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An assisted heating tool design for FSW of thermoplastics

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ABSTRACT

An assisted heating tool design was used to obtain better weld surface finish, and lower chip formation and material loss during friction stir welding (FSW) of thermoplastics. The welded coupons of polypropylene with various tool rotational speeds were tested under tensile loading to test the efficiency of the tool design. The proposed tool improved the tensile strength of friction stir welded coupons of polypropylene and also produced the welds with more ductility than the conventional FSW tool without additional heating. Lack of heat, the reason for improper fusion and void formation during FSW of thermoplastics, was avoided by the proposed tool design.

1. Introduction

Friction stir welding (FSW) is a solid state joining process invented by Thomas et al. which is successfully being used for joining of low temperature metallic materials (Thomas et al., 1991). FSW uses frictional and deformational heating to plasticize the workpiece material, and joins the material using plastic deformation (Oliveira et al., 2010). Fig. 1 shows a simple schematic diagram of conventional friction stir welding process (Nandan et al., 2008).

Nelson et al. showed that heat generated due to friction and plastic deformation during FSW softens the workpiece material leading to successful joint formation (Nelson et al., 2004). FSW of thermoplastic polymers is difficult as the heat generated due to friction and plastic deformation is insufficient to form good joint. The limited heat generated during conventional FSW of thermoplastic materials, partially plasticises the workpiece material. On rotation of tool this partially plasticized material comes out of the weld zone due to centrifugal force as shown by Jaiganesh et al. Upon cooling it forms a fibrous structure instead of a contiguous welded joint (Jaiganesh et al., 2014). Insufficient heat generation causes chip formation, and improper plasticizing resulting in material loss and poor joining. Thermoplastics have lower thermal conductivity (ABS 0.17 W m-1 K-1, PP 0.22 W m-1 K-1) than metals. Strand showed that during the FSW process outer layer of material cools much faster than the inner layer. This leads to the formation of hard shell and voids (Strand, 2004).

Heat generation during FSW can be improved by increasing the tool rotation speed, tool shoulder diameter and pin diameter. However, Squeo and Bruno showed that these parameters also affect the material flow and lead to outward flow of material (Squeo et al., 2009). Arici and Sinmazçelýk (Arici and Sinmazçelýk, 2005) and Bozkurt (Bozkurt, 2012) reported formation of root defect, unwelded bottom part of the weld, during FSW of polymers. Low thermal conductivity of the polymer was suggested as the reason behind lack of heating at workpiece bottom. Bilici and Yükler (Bilici and Yükler, 2012) reported that weld formed with straight cylinderical pin profile tool were of poor strength while tapered cylindrical and threaded cylindrical pin profile tool gave much better weld strength. A study of effect of tool pin thread pitch by Boz and Kurt (Boz and Kurt, 2004) showed that smaller thread pitch produces good welds, whereas increasing thread pitch converts the process into drilling. Panneerselvam and Lenin (Panneerselvam and Lenin, 2014) used a tool with left-hand threaded cylindrical pin to join 10 mm thick nylon-6 sheets. When the tool was rotated in clock wise direction it pushed the material upwards. Such material flow resulted in loss of material and void formation. When the tool was rotated in counter clockwise direction it pushed the material downwards and kept material inside the weld pool. Fig. 2 shows the mechanism of material flow due to the threaded pin as explained in their work. Jaiganesh et al. (Jaiganesh et al., 2014) attempted optimization of the process parameters for FSW of high density polypropylene plate. They observed that 10 mm/min travel speed resulted in less chip formation and improved joint strength.

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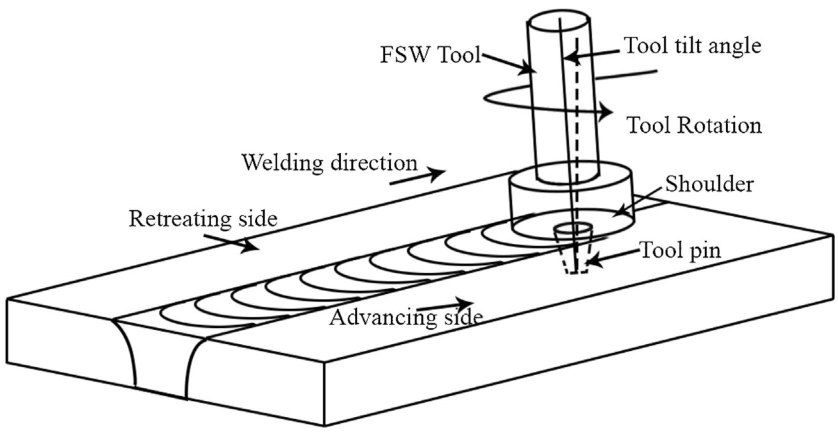

Fig. 1. Schematic illustration of the friction-stir welding process (adapted from Nandan et al., 2008).

