Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 33 (2015) 562 – 567

www.elsevier.com/locate/procedia

9th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '14

Optimization of friction stir welding of thermoplastics

A. Paoletti, F. Lambiase*, A. Di Ilio

Dept. of Industrial and Information Engineering and Economics, University of L'Aquila, Via Campo Di Pile, 67100 AQ, Italy

* Corresponding author. Tel.: +39 0862 434343; fax: +39 0862 434303. *E-mail address:* francesco.lambiase@univaq.it

Abstract

Friction stir spot welding (FSSW) of thermoplastic materials has been recently developed. Early investigations have proved that such joining technology allows achieving high quality joints over conventional welding processes. In this paper, Friction spot stir welding is applied to Polycarbonate sheets of 3 mm thickness. A prototypal setup is developed to monitor the evolution of main forces and tool temperature during the joining phases. The influence of the main process parameters on the joints strength has been assessed by mean of single lap shear test on single joint. The joints quality has been also assessed by means of optical microscopy analysis. Finally an Artificial Neural Network has been developed in order to predict the mechanical behavior of the welded joints.

*Keywords:*Joining, Polymers, Modelling, Polymer, Friction Stir Welding

1. Introduction

Thermoplastic materials are widely employed in different industrial and engineering applications in order to reduce product weight, thermal conductivity and to enhance toughness and stress-to-weight ratio. Joining methods for similar and dissimilar polymer structures are used in the automotive industry [1, 2]. Polymer welding methods are typically divided into three categories: techniques based on heat conduction, processes based on heat radiation and friction welding methods.

In the Friction Stir Welding (FSW) process, a non-consumable, rotating tool with a specific geometry is plunged into and traversed through the material. The two key components of the tool are the shoulder and the pin (probe). During welding, the pin travels in the material, while the shoulder rubs along the surface. Heat is generated by the tool shoulder rubbing on the surface and by the pin mixing the material below the shoulder. This mixing action permits the material to be transferred across the joint line, allowing a weld to be made without any melting of the material. Other than the linear process described above, another major variation of the process is Friction Stir Spot Welding (FSSW). The FSSW process involves only the plunge and retraction of the FSW tool, thus eliminating the traverse part of the process. The FSSW process mimics the Resistance Spot Welding (RSW) process and can be used in place of RSW, riveting, clinching or any other single point joining processes in many applications. It was claimed that for spot FSW the use of energy significantly decreased and the investment cost was about 40% lower due to its minimal equipment requirement. In addition, spot FSW is an environmentally friendly spot welding method due to the absence of fumes or sparks [3].

Friction stir spot welding was initially developed in the automotive industry to replace resistance spot welding for aluminum sheets [4-6]. Being a solid-state process, diffusion plays a central role during joining and metals are particularly suitable for this technique. Moreover, the high thermal conductivity of metals enhances material softening near the pin. For this reason, the process has been successfully applied to aluminum, magnesium and steel sheets, but there are very few publications on polymer friction stir spot welding applications [7, 8]. Recently, some researchers have studied the application of FSSW to thermoplastics but obtaining good joints is a very hard task. In fact, thermoplastic materials are poor thermal conductors and diffusion is not an efficient mechanism because of their macromolecular structure.

doi:10.1016/j.procir.2015.06.078

The effect of tool geometry on plastic flow and mixing of materials during friction stir spot welding is investigated numerically using the particle method [9]. Tool geometry has a significant influence on the material mixing and hence eventually influences the static strength of resultant spot welds. Moreover, tool material properties such as strength, fracture toughness, hardness, thermal conductivity and thermal expansion coefficient affect the weld quality, tool wear and performance [10, 11].

