IR Welding of Glass Filled Polyether Sulfone Composite

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Abstract
A prototype infrared welding (IR welding) system was designed and constructed. Evaluation of IR welding process was performed including effects of process parameters on joint strength and microstructural analysis. IR welding can be divided into three phases, which are heating of the joint surfaces, change-over, and joining and cooling under pressure. This study is to present an analysis of the effects of three welding parameters on the joining properties and to develop a better understanding of physical processes involved. Complete studies have been performed on the effect of IR welding parameters, which also performing a morphological evaluation of welds in glass reinforced polyether sulfone PES composites.

Key Words: Change-over, Forging pressure, Glass-filled reinforced

1. Introduction
Infrared welding is a relatively new method for joining plastics and composites. It is a non-contact heating method that relies on infrared (IR) radiation to heat and melt the surfaces. Generally speaking, welding processes can be divided into non-contact and contact methods. Non-contact welding methods, such as hot gas, extrusion, infrared (IR) and laser welding, are of considerable importance for future industrial applications. The main advantages of these welding methods are their ability to make rapid heating and capacity to minimize contamination risk. From the standpoint of productivity and weld joint quality, these welding processes not only provide continuous, rather than step-wise operation, but also generate higher joint strengths. Nonetheless, contact welding of plastics, especially hot plate welding, can also generate high quality joints. However, the main disadvantages of hot plate welding are relatively long processing times and sticking to the hot tool. These are precisely the reasons for the emergence of IR welding. It is intended to combine the advantages of both contact and non-contact welding methods. Since IR welding is a non-contact process, no sticking of the part to the heat source occurs. Another important difference between the two welding processes, IR and hot plate, is cycle time. For IR welding the total cycle time can be much shorter than for hot plate welding. Therefore this study is aimed at developing a better understanding of the IR welding process including welding parameters and microstructure of the welds.

IR welding can be divided into three phases, which are schematically as shown in Figure 1: (1) IR heating of the joint surfaces, (2) change-over, and (3) joining and cooling under pressure. The heating process is carried out by placing the IR heating lamps in front of the areas to be heated until a melt layer of a desired thickness is formed. Being a non-contact heating method, no pressure is applied.

During the change-over phase, the IR heating lamps are removed from the welded zones and the parts are pressed together. Like in hot tool welding, the elapsed time from retraction of the lamps to contact of the parts is referred to as the change-over time. In IR welding it is also beneficial to keep the elapsed time as short as possible to reduce convection and conduction cooling of the surfaces thereby minimizing the cycle time.

Finally, once the parts are in contact a preset joining pressure is applied to the parts. Under the applied pressure intimate contact between the surfaces is achieved and molecular diffusion across the interface gives the joint its strength. Once the
material resolidifies, the parts can be removed from the welder.

![Diagram of IR welding process]

IR welding process has been employed to explore a new field for low and high temperature thermoplastics such as PP, and natural and black color PBT [1,2]. Large area joining provides one special opportunity for IR welding in the future. Along with these considerations, industry may require knowledge of IR welding of polymeric matrix composites. Thus, there is a need for an established IR welding method, which addresses the joining capabilities of composite materials. Composite materials are now a major field of research and development activity, and they are rapidly becoming important as structural materials. Therefore, the objective of this study is to present an analysis of the effects of IR welding parameters on the joining properties and to develop a better understanding of the physical processes involved. At present, no comparable data exits which covers all the welding parameters, including heating time, change-over time, and forging pressure. Several publications [3,4] dealing with the IR welding process involve the comparison of three welding methods, hot plate, vibration and IR welding processes, for joining 30% glass fiber reinforced polyether sulfone (PES). In these comparative investigations, the IR welding method generated better joining results than either hot plate or vibration welding of 30% glass filled PES composite. Throughout these studies the effect of the IR welding parameters on joint strength was not performed. Therefore a complete study could be performed on the effect of IR welding parameters, while also performing a morphological evaluation of welds in glass reinforced PES composites.

Polyether Sulphone (PES) is a high performance amorphous thermoplastic with very high resistance to heat. It is utilized for high-quality engineering parts exposed to high temperatures in applications where the thermal properties of other engineering plastics, e.g. nylon, and polycarbonate, would no longer suffice. Glass-filled grades of PES are used for precise, electrical, and medical applications. It is also suited for aircraft components and pumps that operate in hot water.

