAZ and may melt and form fine cracks under the influence of thermal stresses induced during welding. Cracking under these conditions is known as liquation cracking (10). However, liquation cracking still needs to be further investigated in laser welding of aluminium alloys in which alloy composition, cooling rate, material thickness and weld geometry may all influence cracking susceptibility (19).

Weld region micro structures

During laser welding of aluminium alloys, three different weld regions are usually produced . These are I) Fusion zone (FZ) ii) Partially melted zone(PMZ)and the heat affected zone (HAZ).According to a study performed on laser welding alloy A6061-T6 (21) with a CO_2 laser, FZ was found to be half the width of what it was in TIG welded joints. Porosity, solidification cracking and lose of alloying elements are the common defects found in this region (19). The grain structure in laser welded (5xxx and 6xxx) alloys primarily consists of fine columnar dendrites originating from the fusion line and some equiaxed grains in the weld center. Contrary to laser welding large fraction of equiaxed grain structure is encountered in casting processes. Lower welding speeds cause columnar grains. Columnar grain structures are very susceptible to hot tearing (14).

Equiaxed grains increase both strength and ductility because of better resistance to crack formation and crack propagation (22). The PMZ experiences temperatures between eutectic and liquids temperatures of the alloy (14). Therefore the low melting point eutectic phases which exists commonly at the grain boundaries of the recrystalisedgrains , remelt during laser welding. Liquation cracking may occur along the weakened grain boundaries in the PMZ. The PMZ in laser welded aluminum alloys is generally narrow which is approximately one or two grains wide.

The HAZ is the outer most area of the three and is characterized by its softness. This softened region is defined as the area where hardness values fall below 70% of those of the base metal. The width of the softened regions in the HAZs of the laser welds are of the order of one seventh to one quarter to those for TIG welds (21). Although the HAZs of laser welded joints are very narrow, many solid state reactions such as grain growth and precipitate coarsening may occur in the zone.

Weldment Properties of Aluminium Alloys

Hardness:

In the case of aluminiumalloys the base material may be precipitation hardened one or workhardened one. Steel shows an increased hardness in the weld zone due to martensitic hardening. Where as, in the case of alluminium alloys the effect of precipitation or work hardening gets destroyed partially or totally by the heat load of the laser welding process (18). The amount of this thermal damage is considerably lower than with arc welding. In the case of heat treatable alloys, the loss of precipitation in the welds and overaging in the HAZ has been identified as the main cause of hardness reduction. Solution treatment and aging heat treatment after welding can be used to recover the hardness to the level of base metal. However it is undesirable to perform solution treatment at high temperatures after welding.

Tensile strength:

Aluminium alloys do not display notable difference in tensile and yield strengths before and after welding. However, they still display some decrease in strength after laser welding. Higher power and shorter wave length are beneficial in the production of higher strength joints of aluminium alloys. Welding speed was reported to have an important influence on the tensile properties of laser welded joints. The tensile strength usually decreases with increasing welding speed because of less penetration depth. The total elongation in the longitudinal and transverse directions decreases with increasing travel speed for heat treatable alloys. Nd:YAG and CO_2 laser welds have approximately 60 to 80% of the original metal tensile strength and reduced elongation to failure of 1% to 3%. The mechanical properties of weld joints are mainly controlled by welding defects composition and metallurgical states of weld metal and neighboring base metal. The presence of defects will reduce the material property of the joints. Selective vaporization volatile constituents from the laser welded fusion zone (FZ) degrade the mechanical properties.

Fatigue strength

Fatigue properties and laser but welded aluminium alloys have shown to decrease to approximately 60% of base material properties .Failure during fatigue testing occurred at the FZ interface. When filler materials ate used the sensitivity to fatigue failure gets reduced

Magnesium and its alloys.

Magnesium is a light weight material. Its density is 1.59 g/cm^3 which is lower than that of aluminium (2.38 g/cm^3). The other light weight materials are beryllium (1.848 g/cm^3) and titanium (4.507 g/cm^3). Its melting point is 650ºC which is slightly lower than that of aluminium. At 850ºC it burst into flames. Magnesium possesses C.P.H. crystal structure. It under goes deformation by slip. It has limited ductility as compared to F.C.C. alloys because there are few slip systems available for plastic deformation. At temperatures above 250º C extra slip system operates for plastic deformation. Magnesium possesses low modulus of elasticity, poor resistance to fatigue, creep and wear. Magnesium costs upto 6 times as much as steel and as much as twice that of aluminium on a mass basis. It is the sixth most abundant element on the earth’s surface and represents about 2.5% of its composition (23). It is also the third most plentiful element dissolved in seawater, with an approximate concentration of 0.14%. Magnesium and its alloys possess high strength to weight ratio. In view of this important property magnesium alloys are mostly used in aircraft and missile industries. Magnesium-aluminium and magnesium-zinc alloys are age hardenable. As the lightest structural material, magnesium alloys have the potential to replace steel and aluminium in many structural applications. Thus magnesium alloys have already found considerable applications in aerospace, aircraft, automotive, electronics and other fields (24).

