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A Review: Welding by Laser Beam of Dissimilar Metals

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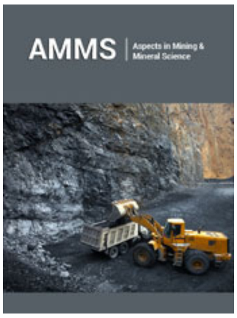

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Abstract

Laser welding has been widely used in different industrial fields. Laser welding is an interesting technology for joining dissimilar metallic materials. Welding of dissimilar metals by laser beam is new research filed. The objective of this paper is to review the previous research works on laser beam welding of dissimilar metallic materials. This paper presents the details of the laser welding technique and its application on the field of dissimilar welding. The most welded dissimilar metallic materials by laser were cited. Metallurgical aspects of some recent investigations dedicated to the joining of dissimilar metallic materials were also presented and discussed. The main advantages and disadvantages of the laser welding technique were mentioned.

Keywords: Laser welding; Dissimilar metals; Microstructures; Mechanical properties

Abbreviations: HAZ: Heat Affected Zone; LBW: Laser Beam Welding; Nd: YAG: Neodymium-Doped Yttrium Garnet; IMC: Intermetallic Compounds

Introduction

Joining of dissimilar metallic materials is often challenging due to different material properties. The problems encountered in realizing welded joints from dissimilar materials that are difficult to obtain by using commonly used technologies, have led to widespread use of new techniques of welding [1]. Welding processes may be realized employing different energy sources: from gas flame and electronic arc to electron or laser beam and ultrasound [2]. Laser welding is potentially a more attractive technology for dissimilar joining, mostly in automotive and aerospace applications [3]. Laser welding has been widely used in various industrial applications such as automobile manufacturing, shipbuilding and bridge construction due to its advantages in realizing high production, automotive processing, and forming a high-quality weld with small heat affected zones [4-6]. From the metallurgical aspect, due to its high speed and power, laser welding creates and narrow interaction zone which is called Heat Affected Zone (HAZ) [7]. In opposite, thermal joining of dissimilar metals tends to the formation of brittle intermetallic phases which decreases the mechanical properties of the joint. Laser beam which has a precise and localized energy input offers the possibility to control these brittle phases [8]. Recent research in laser welding aims at joining a large category of structurally dissimilar metals, such as thin stainless steel, titanium, copper or aluminum components, which are otherwise difficult to be joined using the conventional welding techniques [9]. The objective of this paper is to review the previous research works on laser beam welding of dissimilar metallic materials.

Laser Beam Welding technique

Laser Beam Welding (LBW) processes is a unique welding technique used to joint multiple pieces of metal through the heating effect of a concentrated beam of coherent monochromatic light known as LASER [10]. The laser beam is notable for having the highest power density currently available to industry (up to 109W/cm^2 that is focusable on a small spot (down to 0.1mm) [2]. Laser process is free of electromagnetic fields and is, thus, suitable for welding dissimilar couples. With flexibility in the power intensity, power distribution, and scanning velocity, laser welding is emerging as major joining process [11]. The absorption of such energy leads to material melting [8]. It is a high-energy-density welding process and known for its deep penetration, high speed, small heat-affected zone, fine welding seam quality, low heat input per unit volume, and fiber optic beam delivery [10]. The principle of operation is that the laser beam is pointed on to a joint and the beam is moved along the joint. The process will melt the metals into a liquid, fuse them together and then make them solid again thereby joining the two pieces [10] as illustrated in Figure 1. Laser suitable for welding include pulsed neodymium-doped yttrium garnet (Nd: YAG), fiber, and diode. Each offers unique features that align to specific applications. In addition, the laser welding is divided into two modes, the conduction mode and the keyhole mode, which depend on the power density. The conduction mode is a low energy density process. In this mode a power density lies below 106Wcm^{-1}. Heat conduction welding causes only surface melting up to 1mm, i.e., the surface of the material being welded. The dimension of the weld on the surface is generally larger, and the depth of penetration of the weld is generally shallower. The Keyhole mode starts when energy density exceeds 106Wcm^{-2}. Laser beam is focused on the material surface and the fusion zone rapidly heated up to the boiling point. Melted material begins to vaporize at the centre of the weld spot and creates a blind hole or keyhole [12]. The keyhole is surrounded by a thin layer of molten material. Material at the leading edge is melts and flows around the keyhole, solidifying to form a deep, narrow weld bead. For this reason, this mode is called penetration welding. From the metallurgical aspect, the Heat Affected Zones (HAZ) are very narrow.

