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A Review on Laser in Advanced Material Processing and Manufacturing

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Abstract:
In the present day advanced manufacturing scenario, the components produced must strictly adhere to the dimensional, positional and form specifications, in order to have an edge over competitor's products. Recently, laser materials processing has received much attention due to its clean and controlled transfer of energy, conditioned and intermediated by laser beam incidence. This review summarizes the progress and advantages in the various research activities carried out through laser welding process and related activities. The content of this paper includes brief reviews on important engineering materials.

Keywords: *Laser material processing, welding, surface alloying, drilling, cutting.*

1. Introduction

Welding is the principal industrial process used for joining metals. Welding is the joining of two or more pieces of material by melting a portion of each and allowing the liquefied portions to solidify together. This can be accomplished with or without filler metal, and one or more passes can be made. When significant melting is involved and necessary for welding to take place, the processes are called fusion welding processes. If melting does not occur or is not principally responsible for causing welding the processes are called non-fusion welding processes (e.g. pressure welding). As materials continue to be more highly engineered in terms of metallic and metallurgical continuity, structural integrity and microstructure, fusion welding processes will become more important and more prominent.

2. Fusion Welding Processes

Fusion welding is a joining process that uses fusion of the base metal to make the weld. The three major types of fusion

Welding processes are as follows:

2.1. Gas Welding (Conventional Method)

Oxyacetylene welding (OAW): Melts and joins metals by heating them with a flame caused by the reaction between a fuel gas and oxygen.

2.2. Arc Welding (Conventional Methods)

- Shielded metal arc welding (SMAW): A process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals.
- Gas–tungsten arc welding (GTAW): A process that melts and joins metals by heating them with an arc established between a non-consumable tungsten electrode and the metals.
- Plasma arc welding (PAW): A process that melts and joins metals by heating them with a constricted arc established between a tungsten electrode and the metals.
- Gas–metal arc or Metal inert gas welding (GMAW or MIGW): A process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals (Ar and He as shroud gas).
- Flux-cored arc welding (FCAW): A process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode (electrode is flux cored rather than solid) and the metals.

- Submerged arc welding (SAW): A process that melts and joins metals by heating them with an arc established between a consumable wire electrode and the metals.
- Electroslag welding (ESW): A process that melts and joins metals by heating them with a pool of molten slag held between the metals and continuously feeding a filler wire electrode into it.

2.3. High-Energy Beam Welding

Electron beam welding (EBW): A process that melts and joins metals by heating them with an electron beam at vacuum.

Laser beam welding (LBW): A process that melts and joins metals by heating them with a laser beam without vaccum.

Since there is no arc involved in the electroslag welding process, it is not exactly an arc welding process. For convenience of discussion, it is grouped with arc welding processes.

The traditional (or) conventional methods generally have many of the problems that are inherent to welding and joining that can be avoided (or) minimized by proper consideration of the characteristics and requirements of the process. A few of the important problems are cracks, inclusions, incomplete fusion of the base and weld metal, incomplete penetration, unacceptable weld shape, arc strikes, spatter, undesirable metallurgical changes, excessive distortion and thermally induced stresses etc...

On the other hand, the ecological welding processes must comply with the technical requirements for the environmental protection and occupational health, according to the ISO 9000, ISO 14001 and ISO 18001 standards (V. Verbitchi et al, 2010). But, conventional methods such as the gas metal arc welding process (GMAW), Shielded metal arc welding (SMAW), Flux cored arc welding (FCAW), submerged arc welding (SAW) are emitting gaseous pollutants (including "greenhouse" gases) include carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and ozone (O_3) and fumes include manganese (Mg), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb) oxides (R. M. Evans, et al, 1979). Due to rapid rise of welding industry, the amount of particle of gaseous pollutants increases those are small enough to remain airborne and be easily inhaled. However, these could be dangerous to environment and hazardous to the welder's health.

Laser welding may also be considered an ecological process, as its emission level is very low, due to the efficient filtering systems applied by the modern welding equipment of this class (I. Pires et al, 2006).

Recently, laser materials processing has received much attention due to its clean and controlled transfer of energy, conditioned and intermediated by laser beam incidence. Hence, laser beam welding offering many advantages, for instance, low heat input, small heat affected zone, elimination of flux (autogenous welding), low weld distortion, high welding velocity, absence of mechanically induced material damage and of tool wear, greater resistance to vibration and shock, minimum degradation of heat sensitive components during assembly, increased reliability, single pass thick section capability etc.….

Enhanced design flexibility of laser sources permits to perform various technological operations with same laser system noticeably; delivering the laser beam through an optical fiber system leads the welding to the new era, since welding can be performed in all possible positions even though the weld location is so difficult. In addition, it allows robotic linkages, reduced man-power, full automation and systematization. The theoretical and experimental study of laser welding began in 1962, Since then, the use of laser welding has grown swiftly, as the new manufacturing possibilities became better understood (J. Sabbaghzadeh et al, 2008). Now days, laser is finding growing acceptance in field of manufacturing as cost of lasers has decreased and capabilities are having increased.

