Invited Paper

A BRIEF REVIEW: LASER JOINING OF POLYMER-METAL STRUCTURES

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Abstract

Joining of dissimilar materials especially in the case of polymer and metal structure is significantly challenging due to the difference in chemical, mechanical and thermal properties of materials. Traditionally, metal and plastics are joined together either mechanically or by using adhesives. However, these techniques have limited use in joining small sized and intricately shaped parts. To address this limitation, constant effort on the development of reliable joining processes for polymer-metal structures are currently being explored. This article provides a brief review of joining polymer and metal using laser joining technique. A summary of relevant works carried out in recent years, the choices of lasers available, the most suitable laser technique, the mechanism of joining and significant findings by selected researchers are presented in this article.

Keywords: Direct bonding, Dissimilar materials, Laser joining, Metal, Polymer

Introduction

Today's consumer trends are demanding highly reliable products or devices with increasing number of applications. Manufacturers have been meeting this demands by providing compact products with versatile functions. These enhancements have led to miniaturization and weight reduction of parts, which require the use of dissimilar materials and smaller components for reduction in power consumption. To produce such products, combination of different materials may be required for the specific design. Polymer and metals are amongst the most widely used materials for such purposes.

Polymers are predominantly used in a variety of high-tech applications, especially in coatings, automotive parts, aerospace materials, semiconductors, medical devices, composites and optical materials [1, 2]. In the field of electronics, there is a growing trend to utilize polymeric materials at various levels in the fabrication of advanced devices. Polymers offer a wide variety of chemical and physical properties appropriate for numerous applications. As compared to metals and ceramics, polymers are also cost-effective, lightweight and have a high degree of formability. Most importantly, many polymer properties can be extensively tailored to meet the specific requirements set by a given application. Meanwhile, metal is usually selected in the design of products since it has desirable properties such as high ductility, high thermal conductivity, and high machinability.

The combination of polymers and metals in the product design would contribute to new advancement in engineering applications. However, due to the differences in chemical, mechanical and thermal behaviors of the materials, dissimilar materials joining present significantly different challenges than similar materials joining.

Conventional joining techniques for dissimilar materials such as the use of adhesives have several drawbacks such as long-term stability, shrinkages during curing and additional surface treatment for enhancing bonding [3]. On the other hand, high heat input during soldering or brazing may potentially damage the polymer structures [4]. Therefore, the development of alternative joining technology suitable for polymer-metal structure is essential for ease of product fabrication and assembly.

Laser Joining Technique for Polymer-Metal Structures

Laser process has been known as a versatile tool for high precision manufacturing and material processing of small parts and geometries. Laser beam can be focused into very small spot sizes, which is useful for joining complex shape and micro parts. Moreover, different parts and materials can be joined as a non-contact process [5, 6]. Main applications of the laser joining are in the biomedical components, food packaging, electronics and micro components.

Laser transmission welding (LTW) of plastics has been widely used in industrial applications of joining plastics to plastics and offers many advantages as compared to using mechanical joining or chemical adhesives. In transmission laser welding an incident laser beam passes through a laser transparent top layer and onto a laser-absorbing bottom layer. Bonding occurs due to laser energy absorption by the bottom layer at the interface, resulting in localized heating and melting of both top and bottom layers. Upon cooling, the molten polymer at the interface solidifies, creating a fused seal [7]. The method is successfully used to join polymer-polymer components and can been adopted for laser joining of polymer-metal structures. Usually the transparent polymer is placed on top of the metal as shown in Figure 1. A lap joint configuration is selected for this type of joining technique since laser will pass through the polymer side. The intensity of the laser beam during irradiation is controlled by adjusting the focal distance. However, in some cases, a glass cover such as sapphire or borofloat glass is placed on the top of polymer to reduce the intensity of laser power [8, 10-12]. Some of the research on laser transmission welding technique between polymer and metal is listed in Table 1.

