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# Investigation on the effects of tool geometry on the microstructure and the mechanical properties of dissimilar friction stir welded polyethylene and polypropylene sheets

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ABSTRACT

The extensive usage of polymers in numerous industries has agitated the researchers to promote their joining and assembling processes. Nowadays, friction stir welding was introduced as an alternative method to the conventional joining processes. The aim of this study is to investigate the effects of tool geometry on dissimilar friction stir welding of polyethylene-polypropylene. Four different pin profiles, including threaded cylindrical, squared, triangular and straight cylindrical were considered. The interaction effects of welding variables, including rotational speed and traverse speed were also studied. In order to control the material flow, the used tools were equipped with a stationary shoulder. Tensile test and durometer hardness tests were carried out and microstructure analysis was conducted for all the welded joints. It was observed that the threaded cylindrical pin profile had the best performance for each welding process condition. The SEM observations showed that using the threaded cylindrical tool, provide more laminar and the uniform material flow regime during welding than the other tool pin shapes. In the optimum joining condition, welded joint with defect-free uniform microstructure, with strength equal to 98% of polyethylene and with higher elongation and hardness than the polyethylene was obtained. The optimum rotational speed equal to 1860 rpm with the highest travel speed equal to 12.5 mm/min provides the welded joints with best mechanical properties.

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## 1. Introduction

Utilization of lightweight materials such as thermoplastics and reinforced polymer composites has been increasing significantly to reduce the product weight [1]. Because of the enhanced stress-to-weight ratio of thermoplastics, they are widely used in a variety of engineering and industrial applications [2]. Accordingly, efforts have been made to develop new joining methods for similar and dissimilar polymers [3]. Joining of dissimilar materials by any welding process is always difficult because of the enormous differences in mechanical and metallurgical properties. The joints of dissimilar materials are increasingly employed in different sectors of industries due to its technical and economic advantages [4]. Various welding methods, such as vibration welding [5], laser welding [6], friction welding [7] and friction stir spot welding (FSSW) [3] are known to be effective in different areas of industry. Friction Stir Welding, a solid- state joining process, was invented at TWI in 1991 [8]. The method can guarantee high quality, efficiency, energy saving, and environmental protection [9]. Heat is generated by friction between the rotating tool and the base material, which softened the region near the FSW tool. The traverse movement of tool along the joint line, intermixes the workpieces mechanically and forges the softened material by the mechanical pressure [4]. The plastic deformation and generated heat caused by rotational welding tool, i.e. pin and shoulder, accompanied by the tool's traverse motion joins the materials [10,11]. A simple schematic of FSW process is shown in Fig. 1 [12]. Nowadays, application of friction stir welding on joining of polymers is increased significantly. In friction stir welding of thermoplastics, formation of the slit on the backside of the welded specimens leads to root defects and consequently poor tensile strength [13]. So the determination of proper welding pro-

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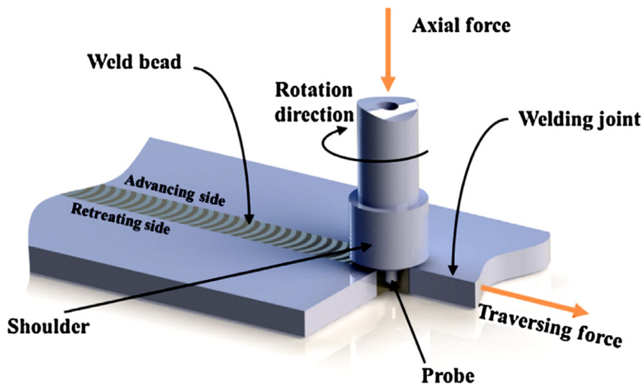


**Fig. 1.** Schematic view of the FSW process [12].

cess parameters and suitable tool design as main effective factors were considered in this study.

