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Clear plastic transmission laser welding using a metal absorber

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ABSTRACT

This paper presents a novel method for obtaining a clean and high-quality joint between clear plastics through transmission laser welding (TLW). In the proposed method, dye is replaced with metal as the absorber. The key factors that affect the welding quality of polyethylene terephthalate were investigated. These factors included laser input power, clamping pressure, and different absorbers (carbon black (CB), and Fe wire). Compared with the joint welded using the CB absorber, that welded using the Fe absorber was cleaner and impurity-free with more stable and higher welding strength. High welding strength was associated with the thermal conductivity of the utilized metal absorber. Results indicated that dye absorber could be feasibly substituted with metal in the TLW of clear plastic.

1. Introduction

The use of thermoplastic polymers is more advantageous than that of metal or ceramic in medical and food packaging applications given their anti-fatigue properties, high fracture toughness, excellent strength-to-weight ratio, and good biocompatibility [1–4]. Plastic products generally comprise two or more injection-molded parts that require assembly. Mechanical fastening, adhesive bonding, and thermal welding are popular methods for connecting different plastic parts [4,5]. However, the use of mechanical fastening or adhesive bonding in medicine and food packaging is inappropriate, particularly for the bonding of miniscule components, because of their complexity and usage of foreign attachments that may be harmful to human health. Thus, thermal welding (including friction welding, electromagnetic welding, hot plate welding, and laser welding) is commonly performed because it effectively bonds polymers without the addition of parts or adhesives. Nevertheless, friction welding, electromagnetic welding, and hot plate welding are only suitable for bonding work that requires low accuracy. Laser welding is a new thermal bonding technology. Given its characteristics of non-contact, small heat-affected zone (HAZ), and high efficiency, laser welding can be used to meet the market demand for high-precision manufacturing and cleanliness and is a good choice for medical and food packaging applications.

In the past two decades, laser welding has gradually become a mainstream plastic processing technology. Early in the technological development of laser welding, most studies have concentrated on welding processes performed with far-infrared (IR) lasers, particularly with carbon dioxide lasers, due to the high absorption of polymers in the IR region [6–8]. Nevertheless, the distinct disadvantages, such as surface damage and low penetration, of far-IR welding have limited its use in plastic processing [8]. To extend laser application in this field, short wavelength lasers (ranging from ultraviolet to mid-infrared; most of them are diode lasers) have been recently developed [9]. These kinds of lasers typically exhibit a low absorption coefficient in optical transparent polymers, which cannot be heated and melted directly. To convert light into heat, some absorbers have been introduced, including CB, resins, metallic oxides, and Clearweld, a special dye with a strong absorption at the near-infrared region (ranging from 940 nm to 1064 nm). For visible or near-infrared plastic welding, the lap-joint configuration is suitable for these diode lasers (Fig. 1). Most of the incident light that penetrates the upper polymer sheet is mostly absorbed by the nether polymer sheet in the lap-weld. The nether polymer sheet can be a polymer with high or low optical absorptivity. For thick polymers with low absorptivity, a dye absorber is often smeared on the top surface of the nether sheet to absorb light. However, the addition of dyes to the welding joint of medicine and food packaging may cause two risks: first, the dye absorber can easily spread outside of the joint and pose as a potential threat to human health [8]. Second, the coating quality of dye

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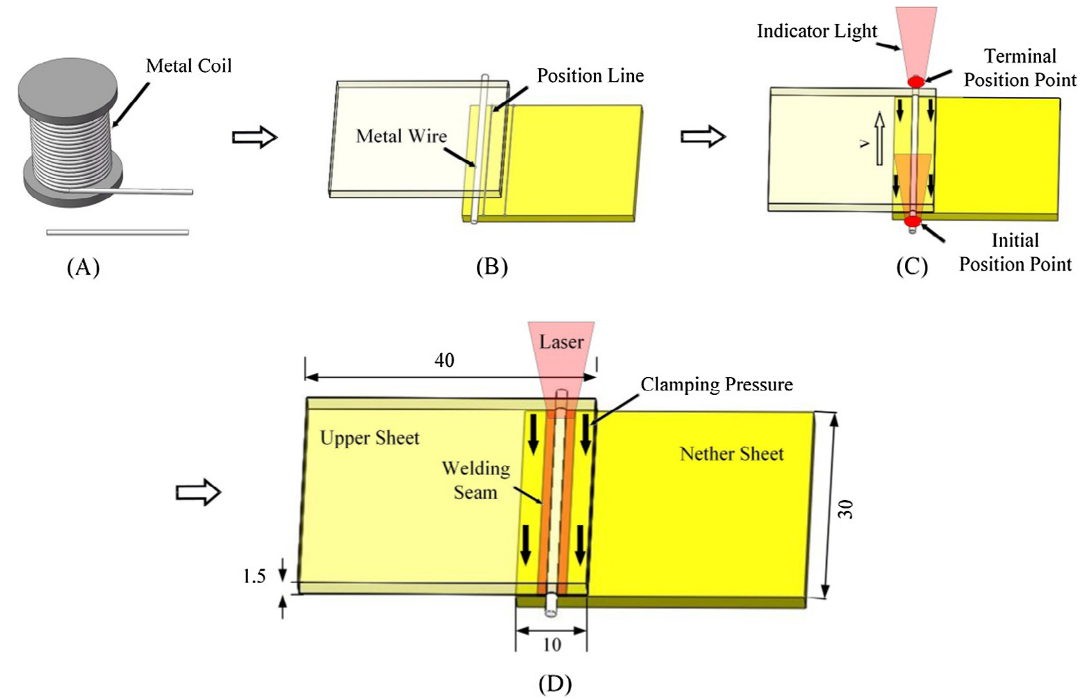