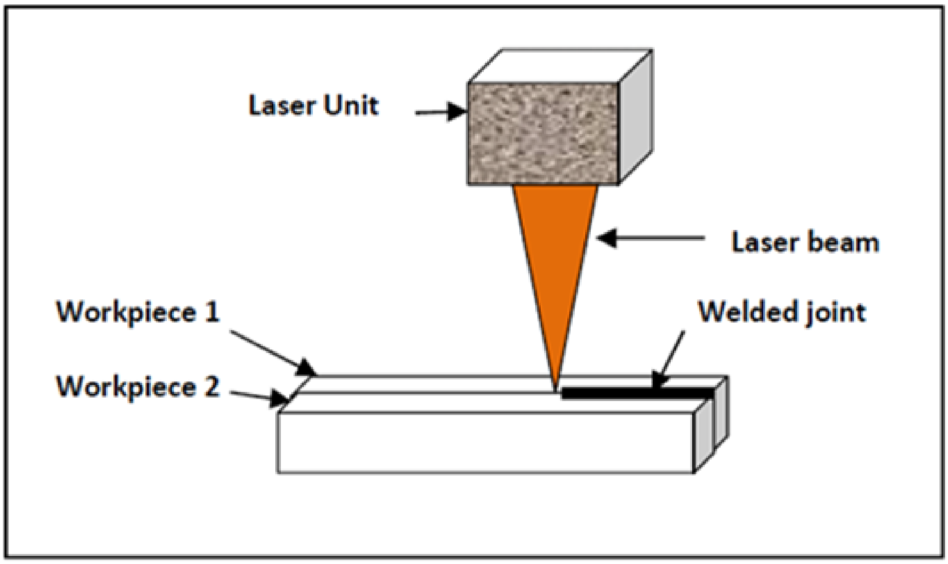

Figure 1: Principle of laser welding of two workpieces.

The laser welding parameters are laser power, beam diameter, welding speed and focal point position; material physical properties such as laser beam reflectivity, thermal diffusivity, surface tension, content of volatile elements and edge surface roughness; environment conditions such as air, atmosphere pressure, shielding gas type, shielding gas flow rate, laser induced plasma and plume [13-15]. However, Laser power, q (W), welding velocity, v (ms^{-1}), rB (m) and focused beam diameter are the three main parameters which affect a laser welding process such as weld penetration and geometry.

Laser Beam Welding of Dissimilar Metals

The welding of the dissimilar metallic materials was usually done in response to a specific engineering need. The investigation on laser beam welding of dissimilar metallic materials in the area of macro-materials processing primarily focuses on potential applications in the automotive and aerospace industry for thin sheet applications. The most research works focused on the relationship between the welding parameters, the properties of the weldment, and metallurgical structure. In dissimilar laser welding, a general rule is that the mechanical and corrosion resistance of the joint has to be at least comparable to that of the metal characterized by the lower properties [16]. Laser welding of dissimilar metals has attracted attention of the researchers worldwide. The first published research works on laser welding of dissimilar metallic materials have been carried out on these metallic wires: Tungsten/Nickel [17], Nichrome wire/Silver-plated brass [18], Gold/Silicon and Al coated Si [19], Copper wire/Tantalum wire [20], Stainless steel wire/Tantalum wire [21], Tungsten wire/Nickel wire [21], Nickel wire/ Tantalum wire [23], Copper wire/ Nickel wire [22], Phosphor wire bronze wire/Palladium wire [23], Copper/Brass [24], Copper /Mild steel [24], Copper/Stainless steel [24], Titanium wire/Gold [25].

However, some recent selected published works carried out on laser welding of dissimilar metals will be presented. Naeem et al. [26] investigated some dissimilar metals: Titanium-Aluminum, Aluminium-Copper, Titanium-Inconel alloy, 304 stainless steel-copper and 304 stainless steel-aluminum alloys. They concluded that the heat input and the cooling rate has major influence on the type and thickness of the intermetallic. Yiyoung et al. [27], CO_2 laser welding using Ni-base filler metal was used to joint cast iron and carburized steel for differential gear. To reduce the influence of the Plasma which happens during CO_2 welding, mixture of helium and argon gas was used as shielding gas. The welding speed and laser output power were adjusted. Mishra et al. [28] studied microstructures and mechanical properties of dissimilar joint Inconel 625 nickel-based alloy and 316 stainless steels welded by laser beam. The dissimilar joint was formed by with one-pass fully penetrated weld using high power CO2 laser. The main parameters used for laser welding both plates were Helium as inert gas, the beam diameter was 2mm, and speed 1.5mm/min. They observed that the microstructure of weld zone near fusion line in Inconel 625 was predominately long columnar dendrites, whereas that near the SS316 was cellular in nature. Stanciu et al. [29] investigated the influence of the laser welding speed on the geometry and microstructure of the welded joint of AISI 321 stainless steel and AISI 1010 carbon steel. For the protection of the weld bead root, argon has been purged through a specially designed channel placed at the bottom interface of the sheets. The laser beam was positioned more on the stainless-steel plate and less on the carbon steel due to the lower thermal conductivity and higher reflectivity of the stainless steel. They found that the weld bead microstructure is composed of strong non homogeneity regions with distinct areas of mixed austenitic-martensitic-ferrite microstructures. The fusion zone microstructure is characterized by ferrite branches enveloped by the austenite matrix towards the stainless-steel side and by a non-interference zone at the carbon steel side. The dissimilar joints present a good tensile behavior with an ultimate tensile strength similar to the carbon steel mechanical characteristics. Chopde et al. [30] have investigated laser beam welding of copper and aluminum joint. They used Nd: YAG diode pumped laser is used. The experiment was designed based on a three full factorial design Laser power, welding speed and focal point position. From experiments, they concluded also that, copper and aluminum 6061 grade are very difficult to lap weld with LBW because of higher intermetallic due to different solidification rate. For this reason, dissimilar metals can be successfully welded using filler wire AlSi12 by maintaining stringent process and fixturing.