During laser welding of magnesium alloys weld defects such as an unstable weld pool, substantial spatter, loss of alloying elements, undercuts, liquation and solidification cracking have been observed (24). The weld ability of magnesium alloys was reported to be significantly better with the Nd:YAG laser due to its shorter wave length. The effects of laser power on the penetration depth and weld width are shown in Figs 8 & 9. For WE43 alloy welded at a speed of 33 mm/sec. It can be seen that high beam powers led to deep and wide beads .It can also be seen that the threshold power for deep penetration mode welding of cast WE43 alloy is approximately 1 kW for a CO_2 laser, i.e. a power density of approximately $2x10^6$ W /cm^2.

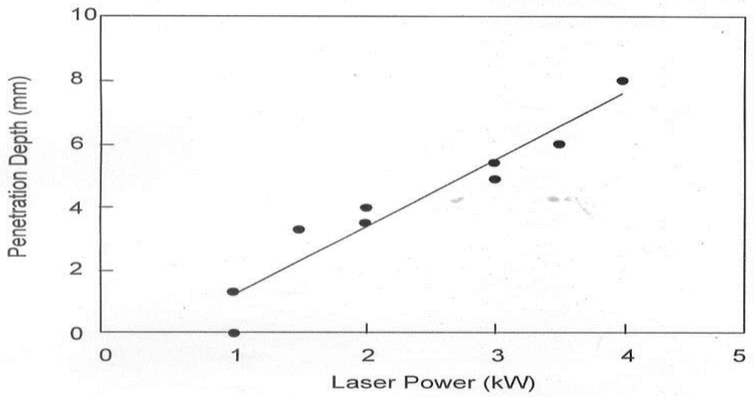

Fig.8. Effect of CO_2 laser power on Penetration depth of cast WE43 alloy joints

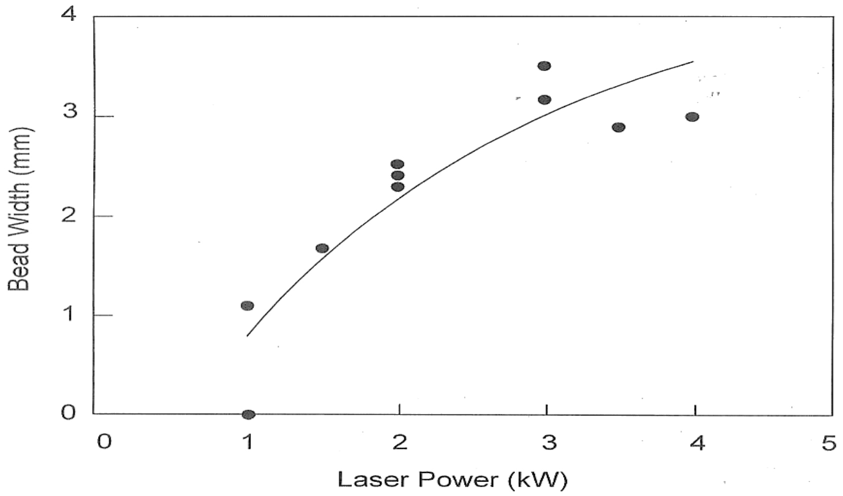

Fig.9. Effect of CO_2 laser power on bead width (mm)

Effects of welding speed on penetration depth and weld width at a different levels of power for CO_2 and Nd:YAG laser respectively are shown in Figs 10 & 11. It can be seen that the penetration depth and weld width both decrease linearly with the increasing welding speed.