2. Welding Procedures

Polyether Sulphone composites with 20% by weight glass fibers JF-1004, manufactured by LNP Engineering Plastics, were prepared as coupons with dimensions of 10 cm x 1.9 cm x 0.0625 cm. The samples were thoroughly dried prior to welding by placing them in an oven for a minimum of 6 hours at 200 °C. During welding the heating distance was kept at 0.12 cm. The sample length was cut precisely to insure a constant heating distance for all samples. The heating time was varied from 11 seconds to 16 seconds and the change-over time from 0.8 seconds to 2 seconds. The power level was maintained at 100%. During welding the specimen was fixed using a finger clamp. During heating, the IR modules were moved in position and radiated the surface of the PES samples. After heating, the IR modules were retracted and the specimens were brought into contact. The pressure with which the PES specimen was joined together was controlled using a pressure regulator connected to the pneumatic cylinder. The forging pressure was varied from 0.56 MPa to 1 Mpa after cooling the samples for 30 seconds, the welded sample was removed from the IR welder. Four samples were welded for each set of parameters.

3. Design and Construction of the IR Welding System

![Diagram of IR welding system]

An infrared welding system was designed and built. In this new infrared welding system, two 15 cm length of the T3 quartz tungsten filament infrared lamps with reflectors are used as further development of heated-tool butt welding. The entire IR welding system includes high intensity IR
modules with power controller, two independent air cylinder systems, timer control system, cooling device, foundation, and fixture.

The high intensity IR heater features two modules in parallel with two reflectors including two IK-0011 quartz halogen tubular infrared lamps. The IK-0011 infrared lamp offers the high power rating (1200 watts, 115-144 volts).

The high intensity IR heater is fixed and mounted on the air cylinder. This IR heater, 15 cm x 10 cm x 3.75 cm, can be adjusted in the horizontal and vertical rotation and plane movement. In this case, it is suitable for three dimensional arrangement for both samples and the IR modules. Therefore, any situation of the samples, for instance, unequal length of the samples, can be welded successfully with excellent joining quality.

The Lux-Therm Model LX25, supplied by ERASER Co., is available in 115V, 50/60Hz and uses a phase angle fired triac power control to allow variation of voltage to the lamps being used. The triac can reduces power using to prevent conspicuous lamp flicker, and obviously increases lamp life. Having a maximum resistive load of the 25 amps, the variable power controller is particular in its capability. This power controller connects these IR modules and a digital timer as shown in Figure 2

![Diagram of IR welding system control flow chart](image)

Figure 2. IR welding system control flow chart

Two independent air cylinders are required to control two different movements. One is designed for extending and retracting the IR modules moving and the other is used for pushing the parts together. In addition, two solenoid valves with electronic switches are used for controlling the two air cylinders. These solenoid valves also connect to the timer in desired amount of time. The gage pressure on each air cylinder changes from 0.083 to 1 Mpa.

The timer, with LCD, can be set from 0.1 second to 999 hours. When the timer is activated by pressing the start timer button, the lamps instantaneously receive full voltage. At the end of the timing succession, the voltage to the lamps is turned off. This timer controls the heating time and change-over time.

Two snap action switches, in series, are used for the change-over time control, when the air cylinder retracts switches on. These snap action switches in series are used to control one single solenoid valve that turn the air cylinder on simultaneously. In addition, two snap action switches, in series, accomplish another function. Two snap action switches in series can prevent possible dangerous motions during the heating stage. Therefore, putting the switches in series the two parts will not be accidentally pressed together during the heating stage, that no damage occurs to the lamp.

A fan is utilized as a cooling tool. Cooling must be provided to each module to maintain the lamp end seals under their rated temperature of 650°F (343°C). Therefore, the cooling air is blown to the lamp and reflector to cool them as quickly as possible.

The distance from one surface of the part to the other should be short enough. In this foundation, one end is fixed on a rigid fixture and the other is moveable by approximately 10 cm. Two unlike fixture is applied to confine the parts at an appropriate position. They also provide strong support and proper alignment. The entire foundation in dimension is 77 cm x 50 cm x 40 cm.

4. Mechanical Testing

Welded and bulk material samples were tested in tension following ASTM D-638. All samples were machined to the dogbone shape, as determined by the thickness of the samples. This dogbone shape was machined by a router and the surface was polished with fine emery paper #240. The dogbone shape used in the test yields a 5 cm gage length with a cross-sectional gage area of about 1.25 cm by 0.625 cm. For the welded samples the weld bead on the top and bottom of the sample were not removed and the weld was placed in the center of the gage area.

