On the Microstructure and Tensile Strength of PC/ABS Polymer Blend Joints

Fuh-Sheng Shieu* and Bo-Hua Wang

Institute of Materials Engineering, National Chung Hsing University, Taichung 40227

Abstract: Large articles of polymeric materials which can not be molded require welding to join the components. Weld zones result in a morphology that differs from the adjacent areas. This difference in structure represents a defect in the article that can result in premature failure during service. Experiments with a Pulse™ 830 (a polycarbonate/acrylonitrile-butadiene-styrene blend) engineering resin showed that weld zones made using hot plate techniques, retained only 30% of the unwelded tensile strength, while 80% was retained if vibration welding was applied. Examination of the weld zone by transmission electron microscopy (TEM) revealed a dramatic difference in the microstructure. The weld zone morphology in Pulse™ 830 engineering resin by hot plate welding is highly laminar and oriented while a much more homogeneous structure, similar to that in the bulk, is produced by vibration welding. This morphology difference accounts for the variation of the tensile strength of the joints.

Keywords: Tensile strength, TEM, Ultramicrotomy, Hot plate welding, Vibration welding.

Introduction

Polymers are widely used for both structural and non-structural applications including aerospace, automotive, electrical and electronic, building and domestic industries. Advantages are taken out of their low processing cost, light weight, insulation properties and chemical resistance. Large articles of polymeric materials which can not be molded require joining. There are a variety of methods available for joining of polymers [1-2], including mechanical fasteners, adhesive and welding. The welding of polymers gains its popularity because it involves mainly the melting or softening of the materials by the application of heat. It is, however, confined to thermoplastics. The common welding techniques for thermoplastics include ultrasonic, friction, vibration, implant, hot gas and hot plate welding. In contrast to pure polymers, our understanding of the structure/property relationships of welding in polymer blends is still rather limited.

Research on polymer blends has drawn great attention in both academic world and industry, reflected from the number of papers on this topic in recent conference proceeding. By combining two or more commercially available polymers through blending offers an inexpensive route to produce differentiation. Polymer blends often show synergistic effects in their properties, compared to their individual constituent. In this paper we examine the microstructure of a commercial polymer blend, polycarbonate/acrylonitrile-butadiene-styrene (PC/ABS), by transmission electron microscopy (TEM) and relate the morphology of the PC/ABS blend in the weld zones to the measured tensile strength of the welded joints. The joints were prepared by two different welding techniques, i.e., hot plate and vibration welding. The main difference between these two processes is the heating source used to melt polymers for joining, in which the hot plate welding needs external heating whereas vibration welding uses frictional heating. It is shown that the different heating sources have resulted in a difference in the joint strength and the microstructure of the weld zones.

Experimental

The material used for welding is a commercially available polymer blend, Pulse™ 830 engineering resin (PC/ABS). The joining components were produced by injection molding with single-gating into a rectangular bar of dimension $100 \times 10 \times 2$ mm. Hot plate welding is carried out by a homemade hot plate welder suitable for welding compo-

* To whom all correspondence should be addressed

nents up to 50 × 50 mm in cross section. The temperature of the heating plate is 250 °C and the welding pressure is controlled pneumatically. The duration of the components against the heating plate is 20 sec. The displacement during the forging process is about 2 mm. Vibration welding using an electromagnetic vibratory machine involves the relative movement of two components under a pressure of 1.0 MPa. The vibration amplitude and frequency are 1 mm and 120 Hz, respectively. The welding time is 20 sec and the penetration is about 1 mm. A schematic drawing of the welding process is shown in Figure 1.

As a result of the pressure applied during welding, flash, also called welding bead, is produced in the weld zone. The joints after removing the welding bead were tested for their tensile strength using a MTS-810 tensile test machine. The microstructure of the weld zones was studied by a JEOL 1200EX transmission electron microscope operated at 120 kV. Samples cut from the weld zones were trimmed and polished into a trapezoid shape suitable for ultramicrotomy. Thin sections of about 80 nm thickness were produced by a Reichert Ultracut E ultramicrotome. They were then stained with aqueous OsO_4 overnight. To reveal the domain structure of the PC and SAN (styrene-acrylonitrile) in the ABS of the hot plate welding joints, the thin sections were further stained with RuO_4 vapor for 3 minutes. The region of the weld zones examined extends for about 0.5 mm from the center of the joint, i.e., the weld line. A detailed description of the sample preparation for TEM can be referred to Sawyer and Grubb [3].