Fig. 1. Schematic diagram of operating steps in transmission laser welding with metal absorber.

absorber depends greatly on craftsmanship and can lead to instability in welding quality [3].

To solve these problems, the substitution of a metal absorber for a dye absorber in plastic transmission laser welding (TLW) is proposed in this paper. No impurities would be generated in the joint due to the physical and chemical stabilities of the metal absorber. In addition, metals have higher optical absorption than polymers in short wavelengths (808 nm, for example). Therefore, metal is a potential absorber in theory. However, no study on the use of metal absorbers in plastic TLW has been reported to date. Therefore, this study aims to investigate the effect of input power, clamping pressure, bubble, and thermal conductivity on welding quality with a metal absorber. The quality of traditional welding with the CB absorber is also compared with that of welding with a metal absorber.

2. Experimental materials and procedures

A polyethylene terephthalate (PET) sheet with a thickness of 1.5 mm was used as the polymer. The PET sheet was manufactured by Changhong Plastic Material Co., Shenzhen, China, and was cut into small 40 × 30 mm rectangular specimens (Fig. 1D). Two high-purity metal Fe and Cu wires with a purity of 0.9999 and diameter of 0.2 mm were used as the absorbing medium. The PET sheets were cleaned using ethyl alcohol with a purity of 0.997. CB powder supplied by Xinzheng Chemical Co., Jinan, China, was used for comparison. CB powder was dissolved in pure alcohol, smeared uniformly onto the surfaces of PET sheets, and then allowed to dry through evaporation.

As shown in Fig. 1D, light will be mostly converted into heat when it illuminates the Fe wire (or CB). Then, the heated Fe wire (or CB) will heat and melt the nearby PETs, thermally welding the plastic pieces together. The light source was a diode laser with the maximum output power of 50 W and wavelength of 808 nm. Light was guided by a multimode fiber and coupled with a collimating and refocusing system. The spot diameter at the focusing point was 0.5 mm. A computer-controlled 3-D mobile work platform coupled with diode lasers was used to monitor the position and feed speed of the work pieces. A suit of welding jigs was designed to obtain the necessary clamping pressure. The plastic sheets were held using a pair of high-temperature-resistant (melting point of 1750 °C) and high-transparency (transmittance of 95% at 808 nm) optical quartz sheets.

Experimental procedure of welding with metal absorber was presented in Fig. 1A–D. The metal wires were straightened and cut from the coil with length of 40 mm, and then put on the position line marked beforehand. After the closing of jigs, the welding path was set as a straight line between the initial and terminal position points located by indicator light. Then, laser welded

Table 1
Experiment design.

Fe wire group		CB group	
	Independent variable		Independent variable
Input power/W; (1 mm/s; 0.4 or 0.6 MPa)	0.5, 2.2, 3.8, 5.5, 7.1, 8.8	Input power/W; (1 mm/s; 0.4 or 0.6 MPa)	0.5, 1.1, 2.7, 4.4, 6.0, 7.7
Clamping pressure/MPa; (5.5 W; 1 mm/s)	0.2, 0.3, 0.4, 0.5, 0.6, 0.7	Clamping pressure/MPa; (3.8 W; 1 mm/s)	0.2, 0.3, 0.4, 0.5, 0.6, 0.7
Cu wire group			
	Independent variable		
Input power/W (1 mm/s; 0.6 MPa)	18.5, 23.2, 27.8, 32.9, 37.6, 42.4		