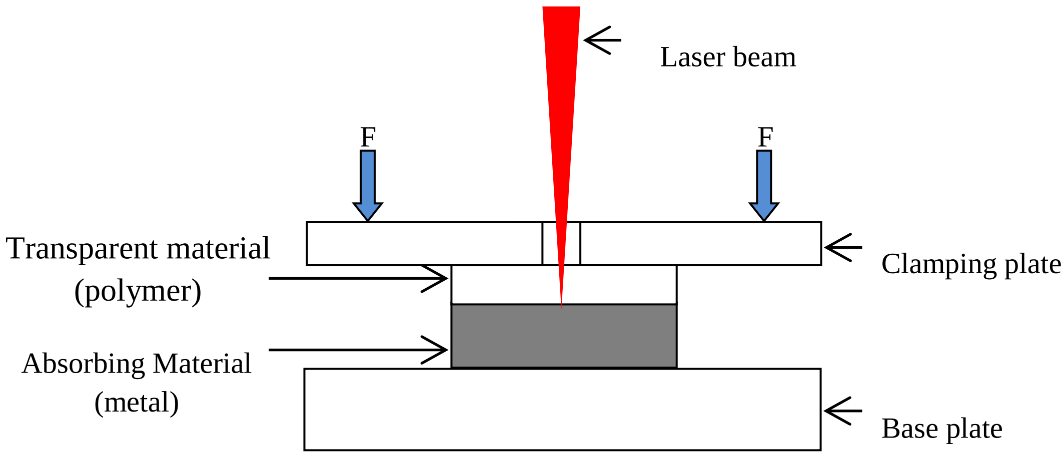

Figure 1. Schematic diagram of transmission laser joining for dissimilar materials

In this joining process, the laser scan speed and laser power are the main factors in attaining the highest possible bond strength. Excessive laser power could deteriorate the polymer surface and reduce the bonding strength. Moreover, if the scan speed is too fast, the bonding may not successfully form. Careful selection of laser joining parameters would reduce those problems. The type of laser used could be varied depending on the requirements of the joining process. Table 2 summarized several types of laser used for joining polymer and metal.

Table 1. Relevant Works Carried Out on Laser Transmission Joining Between Polymer and Metal

Author (s)	Material	Description
A. Mian et al. [8]	Polyimide (PI) and titanium	Microjoints of polyimide and titanium for medical implant applications.
Seiji Katayama et al. [9]	Amorphous polyamide (PA) and Stainless steel (SUS304)	Evaluation of the mechanical and physical appearance of the weld properties.
T. Mahmood et al. [10]	Polyimide sheet (PI) and titanium	Finite element analysis of the laser transmission joining for PI and titanium.
T. Sultana et al. [11, 12]	Polyimide and thin film titanium coating	Detailed investigation on laser joining of polymer and thin film metallic coating surface. The effect of chemical reaction between both materials is discussed.
Yukio Miyashita et al. [13]	Polyethylene terephthalate (PET), polycarbonate (PC) and stainless steel (SUS304)	Different specimen arrangement is employed. Metal is placed on the top side while polymer in the bottom and laser is penetrated from metal side.
Xiao Wang et al. [14]	Polyethylene terephthalate (PET) and titanium foil	Laser transmission joining of the thin sheet PET and titanium. Determination of the chemical reaction is achieved by using XPS machine.
Jens Holtkamp et al. [15]	Polycarbonate (PC), polymethyl methacrylate, titanium alloy (Ti-Al6-V4) and stainless steel.	New process development for joining polymer and metal. The metal parts will be heated first using laser radiation and then it pushed mechanically onto polymer parts.
Y. Farazila et al. [16]	Polyethylene terephthlate (PET), stainless steel (SUS304), aluminium alloy (A5052) and copper	Detailed investigation on laser spot joining process between polymer and metal.

Overall, the advantages of laser joining technique as compared to existing joining methods for polymer-metal structures can be summarized as follows: (a) does not require any special surface treatment to achieve bonding, (b) is suitable for macro and micro components, (c) has low possibility of contamination, (d) is suitable for dissimilar materials combination, (e) has short joining cycles and lead to cost saving, and (f) is able to be used for spot and continuous laser joining without sacrificing the weld properties. On the other hand, disadvantages of these methods are also identified as follows: (a) polymer could easily deteriorate due to excessive laser power, (b) has insufficient bonding strength for high load applications.