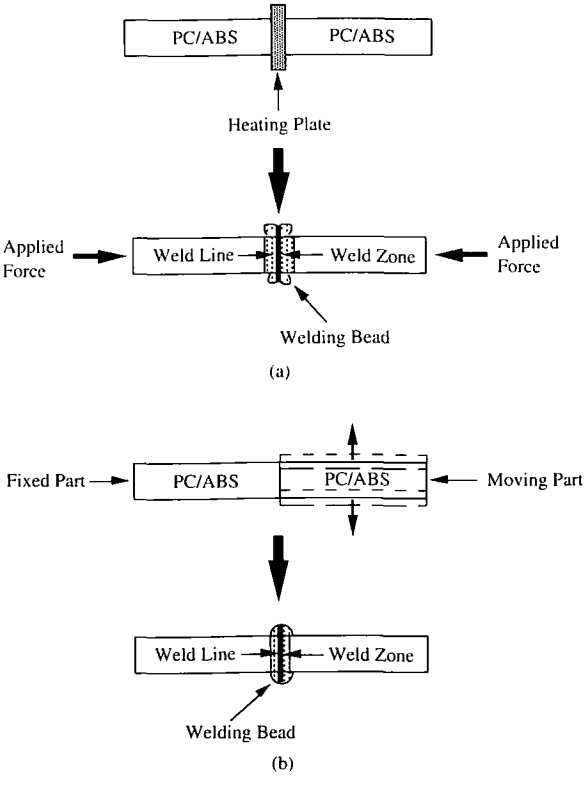


Figure 1. A schematic drawing of the two welding techniques: (a) hot plate welding and (b) vibration welding. The hot plate welding needs external heating plate to soften polymers for joining, whereas vibration welding uses frictional heating. The drawing is not to scale.

Results and Discussion

Since the tensile strength of the welded joints is of the most concerned mechanical properties in practice, tensile testing is frequently used to evaluate the weldability of thermoplastics [4]. After removing the welding bead, the joints with weld line in the center of the tensile bar having dimension 150 × 10 × 2 mm, were tested under uniaxial loading at strain rate of 50 mm/min. The tensile strength of the joints was measured to be 13.5 and 36 MPa for the hot plate and vibration welding respectively, compared to 45 MPa for the unwelded components. It is observed that failure of the joints is always occurred in the weld zones. This can be explained from a discussion of the microstructure in the weld zones examined by TEM in the following section.

A typical microstructure of the Pulse™ 830 engineering resin is shown in Figure 2. This resin is composed of an elongated ABS domains, where the styrene-butadiene rubbers (SBR) are evenly distributed in the SAN matrix, dispersed in a continuous PC phase. The flow pattern of the resin during injection molding can be seen from the micrograph in

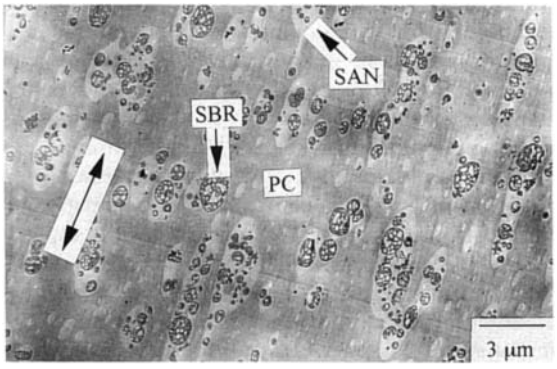


Figure 2. Transmission electron micrograph of a PC/ABS polymer blend produced by injection molding. The double-side arrow indicates the flow direction of the polymer during molding.

Figure 2. The morphology of the rubber particles and the distribution of the PC and ABS phases will depend on the manufacturing process and their relative concentration [5].

Figures 3 is the TEM micrographs of the microstructures in the weld zones for vibration welding and hot plate welding, respectively. As shown in Figure 3(b) for the hot plate welding, the microstructure of the joints in the weld zone changes very sharply. It is observed that the morphology of the rubber particles at the weld line is very different from its neighborhood. A highly laminar and oriented structure is present at the weld line. The shape of the rubber particles changes from an elongated ellipsoid at the weld line to a distorted polygon, and then gradually restore to their regular sphere. It is observed that the morphology of the rubber particles at distance about 0.5 mm from the weld line only shows a little different from those in the bulk.

