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Laser transmission welding of Clearweld-coated polyethylene glycol terephthalate by incremental scanning technique

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ABSTRACT

Transmission laser welding using Incremental Scanning Technique(TWIST) mode and conventional contour welding mode were adopted to investigate laser transmission welding of 0.5 mm thick PET plate. A 1064 nm fiber laser was used to weld PET at the (TWIST) mode, and an 808 nm diode laser was applied to conduct the conventional contour welding. The Clearweld coating was used as laser absorbing material. The influences of laser parameters (i.e. defocusing distance, distance between two circles) on the quality of weld seams were analyzed by optical microscopy. Moreover, geometry and shear strength of the weld zone were tested to optimize laser parameters. Additionally, the water vapor permeability (WVP) of weld seams was measured to test hermetical capacity. Results show that the shear strength and hermetic capacity of weld seam by TWIST mode are at the same level in comparison with that of the conventional contour welding.

1. Introduction

Thermoplastic are found in a wide use in food and medical product packages, due to its various advantages [1]: they are able to be reheated, refrozen and remolded, which make molding and joint possible; they have good fatigue resistance, high fracture toughness, and cost and weight reduction [2]. Moreover, Polymer such as polyethylene (PE), acrylonitrile–butadiene–styrene (ABS), polyethylene glycol terephthalate (PET) and polymethyl methacrylate (PMMA) [3–6] have been used in medical industry successfully. Besides, PET has been applied in biomedical products packaging for its good chemical stability, and biocompatibility [5,7,8].

There are a number of techniques available for joining and sealing thermoplastic components, such as mechanical fastening, adhesive bonding, and welding. Not all of these are suitable for packages. Mechanical fastening are rarely used when hermetic vessel is needed. Adhesive bonding introduces third materials (the adhesive) during process, and then the safety and property of the adhesive need to be considered. However, welding could make a joint that possesses same strength of original material, and without application of the adhesive. As a novel joining method for thermoplastic, laser transmission welding offers distinctive advantages over conventional welding: one step process, instantaneous bonding, highly localized heating, no vibration, contact or particulates, low residual stresses [2,9]. Therefore, it could be applied in food and medical product packages.

Different kinds of laser were used in welding thermoplastic. CO_2 laser is commonly applied in welding plastic film for its poor penetration depth and good absorption in thermoplastic at 10.6 μm [10]. Conventional laser wavelength range for transmission laser welding is 400–1000 nm [10,11]. Because of high laser transmittance of thermoplastic in this range of wavelength, a light-to-heat conversion interface layer is needed for forming a fusion weld joint at interface. This kind of laser is suited for welding polymer part required a smooth, flat surface. Finally, a part of thermoplastics, i.e. low-and high-density polyethylene (PE-LD, PE-HD), polymethylmethacrylate (PMMA), polypropylene (PP), polyoxymethylene (POM) and glycol -modified polyethylene terephthalate (PETG), absorb laser beam at 2 μm wavelength, this kind of laser could be applied in butt-welding [12]. Conventional contour welding usually adopts diode laser with millimeter-level spot, and increases the defocusing distance to obtain wider joint [13]. Fiber laser is often applied in marking and drilling [14,15], on account of micro-sized laser beam and high energy density. Nevertheless, Andrei [16] welded microfluidic-biochips by Transmission Welding using an Incremental Scanning Technique

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(TWIST), which could change the width of weld seam by changing the size of the dynamic movement, i.e. (the diameter of the circular), reduce the depth of heat affect zone (HAZ), and the collapse of the channel walls. This technology has been successfully applied in microfluidic-biochips. The research presented here focused on TWIST, aiming to make it possible for daily packaging.

Laser processing parameters are of great importance for joint application, because they can control the temperature field inside the weld seam, and hence the weld quality. The independently controllable parameters of conventional contour welding are power, welding speed, stand-off-distance, and clamp pressure. Many experiments have been carried out to study the influence of these parameters on weld quality [17,18]. Liu [5] focused on achieving good bond strength and minimal bond width through transmission laser micro-joining of Ti coated glass and PET, and found that laser power had a stronger effect on bond strength more than speed. According to Acherjee [17], clamping pressure had slight positive effect on weld strength. Tamrin, K.F [19] used Grey rational analysis to optimize process parameters in CO_2 laser welding, and found that the welding speed had dominate effect compared to defocusing distance. However, the influences of parameters in TWIST mode (i.e. scanning speed, distance between two consecutive circles (DCC), and the diameter of circles, laser power, defocusing distance, and clamping pressure) on the quality of weld seam have not been reported yet.

Under these circumstances the present paper aims to investigate the effect of process parameters of TWIST mode (i.e. defocusing distance, DCC, welding speed) on the quality of weld seams. Furthermore, the shear strength and WVP properties were tested to optimize laser parameters by TWIST mode.

