Materials and Design 43 (2013) 402–409

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

An experimental study on mechanical properties of friction stir welded ABS sheets

Arvin Bagheri, Taher Azdast *, Ali Doniavi

Mechanical Engineering Department, Faculty of Engineering, Urmia University, Urmia, Iran

ARTICLE INFO

Article history:
Received 1 May 2012
Accepted 29 June 2012
Available online 20 July 2012

Keywords:
Friction stir welding
Mechanical properties
Acrylonitrile butadiene styrene
Design of experiment

ABSTRACT

By the increasing development in applications of engineering plastics, demand for rapid and reliable welding methods has been increased. One of these joining methods of engineering thermoplastics is friction stir welding (FSW) which is based on frictional heat generated through contact between a rotating tool and the workpiece. In this paper, acrylonitrile butadiene styrene (ABS) sheets were joined using a fixed heated shoe called "hot shoe" while a rotating pin through this shoe stirs melted material. Rotational speed of the pin, traveling speed and shoe temperature at the beginning of the welding procedure were considered as varying parameters. In order to study their effects on the mechanical properties of welded parts, a 3^3 full factorial design of experiment was used. Welds tensile strength was considered as the mechanical property of welded samples. Obtained results show a significant relationship between considered properties and processing parameters through an analysis of variance (ANOVA) study and the response surface method (RSM).

1. Introduction

In recent years the selection and development of lightweight materials (e.g. thermoplastics, lightweight metals and fiber reinforced plastics) has increased widely for industrial structures, such as transportation. The main drivers for this are new environmental policies for the reduction of greenhouse gas emissions [1]. Although plastics offer high degrees of design freedom and processing ability, the fabrication of larger and complex parts usually requires joining technologies, such as welding [2]. Application of welding technologies is useful not only during production but also during repair or recycling process, therefore, new, economic, environmentally friendly technologies are being developed. Based on the method of heat introduction polymer welding technologies can be divided into three groups: methods based on heat conduction (such as hot gas or hot plate welding), heat radiation (laser welding) and mechanical friction (friction welding) [3].

The technical basis of friction welding methods is the heat produced by surface friction, which causes intense motion in the molecular structure of the material to be welded; therefore the material changes into a state suitable for welding. This family of technologies includes ultrasonic, rotation and vibration welding [3].

Friction stir welding (FSW) is the newest member of this family, and was developed at the end of the 1990s by the "institute of welding technologies (TWI)" in order to weld aluminum and its alloys. This method is based on heat supplied by friction between the tool and the two parts to be welded and a strong plastic deformation in the material [4,5].

In conventional FSW, a cylindrical, shouldered tool with a profiled pin is rotated and slowly plunged into the joint line between two pieces of sheet material, which are butted together [5]. A simple schematic figure of friction stir welding process is shown in Fig. 1.

The parts are clamped to prevent the abutting joint faces from being forced apart during the welding process. The generated frictional heat causes the material to soften or melt, and allows traversing of the tool along the joint line. The plasticized material is transferred from the leading edge to the trailing edge of the tool pin and is forged by the intimate contact of the tool shoulder to produce a weld between the two pieces [5].

Unlike metallic materials, polymers have a low hardness, a very low melting temperature reached quickly by the friction phenomenon, a very short time of solidification and a low thermal conductivity [4]. Researchers at the Brigham Young University (BYU) in the United States investigated this process and have a patent for FSW in combination with a heated shoe, called hot shoe, which is claimed to eliminate voids and improve mixing [6].

Because of different material flow in the friction stir welding process around the rotating tool, two distinct areas would be created: an area in which the rotational direction of the tool is the same as the traverse direction (advancing side) and the area where the rotational direction opposes the traverse direction of the tool (retreating side) [7,8].

Fig. 2 shows two different material flow at advancing and retreating side of the weld. In these two figures, the material on the retreating side does not rotate with the pin but the one on the

* Corresponding author. Tel.: +98 9125478549; fax: +98 4412773920.
E-mail address: t.azdast@urmia.ac.ir (T. Azdast).

0261-3069/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2012.06.059

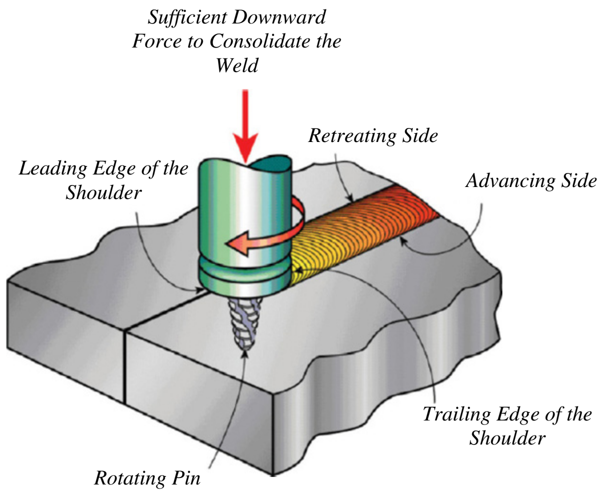

Fig. 1. A schematic figure of the FSW process [5].

advancing side forms a rotational zone around the pin. After several revolutions the material points start to slough off in the wake behind the pin. This means that the material on the retreating side never enters into the rotational zone near the pin, but the material on the advancing side forms the fluidized bed near the pin and rotates around it [9].