In contrast, the morphology of the rubber particles in the weld zone of the vibration welded joints is quite homogeneous, Figure 3(a). It is very difficult to locate the weld line because the microstructure of the weld zone is very similar everywhere. In addition to the rubber morphology, the degree of mixing between the PC and the SAN phases in the ABS is also different for the two welding techniques. The boundary of the PC and the SAN phases in the ABS can be easily distinguished for the hot plate welding from Figure 3(b). While in the vibration welding, the mixing of the two phases excluding the rubber particles looks much more thorough and homogeneous.

There are several key parameters that can influence the microstructure and hence the mechanical properties of the welded joints [2], e.g., the heating plate or melt temperature, heating time and pressure in the hot plate welding, and welding time, pressure, vibration amplitude and frequency in the vibration welding. The effect of each parameter depends on the types of materials. Although the heating or welding time can change the temperature profile in the weld zone, it is reported [6] that in pure polymers melt temperature has little effect on the welding strength of ductile amorphous thermoplastics such as PC or ABS where yielding can readily occurred. For unyielding amorphous thermoplastics such as PS or SAN, it was found low melt temperature can reduce the welding strength dramatically.

Applied pressure during welding is related to weld defects such as voids and the morphology of the weld zone [6]. Since no void was observed in the TEM micrographs shown in Figure 3, it seems reasonable to speculate that the microstructure of the weld zones could solely account for the difference in the tensile strength of the joints. The laminar structure in the weld line of the hot plate welding may be regarded as a multilayer of PC and SAN in which dispersed with discontinuous rubber phase. Since the morphology of the rubber particles in the weld zones has changed from sphere with inclusions to highly elongated ellipsoid, the curvature of the rubber particles increases sharply. If we ignore the shear yielding of the continuous PC phase and assume that fracture behavior of the blend is controlled by the ABS phase. It is then the rubber particles in the glassy SAN phase which initiate crazing, and determinate the tensile strength and toughness of the materials. If the rubber is regarded as a crack of length 2c and the curvature at its tip of k the maximum stress at the tip of the crack σ_{max} is given by [7]

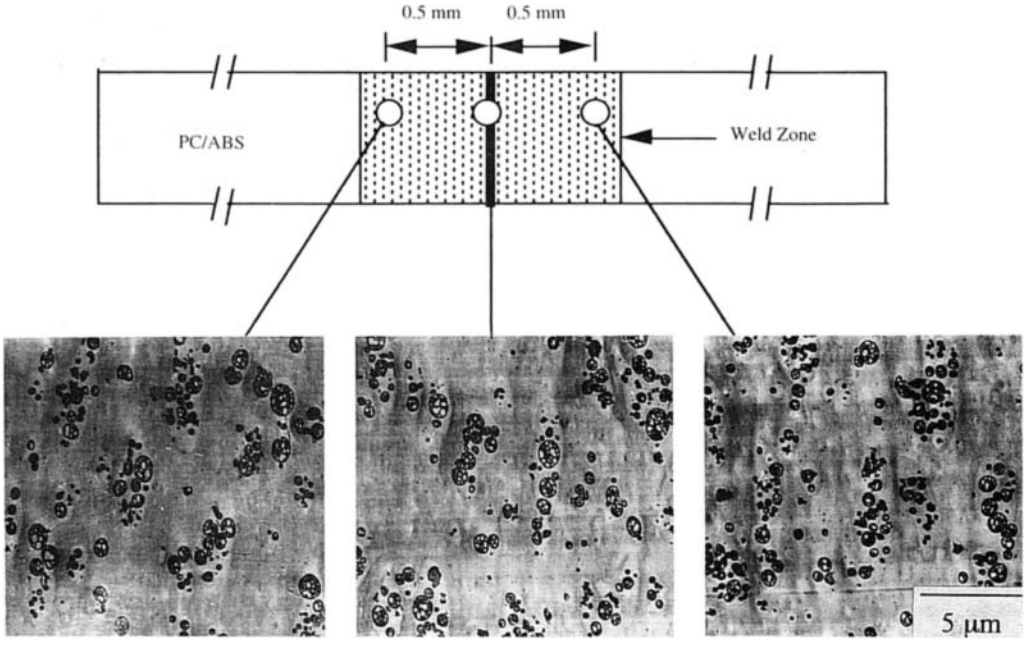
$$\sigma_{max} = \sigma [1 + 2(ck)^{0.5}] \sim 2\sigma(ck)^{0.5}$$