An Instron tensile test machine model #4468 with 44500 newtons load cell was used to determine the tensile strength of the samples at room temperature. A constant crosshead speed of 0.5 cm/min and load range of 13350 newtons was employed. The average tensile strength and standard deviation of the tested specimens were calculated.
5. Microscopic Evaluation

Microscopic analysis was performed using an optical reflected microscope. It was used to characterize glass fiber orientation at the welded area. The observation area in either transverse or longitudinal direction as shown in Figures 3 and 4 was sectioned, ground, and polished for micrographic examination.

Figure 3. A 20% glass-filled reinforced PES weld in longitudinal section

Figure 4. A 20% glass-filled reinforced PES weld in transverse section

6. Results and Discussion

Tensile Testing

Figure 5 shows the effect of heating time on joint strength for 20% glass-filled reinforced PES. The joint conditions were a heating distance of 0.12 cm, and a change-over time of 1 second, a forging pressure of 0.744 MPa. It can be seen in Figure 5 that increasing the heating time increased the weld strength until an optimum was reached. For 20% glass-filled reinforced PES joint strengths of 84% of bulk strength were achieved for a very short heating time of 15 seconds. Heating beyond the optimum resulted in a slight decrease in strength for 20% glass-filled reinforced PES.

Figure 6 shows that for change-over times of 1 and 0.8 seconds weld strengths exceeding 84% of the bulk strength were achieved for a heating distance of 0.12 cm, a heating time of 15 seconds, and forging pressure of 0.744 MPa. Therefore the optimum change-over time for obtaining a high joining quality is 1 second or less. Due to convection and conduction cooling of the molten polymer, increasing the change-over time beyond 1 second results in a decrease in joint strength. As was expected, increasing the pressure improves the joint strength until an optimum is reached. Figure 7 shows the effect of forging pressure on 20% glass-filled reinforced PES. These welds were prepared using a heating time of 15 seconds at a heating distance 0.12 cm and with a change-over time 0.8 second. In this case the optimum was achieved at a forging pressure of 0.744 MPa producing a weld strength of 75.79 MPa which is 84% of the bulk strength. Further increases in pressure beyond the maximum result in reduction of the molten layer thickness and adverse molecular and fiber orientation, thereby decreasing the joint strength.

Figure 5. Effect of heating time on joint strength for PES
Figure 6. Effect of change-over time on joint strength for PES

Figure 7. Effect of forging pressure on joint strength for PES

7. Microstructural Testing

As shown in Figure 8, microstructural examination of the weld in the A-A section shows fiber orientation obtained for welds whose strength is 84% of the bulk strength. The optimum joining parameters employed were a heating time of 15 seconds, a heating distance of 0.12 cm, a change-over time 0.8 second, and forging pressure 0.744 MPa. Since glass fibers align themselves in the flow direction, then orient in thickness direction (the direction of maximum flow). Fiber orientation of 20% glass-filled reinforced PES were compared for the A-A and B-B sections in order to further understand the effect of IR welding on joint strength. Figure 9 shows the microstructural examination of the weld in the B-B section. As can be seen, few fibers orient in the B-B section as compared to the A-A section. Due to more flow in the thickness direction the glass fibers align themselves in this direction and thus are much more visible when a A-A section is performed. Due to glass fiber orientation in the thickness direction the strength properties of reinforced PES are lower in this direction, therefore welds should not be loaded at full capacity in the A-A direction. If the samples were not completely dried prior to welding, defects generate during heating and reduce joining strength. As shown in Figure 10, microstructural examination of the weld in the A-A section shows some moisture entraps inside the welds.

Figure 8. Polarized optical micrography of 20% glass-filled reinforced PES weld in A-A section under the condition; heating time 15 sec., change-over time 1 second, and forging pressure 0.744 Mpa (x100)

Figure 9. Polarized optical micrography of 20% glass-filled reinforced PES weld in B-B section under the condition; heating time 15 sec., change-over time 1 second, and forging pressure 0.744 Mpa (x50)

8. Conclusion and Recommendation
Based on this study the joint strength of 20% glass-filled reinforced PES is 84% of bulk strength. The microstructural examination of the weld indicates that the fiber orientation affects the joint strength of PES composite materials. The fiber orientation at the weld tends to be greater in the thickness direction as compared to the other directions thereby reducing the weld strength as compared with the bulk strength of the composite.

**Reference**


Figure 10. Polarized optical micrography of 20% glass-filled reinforced PES weld