Table 2. Types of Laser Used for Laser Transmission Joining of Polymer and Metal

Type of Laser	Wavelength	Minimum Spot Size	Maximum Laser Power	Mode	References
Diode laser	808 nm	800 μm	30 W	CW	8
Nd:YAG laser	1064 nm	600 μm	1.8kW	CW	9
Diode laser	807 nm		200 W	CW	9, 19
Fiber laser (Yb-doped)	1100 nm	200 μm	25 W	CW	11, 12
Near infrared diode laser	980 nm ± 10 nm	800 μm	130 W	CW	14
Diode laser	810 nm	-	50 W	CW	15
Nd: YAG laser	1064 nm	200 μm	-	PL	13, 16

CW = continuous wave PL = pulsed laser

Joining Mechanism between Polymer and Metal

Bonding polymers to metals is a complex phenomenon involving interfacial reaction between both surfaces. Usually polymers have poor wettability as compared to metals due to their low surface tensions. However, several common practices such as thermal simulation of molecular mobility, polymer surface excitation, corona discharge could improve this condition [17]. In laser joining, the laser beam is converted into heat when it penetrates onto the material and simultaneously melts the irradiated area. Therefore, in the joining between polymer and metal, the generated heat would enhance bonding at the interface region. The possible mechanism for the polymer and metal joint using laser joining technique is discussed here based on the information gathered from the available research articles.

The laser joining sequence between polymer and metal is illustrated in Figure 2. During laser joining process, the laser beam will pass through the transparent part (polymer) and dissipates as heat in the absorbent part (metal). The material at the interface is heated up, melts, expands, and potentially flows out of the weld zone and solidifies. It is presumed that the polymer will somehow melt and flow downward onto the metallic surface. Some researchers have reported that tiny bubbles were formed in the polymer during the process [9, 15, 16, and 19]. It is speculated that these bubbles would push the molten polymer to stick onto the metal surface due to high expansion pressure. The polymer will then solidify through rapid cooling process. It is thus believed that the main joining mechanism for polymer and metal is mainly due to the mechanical effect. An example of polymer residue which could occur on the metallic surface is shown in Figure 3.