It is without a doubt that stainless steels are an important class of alloys from low end applications like cooking utensils and furniture to very sophisticated ones such as nuclear power plant and space vehicles. Certainly, laser welding will be an important joining technique for stainless steels with their increasing applications. Hence, it's necessary to update the laser materials and welding process on stainless steels for considerations.

This article provides a review on the various material processing carried out through laser welding process and related activities. The content of this paper includes brief reviews on important engineering materials.

2.4. Laser Materials Processing

2.4.1. Laser Beam Welding

Laser welding has recently received growing attention due to its special features and potential which are mainly based on the special characterizations (Having high mono chromaticity, coherence, directionality and intensity) of the laser beam. Thus, its findings many applications in the field of metallurgy, different types of lasers source in use are investigated and compared with other forms of material processes (G.A. Abilstttov and E.P. Velikhov, 1984). The focused laser beam is one of the highest power density sources available to industry today. It is similar in power density to an electron beam. Together these two processes represent part of the new technology of high-energy-density processing. Unlike electron beam, laser beam required no vaccum space to use. Moreover, any technological action of Laser Beam processing represents a controlled transfer of energy, conditioned and intermediated by laser beam incidence and respectively, absorbance on the work piece's surface. (Adelina Han et al, 2005) represents a group of technological processing methods by laser beam such as heat treatment, welding, removal of the material, alloying, cladding, cutting and drilling.

2.4.2. Surface Alloying/Cladding

Surface alloying with laser is similar to laser surface melting with the exception that another material is incorporated into the melt pool. Laser surface alloying has similarities with surface cladding, which if performed with excess power, can result in surface alloying. Surface alloying and cladding when performed by a laser, require minimal post-process re-machining of the surface.

There has been a substantial amount of research work on the effect of laser alloying process on substrates, for instance, alloying of AISI 304 SS with molybdenum to enhance pitting and corrosion resistance (J.D. Mazumder and I. Manna,1999), AISI 304L SS powder cladded inclined shape over mild steel substrate to increase laser absorbance and powder catchment during cladding (J. Lin and B.C. Hwang, 1999), both the incline angle and the thickness of substrates will dominate as increase in the catchment efficiency and profile of edge welding with a coaxial powder filler nozzle by modified Gaussian mode of powder stream (J. Lin and B.C. Hwang, 2001), Inconel 625 and Rene 142 powders are alloyed over C1023, Inconel 792, Rene 80, Rene125 and DS Rene 142 substrates by laser and TIG sources. The report concludes that laser cladding superior to TIG in lower dilution, good fusion, bonding, less porosity, high longitudinal and transverse hardness except in cracking (L. Sexton et al, 2002). The Ti_2Ni_3Si / NiTi intermetallic coating on low carbon steel have excellent abrasive and adhesive wear resistance, high yield strength, high toughness and high hardness (H.M. Wang et al, 2003), Au/Ti coated over cu-lead frames are highly reflective in cold surface which complicating the process initiation of conduction, highly sensitive to little pollutions but not reliable for strong heating process (A.F.H. Kalpan, 2005). Austenitic stainless steels such as AISI 316 L SS, AISI 316 SS are coated with Colmonoy 6 powder at 450º C preheating and cooled gradually after cladding which results 53 times increased in wear resistance with lower coefficient of friction (H. Zhang et al, 2010), laser weldability of Al coated sheet was studied that the Al-rich zones in Fe-Al intermetallic compounds which cause the decrease in strength of weld (J.H. Lee et al, 2009). Surface alloying and cladding when performed by a laser, require minimum post-process re-machining of the surface.

2.4.3. Surface Heat Treatment

Laser beam has qualities which make it superior to other surface heaters (W.M. Steen and J. Powell, 1981), consider; 1. It's absorbed by most metals and many non-metals with in 2 or 3 atomic diameter. This very small interaction depth means that it is a true surface heater with effectively no depth of penetration (e.g. induction heating). 2. The energy is chemically clean, unlike flame heaters. 3. It is easily, quickly and precisely shaped without the use of coils and there is no heat spillage as with all jet heating systems (e.g. flame, plasma etc.). 4. The beam is not deflected by magnetic fields, nor is it possible for a laser beam to generate X-rays. 5. It does not need to work in a vacuum as in the case of electron beam heaters.