In the field of plastic materials, FSSW has been successfully applied to high density polyethylene (HDPE), polypropylene (PP), polymethylmethacrylate (PMMA) and acrilonitrile butadiene styrene (ABS) sheets [12-14]. In a wide range of lighting applications including automotive lighting, there is a need to join PMMA to ABS to reduce costs and increase performance of lamps. Although PMMA and ABS are dissimilar materials, they are compatible with each other and are frequently blended or welded together [15]. Welding of PMMA to ABS by friction stir spot welding is feasible and process parameters have a significant effect on weld strength. The lap-shear strength of welded PMMA/ABS specimens was investigated as the mechanical property of the joints. Results indicate that variable parameters of process including tool rotational speed, tool plunge rate and dwell time, have dramatical influence on the weld strength [16]. The effects of tool penetration depth and dwell time on joint strength of polypropylene using a conventional tool was also investigated; increasing the dwell time causes a significant improvement on tensile shear strength, however there is an optimal point for tool penetration [17]. An improved tool in which the pin and shoulder could rotate independently of each other was used for of FSSW of PMMA plates. The results showed that the weld strength is comparable to other available welding techniques, while the joining times are equal or shorter [18].

This paper introduced a preliminary work aimed at optimizing the operative conditions in friction spot stir welding process of thermoplastic materials. To this end, a prototypal setup has been developed to monitor the evolution of plunging force, torque and tool temperature during the joining phases of Polycarbonate (PC) friction spot stir welding. A campaign of experimental tests involving the variation of the main process parameters was conducted and the collected data were used to develop an Artificial Neural Network, which is aimed at predicting the maximum plunging force, maximum torque and temperature as well as the shear strength of friction spot stir welded connections.

2. Experimental setup

The experimental set up consists of a drilling press equipped with a servo-system, an asynchronous motor driven by an inverter, a piezoelectric dynamometer, and an infrared pyrometer, as shown in Figure 1.

The servo-system has allowed to regulate the axial tool plunge rate, while the inverter has been used to adjust the revolution speed of the spindle motor. Both systems have been controlled by a computer. Plunging force and torque signals have been detected by means of a piezo-electric dynamometer, filtered by low-pass filters and acquired by data acquisition card.

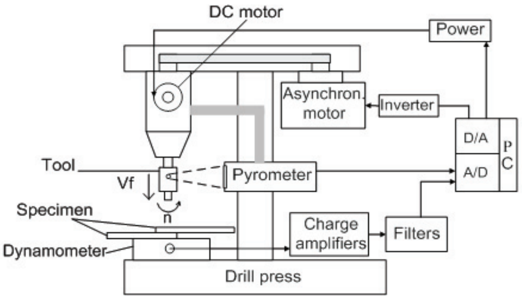

Fig. 1. Experimental apparatus.

Contactless temperature measurements have been carried out employing a radiation sensor type 1060-2 in connection with Thermophil INFRA type 4472 thermometer. The sensor detects the IR radiation heat emitted by the tool and converts it into an electrical signal which is amplified, processed and then acquired by the computer. Type T1060-2 sensor acquires the radiation on a measuring field of 3 mm diameter from a distance of 100 mm, which can be adjusted by means of a focusing device. Temperature measurements has been taken at a fixed distance from the tool-workpiece interface.

3. Experimental procedure

Polycarbonate sheets having 3 mm thickness, 20 mm width and 90 mm length have been cut from commercial plates. Polycarbonate is an amorphous thermoplastic polymer having a tensile strength of about 58÷62 MPa, a glass transition temperature of about 147° C and a melting temperature of about 155 °C.

The specimens have been overlapped by 30 mm in length. Figure 2 shows the polycarbonate specimens in lap position.

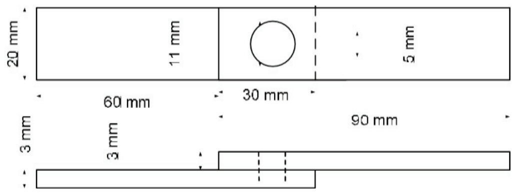

Fig. 2. Typical configuration of the lap-shear test specimen.

A view of the tool, which is used in this investigation, is shown in Figure 3.