Meco et al. [31] have presented an investigation about application of laser in seam welding of dissimilar steel to aluminum joints for thick structural components. The steel surface was irradiated by the laser and the heat was conducted through the steel plate to the steel-aluminum interface, where the aluminum melts and wets the steel surface. The welded samples were defect free and the weld micrographs revealed presence of the brittle Intermetallic Compounds (IMC) layer resulting from reaction of Fe and Al atoms. Besna et al. [32] studied the processing parameters effect, like welding speed and laser power on the joining of copper with stainless steel. Differences in the physical properties of the two metals, including the melting point, thermal conductivity and thermal dilatation are the main reasons for obtaining an inappropriate laser welding bead. Particularly, the laser welding process of copper is complex because of the very high reflectivity of cooper and in almost situation it requires a specific surface pre-treatment. The Nd: YAG laser is used for very small dimensions of the material. They concluded that the preparation of the parts before welding, i.e., they have to be very clean and without pollutants [33-45]. However, the welding energy vaporizes some elements, so some defects could appear as cracks for instance. Table 1 presents some selected published investigations dedicated to the welding of dissimilar metallic materials by laser welding technique [33-39].

Table 1: Dissimilar metallic materials jointed by laser welding technique.

Dissimilar Welded Metals
Zinc coated steel/Aluminum alloy [34]
AIS 321/AISI 630 stainless steels [35]
AISI 304/AISI 420 stainless steels [36]
Copper-steel [27,37]
Superalloy K418/42CrMo steel [37,38]
AISI 310 austenitic stainless steel/Nickel-based alloy Inconel 657 [39]
Carbon steel/5754 aluminum alloy [40]
AZ31B magnesium alloy/316 stainless steel [41]
Steel/Aluminum [32]
Copper/Aluminum [27,42]
Titanium-Aluminum [27]
Ti-66Al-4V/Inconel 718 [43]
Copper/Nickel [44]
DP1000 Steel/Aluminum Alloy 1050 [45]

Discussion

According to the content of these studies, we can conclude that a new dissimilar metallic material has been welded by laser welding technique such as Magnesium with steel. In addition, the most welded materials were plates with butt configurations. The different types and modes of laser welding were applied. According to Naem et al. [26], a number of researchers have carried out in depth study of laser welding of dissimilar materials with different laser sources i.e., fiber, lamp pumped Nd: YAG and disk lasers in order to investigate the formation of the intermetallics during mixing of molten materials. To improve the weld quality, the main welding parameters were also tested [40-44]. Weld quality is the main factor that should be taken into account in analysis of LBW process efficiency. Appropriate selection of process parameters is not a function for maximization of welding process efficiencies, but a search for an acceptable balance between contending factors of physical and metallurgical effects [45]. The main observed defects in welded joint by laser welding technique are incomplete penetration, incompletely filled groove, excessive penetration, cracks, porosity and pores [45]. Therefore, processing parameters optimization is a goal of many research projects to improve productivity and decrease occurrence of defects that results in lower production costs [46].

The main advantages of laser welding are a high-quality weld, a narrow heat affected zone, and laser systems can be made fully automatic. Due to the high local energy concentration of the laser beam, laser technology is by far the most suitable method for joining particular metals such as stainless steel. By applying this technology, chromium precipitation on the grain boundaries is avoided by using a high laser welding speed that diminishes the exposure of the weld to high temperatures. However, the major disadvantages of laser welding are its associated high costs.

Conclusion

From the above literature, followings main points can be summarized:

a. Laser beam welding is appropriate for some dissimilar metals and alloys.

b. The main advantages of laser welding are a high-quality weld, a narrow heat affected zone, and laser systems can be made fully automatic.

c. The welding parameters must be controlled for improving the weld quality.

d. There are limited number of dissimilar metals have been welded by laser welding technique.

e. Certain difficulties require a special interest, such as vaporization of some elements and phenomenon of cracks formation in the weld.

f. A difference in the physical properties of the two dissimilar metals represents an obstacle to weld some dissimilar metals by laser welding method.

g. Many points have not received enough attention in the previous works such as corrosion resistance of the welded joint, which needs a particular investigation in future.

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