where σ is the nominal stress. Providing the curvature of the elongated bubber in the weld line of the hot plate welding (Figure 3(b)) is three times that in the bulk (Figure 2), the stress concentration factor (σ_{max}/σ) at the tip of the rubber would have tripled its value. In other words, crazes would be initiated at one thirds of the nominal applied stress. Therefore, craze-induced crack would propagate much easier, resulted in a premature failure of the joint. Although this argument oversimplifies the state of stress in the weld zone, the measured tensile strength of the hot plate welded joints which retained only 30% of the unwelded components, agrees with prediction quite well. It is, however, noted that the chemistry, besides morphology, of the weld zones is also important and needs further study for a fully understanding of the structure/property relationship of the polymer blend joints.

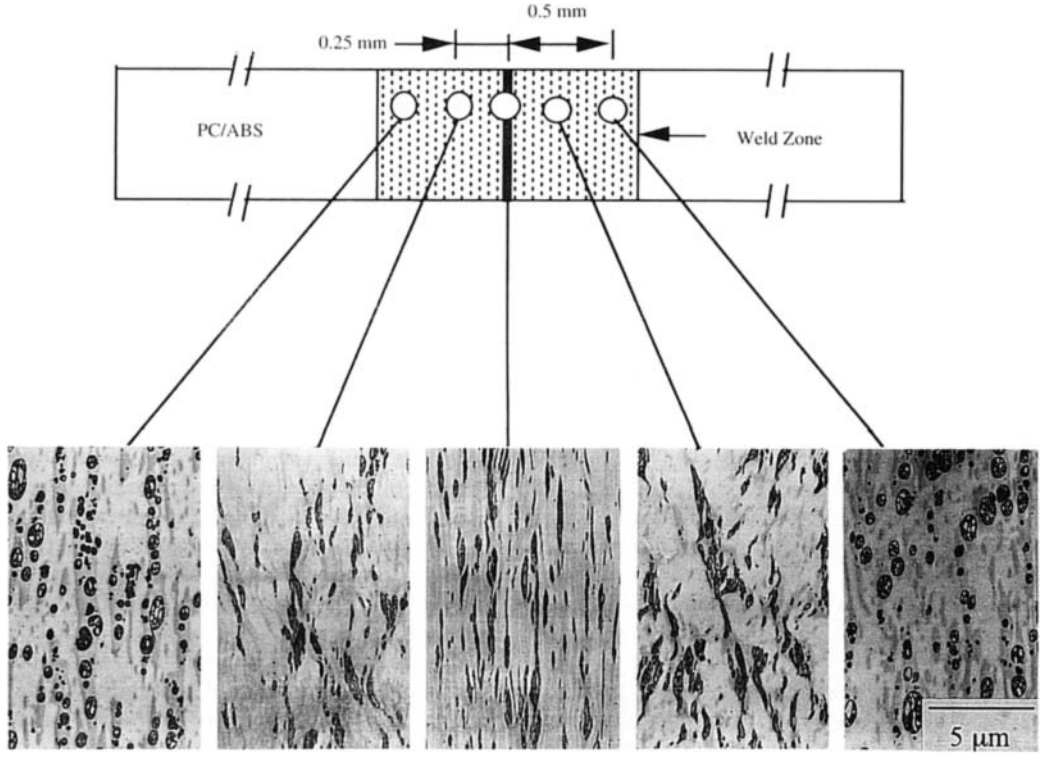
Conclusions

The joining of polymeric materials by welding usually involves mixing and interdiffusion of polymer chains without complex chemical reactions near the interface. The mechanical properties of the welded components is closely related to the morphology or the microstructure of the weld zones. Vibration welding producing a homogeneous microstructure in the weld zone resulted in a much stronger joint than that of hot plate welding where a sharp transition of microstructure in the weld zone is occurred.

References



(a)



(b)

Figure 3. Microstructure of the weld zones in (a) vibration welding and (b) hot plate welding joints. The SBR rubber remains spherical in (a), while it is highly distorted and elongated in (b). Unlike those in the vibration welding, the PC and SAN phases can be distinguished readily in the weld line of hot plate welding, which form a multilayer structure.

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