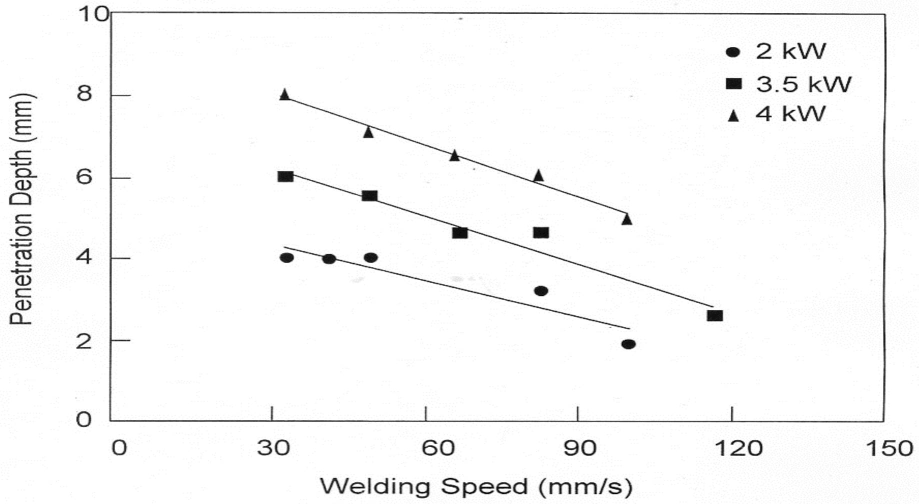

Fig.10. Effect of welding speed on Penetration depth of cast WE43 alloy joints

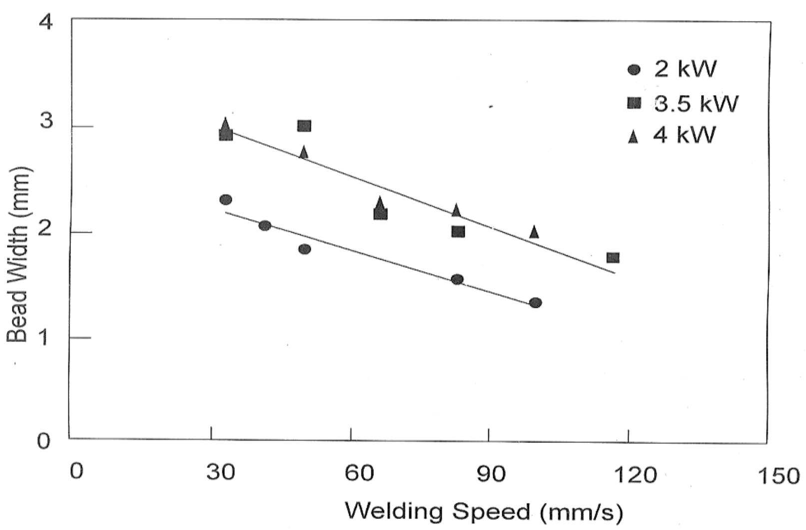

Fig.11. Effect of CO_2 laser power on bead width of cast WE43 alloy joints

Discussion:

Significance progress has been achieved in recent years on the laser welding aspects of different materials (2, 7, 14, 25 – 27). It is interesting to note that there are many unanswered questions that need to be solved. As regards to the laser welding of aluminium and its alloys the following are the unanswered questions: Prevention of solidification cracking, alloying elements, control of porosity formation, better understanding of role of surface active elements, control of weld-pool geometry mechanical behavior and formability of aluminium and its alloys. The major concern during welding of magnesium and aluminium alloys is the presence of the porosity in the weld metal that can deteriorate mechanical properties like hardness, tensile strength, elongation and fatigue strength. As compare to magnesium the mechanism of pore formation during laser welding of aluminium and its alloys is well understood in aluminium and its alloys.

Dual beam laser welding is an emerging welding technology. It may be of research interest to study the effects of dual beam welding on the weldability of carbon steels, stainless steels aluminium alloys and magnesium alloys. It is known that the dual beam process reduces significantly the cooling rates , results in the reduced hardness and a smaller volume percentage of martensite in steels when compared to single beam laser welding. This process minimizes the instability problem during the laser welding and reduces the tendency towards pore formation.

Conclusions

1. Laser welding process is finding increased usage for joining wide variety of materials used in aerospace, automotive, electronics and medical applications.
2. Dual – beam laser welding process achieve improved weld quality over single beam laser welding.
3. Laser welding process can successfully be employed for the construction of nuclear reactor components. Welding of such components have to be performed in an inert atmosphere.
4. The weldability of aluminium alloys have been understood to a considerable extent as compared to that of magnesium alloys.
5. Detailed studies are required to understand the weldability of carbon steels and stainless steels.

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