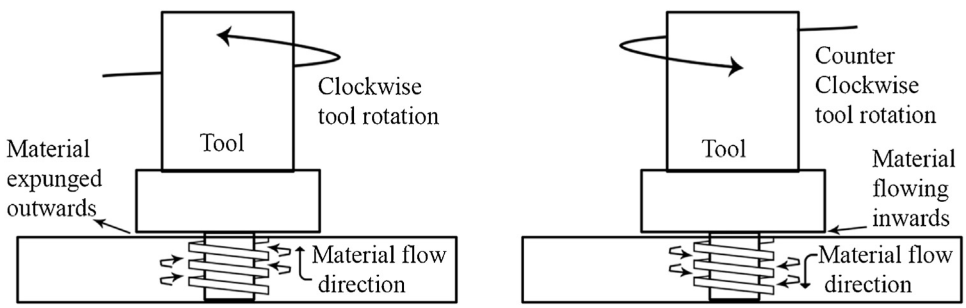

Fig. 2. The effect of the tool rotation in clockwise and counter-clockwise direction on the material flow (adapted from Panneerselvam and Lenin, 2014).

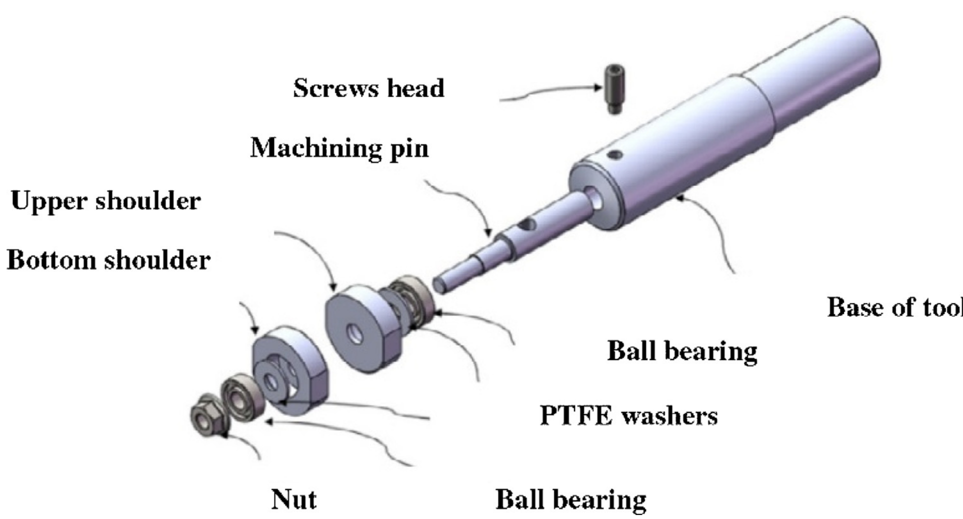

Fig. 3. A self-reacting tool with non-rotating shoulder (Pirizadeh et al., 2014).

Essential condition for efficient joining of polymers require proper heating at the tool workpiece interface and proper mixing of the base material to avoid chip formation and produce better surface finish (Payganeh et al., 2011).

Recently some tool designs were proposed to provide additional heating during FSW of thermoplastic materials to avoid underheating during joining (Nelson et al., 2004; Pirizadeh et al., 2014). Pirizadeh et al. (Pirizadeh et al., 2014) used a self-reacting tool as shown in Fig. 3 that has non-rotating shoulder to avoid chip formation. Non-rotating shoulder was made of PTFE (Teflon) which has very low friction coefficient. The shoulder kept the material within the weld pool which resulted in welds with good surface finish. The self-reacting mechanism resolved the root defect in the welds. However, the joint strength is not sufficient due to less frictional heat. Kiss and Czigány (Kiss and Czigány, 2008) explored the feasibility of FSW of polypropylene using milling tool having grove slope of 15° and 45°, where the direction of the tool rotation used was reversed from the regular cutting direction during milling operation. They were able to weld the polypropylene sheets but with poor weld strength.

Various researchers have suggested tool designs to provide additional heading during FSW of polymers to reduce chip formation and improve material flow around the tool. Nelson et al. (Nelson et al., 2004) used an FSW tool with hot shoe to join poly-