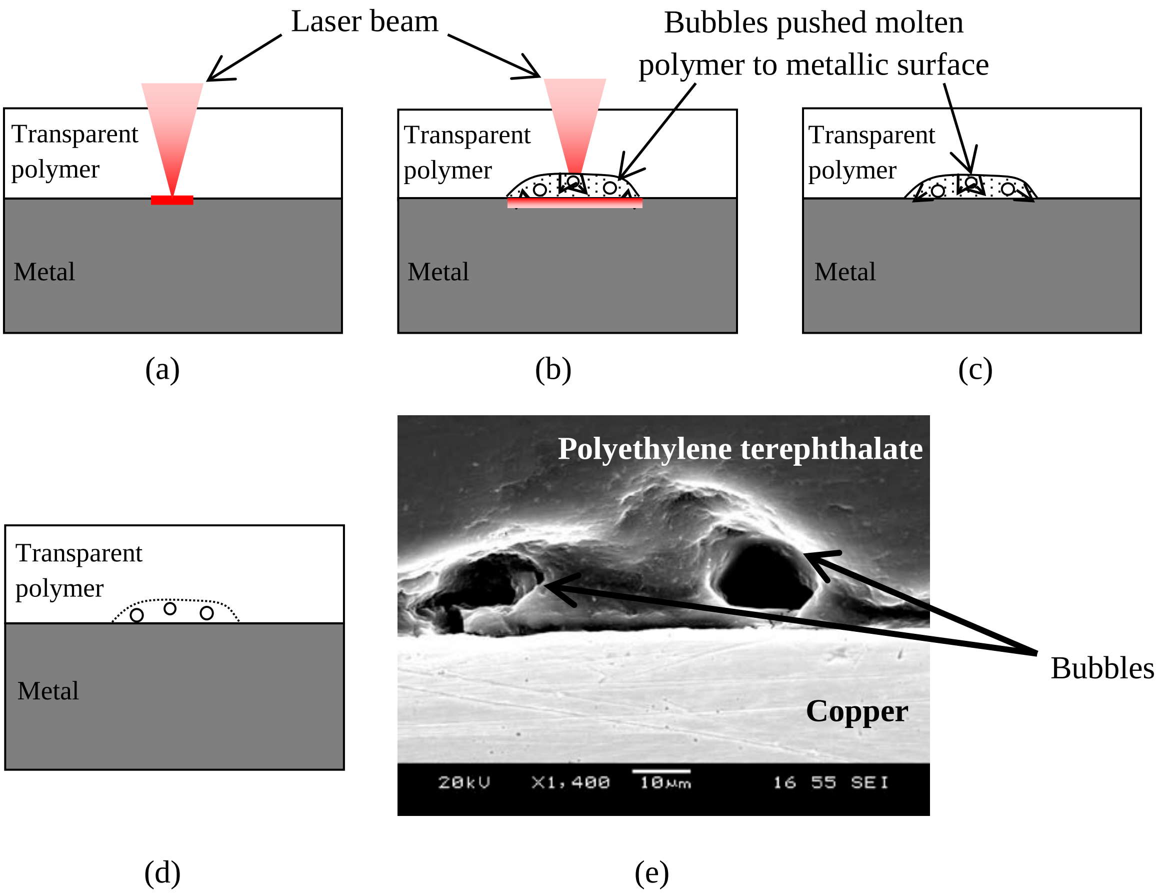

Figure 2. Sequence of laser transmission joining process (a) laser beam passes through transparent polymer and irradiate metal surface, (b) polymer is heated up and bubbles formed, (c) bubbles would push the molten polymer to stick onto the metal surface, (d) polymer solidifies and bubbles remained on polymer side, (e) an example of the cross-section of the laser joined interface [18]

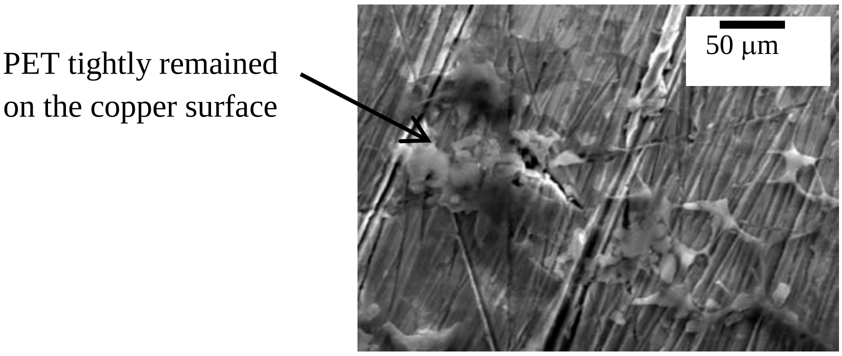

Figure 3. Example of polymer residue occurred on metal surface [16]

In addition to mechanical bonding effect, chemical bonding could also occur in the joining between PET and metal. According to Katayama et al. [20], a new chemical bonding is formed when PET and SUS304 is laser welded. TEM images have shown that the PET and SUS304 are tightly bonded on the atomic or molecular level. The base metal and the intermediate layer were identified from these diffraction patterns to be a face-centered cubic γ phase and a 5 nm thick Cr oxide film, respectively.

Xiao Wang et al. [14] also reported the formation of a chemical bond in the joining of PET and Ti. The examination of the interface analysis using X-ray photoelectron spectroscopy (XPS) gave evidence on the formation of Ti–C type chemical bonds believed to be responsible for the observed bond strength. Georgiev et al. [21] have also mentioned the occurrence of chemical interactions during laser joining of Kapton® FN/Ti pair. The chemical reaction was similarly evaluated using X-ray photoelectron spectroscopy (XPS) giving evidence for the formation of Ti-F bonds in the interfacial region.

In other report [22], new chemical bonds were observed on the XPS spectra when aluminium was deposited on the PET surface (Al/PET). It is believed that aluminium interacts with ester groups (from PET) to form new chemical bonds. This situation is in contrast with that for the aluminum deposited onto poly (Al/PS) where the aluminum appears to cover the polymer surface evenly, without evidence for new chemical bond formation.

Conclusions

Laser joining of polymer to metal is potentially beneficial for the production of micro and intricate hybrid components. Its precision, short joining cycle, and non-stringent requirements on surface preparations make it suitable to be integrated into the production line. Laser transmission welding (LTW) is found to be the most suitable laser technique for joining polymer to metal in a lap-joint configuration. The choice of laser source can be varied, with various researchers utilizing diode, fibre or Nd:YAG lasers. The two main factors which influence the bonding strength are laser scan speed and laser power.

The bonding of the polymer to metal is believed to have been influence by the physical attachment of the polymer to the metal. The tiny bubble formation in the molten polymer is thought to have exerted a high pressure on the polymer to adhere to the metal surface. Furthermore, some researchers have identified the occurrence of chemical bonding in some pair of polymer to metal laser joints. These chemical bonds can be identified via X-ray photoelectron spectroscopy (XPS).

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