2. Background

Various papers have been written on the subject of FSW for the joining of thermoplastic materials. TWI research group studied FSW on polymeric materials by a rotating tool, but because of the formation of voids along the length of the weld they focused on FSW using a vertical reciprocating blade [10]. Sorensen et al. [10] at BYU invented an improved method for FSW, called hot shoe, with the purpose of containing the melted material, improving surface quality, and aiding in the fusion process. Several polymeric materials have been successfully welded included LDPE, HDPE, UHMWPE, PP, PC and ABS [6,10]. They finally studied the effects of rotational speed, feedrate and geometry of the tool on the tensile strength, flexural modulus and impact energy of friction stir welded ABS sheets in 2 levels using a design of experiment (DOE) method and showed that at low rotational speed and high feedrate with a tapered tool, better weld properties would be accessible even though their method of analysis had many problems.

Strand et al. [11] studied the mechanical and microstructure properties of polypropylene (PP) friction stir welded sheets using hot shoe method. They finally came to the conclusion that to achieve minimal disruption of polymer microstructure, welds should be made at low feedrate, high shoe temperature, long pressure time and large pin diameter.

Rezgui et al. [4] used a fixed "scraper" instead of shoulder of the tool in order to retard the cooling of welded plates and contribute to a better distribution of temperature in the weld cordon. Applying a factorial DOE and an optimization using Taguchi approach, they declared that rotational speed, welding speed, pin diameter and holding time at the beginning of welding influence flow stress and maximum temperature of welded samples and do not have any significant effect on yield stress.

Erica Anna Squeo et al. [12] studied friction stir welding of polyethylene (PE) sheets using a standard tensile machine for mechanical and a differential scanning calorimeter (DSC) for the thermal test. They declared that even if the friction stir welding process in polymeric materials seems a promising technique because of some advantages over other joining technologies, as the low cost of machine and tooling cost, it is not a ripe technology yet. In order to make the process more robust and gain higher strengths (close to the strength of the base material) and obtain more process repeatability, heating the plastic material is a good way using a hot tool process.

There are few publications concerning polymer FSW applications. No publication has been found on FSW of ABS sheets using ANOVA method. In this paper, ABS sheets were welded using the hot shoe tool because of its advantages.

Pin rotational speed, shoe temperature at the beginning of the process and traveling speed of the tool are considered as variable parameters in order to study their effects on the tensile strength as a mechanical property of welded samples using a full-factorial 3^3 DOE.

3. Experimental procedure

3.1. Materials

Compression-molded ABS sheets produced by "Aida Plastic" in Tabriz, Iran were chosen for this paper for several reasons. First, ABS is a very common commodity thermoplastic with a variety

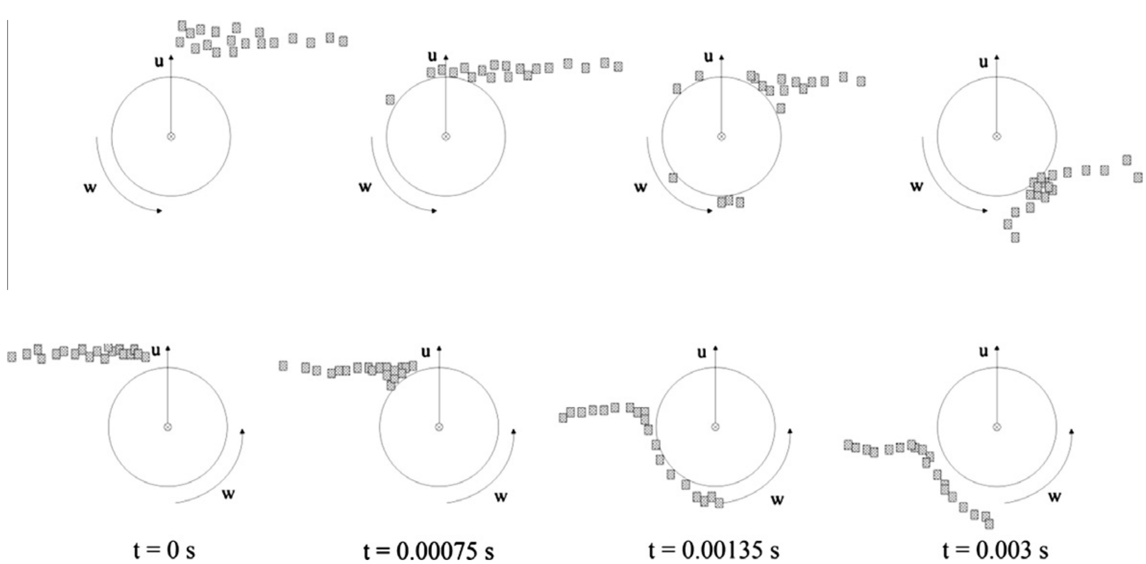

Fig. 2. Different types of material flow at advancing (above) and retreating side (below) of the weld [9].