2. Material and experimental procedure

2.1. Materials

The amorphous unfilled PET plates(Lanjingdetai, Guangdong, China) with the dimension of $40 \times 26 \times 0.5\ mm^3$ were used for transmission laser welding because it has been widely used in food and drug package industry and presents relatively translucent to visible light, as shown in Fig. 1 (LabRAM HR800, Horiba JobinYvon).

The infrared absorbing medium, Clearweld (140F, Gentex Corporation), was applied to the top surface of lower plate. The infrared absorbing property of the Clearweld-coated PET sample is shown in Fig. 1.

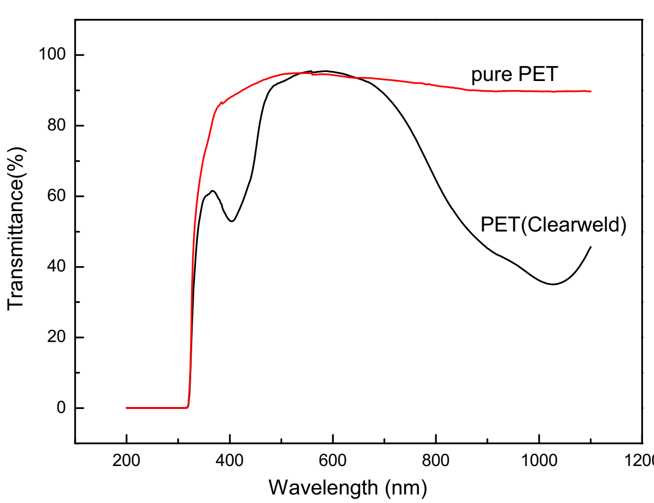

Fig. 1. UV–vis-NIR transmittance spectra of pure PET film and Clearweld-coated PET film with the thickness of 0.5 mm.

Table 1
Specifications of lasers used in the experiment.

Wavelength (nm)	Focal spot diameter (mm)	Maximum power (W)	Focal length (mm)
808	About 0.05	65	120
1064	About 0.03	20	160

2.2. Experimental procedures

In the present work, bolted connection was used to provide necessary pressure to form intimate contact at the interface, and torque wrench (OUTIAN ACD 0-3Nm) was applied in the conversion between torque and pressure, which means that the indicated torque was converted to effective pressure. To compare the quality of the welded seam at TWIST mode and conventional contour welding mode, a 1064 nm SPI 20 W/HS laser for marking and an 808 nm Raycus 60 W diode laser for welding were adopted for TWIST and conventional contour welding, respectively [16,20]. The specifications of two lasers used in this experiment are given in Table 1.

At TWIST mode, circle was chosen as the high dynamic movement to achieve weld line (Fig. 2). For all welded samples, the diameter of circle (D) was set as 1mm, while other laser parameters (d – defocusing distance, a – DCC, and v_s – scanning speed) were varied and positive defocusing distance was adopted (positive defocusing distance means that sample surface is below the laser focus point). In addition, the welding speed (v_w) of TWIST mode can be expressed by Eq. (1).

$$v_w = \frac{a(\mathrm{mm})}{t(\mathrm{s})} = \frac{a(\mathrm{mm})v_s(\mathrm{mm/s})}{\pi D(\mathrm{mm})} = a(\mathrm{mm})f\left(\mathrm{s}^{-1}\right) \tag{1}$$

where f is the frequency of the circular movement, the number of circles per second.

The specific energy [21] mentioned at this paper was calculated as energy power divided by welding speed and weld seam width. While at conventional contour welding, a defocusing distance of +2 mm was used to ensure homogeneous weld seam, as well as a wide enough weld seam so the good hermetic encapsulation could be reached. The welding speed was varied to achieve well weld seam.

The melted zone and the HAZ were observed and analyzed by an optical microscope (Dino-Lite Pro,Taiwan). h_1 and h_2 represent the depth of HAZ of upper plate and underneath plate respectively.

The weld strength of weld seam was evaluated by tensile shear-strength test. Dimensions of the lap-joint were shown in Fig. 3a. During shear strength test process, some adjustment was made

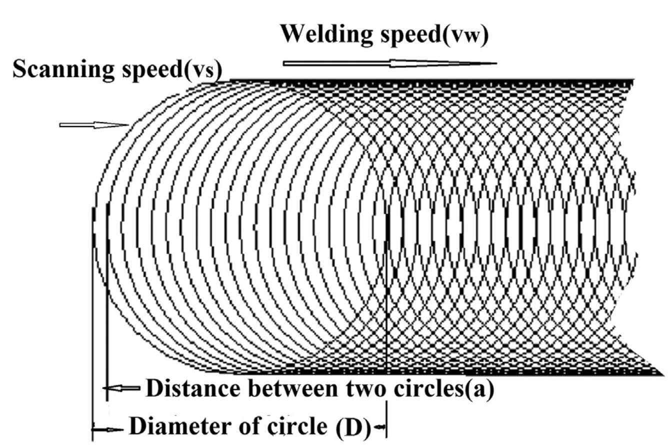

Fig. 2. Contour of TWIST welding mode.