With many advantages it is not surprising to find that the laser is used in various ways to surfaces (W.M. Steen and J. Mazumder, 2010), such as,

- Transformation hardening or Annealing –Surface harden of certain alloys.
- Surface melting or Homogenization–Microstructure refinement, generation of rapid solidification structures and surface sealing.
- Surface alloying-Improvement of corrosion, wear or cosmetic properties.
- Surface cladding-Changing thermal properties such as melting point or thermal conductivity.
- Surface texturing-Improved paint appearance.
- Surface roughening-Enhanced glue adhesion.
- Surface plating - Enhanced cementation or improved deposition rates by laser chemical vapour deposition (LCVD).
- Noncontact bending.
- Magnetic domain control.
- Stereo lithography and other forms of layer manufacture.
- Paint stripping and cleaning
- Laser marking
- Micromachining and Shock hardening.

Surface modification of traditional materials such as stainless steels, aluminium, titanium alloys etc.… through laser alloying, cladding and hardening becoming more significant growth in industrial applications. AISI 316L stainless steel was laser surface treated with different compositions of Si_3N_4 and Ti shown an improved hardness about 800 HV with smooth surface and good interfacial bonding without pores and cracks. Wear and corrosion resistance also enhanced due to reinforced titanium silicide (A. Viswanathan et al, 2007).

The influence of laser surface treatment on interfacial microstructure and thermal performance were investigated by post weld surface treatment of 22Cr-5Ni-3Mo duplex stainless steel shown improved structural control as both microstructure and elemental distribution between δ-ferrite and γ- austenite could be restored to values close to parent material (E. Capello et al, 2003), (P. Kapadia and J. Dowden, 1996), surface treatment of Al- aerospace alloys shown high level of homogeneity and refined microstructure, relative to the substrate material (P. Ryan and P. B. Prangnell, 2007).

on the basis of original metal powder laser rapid prototyping, a three - stock–bin coaxial powder delivery device and extended software disposal function are used in layered manufacturing and scanning fill to employ to design and express the functionally graded materials component distribution (W. Wei and S. Xiaofeng, 2009), a three dimensional heat transfer model on melt pool incorporating Marangoni- Rayleigh- Benard convection was observed that varying the scanning speed and marangoni number the melt pool size and strength of the convection changed its influence on clad built up geometry, dilution level maximum and average melt pool temperatures and the form and scale of the microstructure of the solidified clad track (A. Kumar and S. Roy, 2009).

a series of Inconel 625 samples were successfully fabricated by laser assisted direct metal deposition process that are free from relevant defects like crack, bonding error or porosity (G.P. Dinda et al, 2009), increased over lapping rate of pulsed laser forming of HAZ on stainless steel sheet was improved the microstructure, micro hardness and anticorrosion (L.J. Yang et al, 2010), morphological changes of AISI 304 stainless steels surface induced by laser beam at 1064 and 532 nm wavelength with irradiation of 1,100,1000 and 10000 incident laser shots were observed that well-proportioned micro grains and ultra-fine grains with vermiform like microstructure at 532 and 1064nm respectively but only after 10000 laser shots (Y.H. Liu et al, 2010).

Thermal conductivity and performance of surface modified AISI 410 stainless steel was improved up to 38 and 54 % respectively due to defect free diffuse interface and dense coating structure (F.A. Espana et al, 2010), and when a re-melt the surface of the sintered tool, the percentage of porosity crack free and strongly bonded structure are decreases with increase in cladding layers, adverse results for single layer cladding (E. Capello et al, 2005). Surface treatment with a laser has become one of the most principal areas of laser materials processing research and new engineering possibilities.

2.4.4. Cutting and Drilling

Laser beam machining processing has been shown as a versatile tool for high precision manufacturing of small parts and geometries in the sub micrometre range (A. Gillner et al, 2005). The main strength of laser beam machining process lies in its capability to machine almost all type of materials in comparison to other widely used advanced machining methods such as EDM, ECM and USM. Unlike other, non-conventional energy sources laser can also be used as assistance during conventional machining of difficult to machine materials known as hybrid machining process (Avanishkumar Dubey and Vinod Yadava, 2008).

Laser beam machining method for cutting complex profiles and drilling holes are used in wide range of materials including papers, plastics and semiconductors. Stainless steels in automobile and home appliances, advanced high strength steels for car and boiler industries, titanium alloys in jet engines, aluminum alloys in fabrication of antenna array, nickel based super alloys in aerospace, coronary stents for medical and machining of ceramic tiles etc.… were done with less tolerance and cost. This ability of laser machining technology applied to Flat Panel Display (FPD) industry to repair short, open or protrusion defects in colour fitters of LCD are repaired (Kihyum Kim et al, 2008). High power diode lasers are being introduced to extend its application to industrial manufacturing from communication, computer and electronics technology (Friedrich Bachmann, 2003).

3. Conclusion

Laser sources are now being used in the automotive industry to produce welds, as alternatives to conventional welding, which are used extensively for attaching auto-body panels to subassemblies due its accuracy, less tolerance and low processing cost. Arc assisted hybrid laser welding enable even high thick metal weld in heavy industries.

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