## 2. Background

Recently, some researchers have studied the application of FSW on the thermoplastics polymers. Arici and Sinmaz [14] studied the effect of double passes of the tool on FSW of polyethylene. Double passes allowed them to increase the joint mechanical properties. Saeidi et al. [15] studied the properties of plastic sheets joined using FSW, presented low tensile strength (25% of base polypropylene (PP) composite strength). Strand et al. [16] 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 the minimal disruption of polymer microstructure, welds should be made at low feed rate, high shoe temperature, long pressure time and large pin diameter. Erica Anna Squeo et al. [17] studied friction stir welding of polyethylene (PE) sheets. 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. They found that in order to make the process more robust, gain higher strengths and obtain more process repeatability, heating the plastic material is a good way using a hot tool process. Mustafa Aydin [18] studied the effect of preheating on the FSW of Ultra high molecular weight polyethylene (UHMWPE). The preheating enabled the plastic material to be easily stirred. It was concluded that the achieved weld efficiency is 89% of base material. Hosein et al. [19] investigated the effects of friction stir welding process parameters on the weld quality and creep properties of welded polyethylene (PE) sheets. The results showed that the creep resistance of the welded samples reaches to the base material resistance. The stress-strain behavior of the welded joint was also modeled using mathematical methods. Sadeghian and Besharati [20] studied the mechanical properties of friction stir welding of thermoplastic acrylonitrile butadiene styrene (ABS). Statistical optimization, using response surface method, was used to investigate the mechanical strength of the welded samples. Azarsa et al. [21] investigated flexural behavior of high-density polyethylene welds produced with a stationary shoulder and a heating system inside it. Bagheri et al. [22] presented FSW of ABS using a fixed heated shoulder called a hot shoe, while a rotating pin through this shoe stirs the melted material. Kiss and Czigány [23] employed conventional friction stir welding process for joining of polypropylene sheets. They examined the effects of process parameters on the joint strength. The maximum joint strength equal to 50% of base material was achieved. Joining the dissimilar polymethyl methacrylate (PMMA) and acrylonitrile butadiene styrene (ABS) sheets were conducted using friction stir spot welding by Dashatan et al. They found that this method was a feasible way to weld dissimilar polymers. They also demonstrated that the process parameters have a significant impact on the weld strength [3]. To study the combined effects of tool geometry and welding parameters, dissimilar friction stir welding of thermoplastic PE and PP with four different tool pin profiles (threaded cylindrical, squared, triangular and straight cylindrical) were investigated in this study. The effects of main process parameters such as tool rotational speed and tool traverse speed on the joint properties were experimentally studied and discussed. For evaluating the mechanical properties of the welded joints, tensile and hardness tests were conducted for all welded samples. The scanning electron microscopy (SEM) was also employed for the microstructural observations.

## 3. Experimental procedures

### 3.1. Material properties

In this paper, the Polyethylene and Polypropylene sheets were used as the base material. High-density polyethylene is one of the most popular polymers due to its availability and competitive cost. Furthermore, it is a thermoplastic with noticeable mechanical properties [24]. The need to produce larger and more complex parts from polymers such as PE has created an increased demand for their joining. In addition, with the increasing development of engineering plastics, the demand for reliable, rapid, highly productive and cost effective joining methods was also increased [25]. Polypropylene is a linear hydrocarbon polymer used for a wide range of applications in the field of automobile, aerospace and reusable containers of various parts. Polypropylene is weathered and unusually rebellious to many chemical solvents. It provides better results in terms of ductility fracture toughness and fatigue compare to other plastics materials [12]. A summary of the physical properties of these two polymers, obtained from experiment, is presented in Table 1.

### 3.2. Tool design

To evaluate the effects of the tool shape on the weld quality, four different tool pin profile were employed in this study. Tools with square (S), threaded cylindrical (TC), triangular (T) and straight cylindrical (SC) pin shape from H13 hot work tool steel were used. The geometrical dimensions and the image of the welding tools are shown in Fig. 2. The tool shoulder diameter of 17 mm and pin inscribed diameter of 10 mm were considered fix for all the prepared tools.

A flat sheet called “stationary shoulder” along with the welding tool was employed to prevent the outflow of the lava, flatten the weld surface and remove the surface imperfections. The stationary shoulder was fabricated from 7075 aluminum alloy owing to its high thermal conductivity and mechanical strength. High thermal conductivity of the shoulder provides a hot surface which can slow down the cooling rate of the lava. Due to the traverse movement of the tool, the tool inserted at the front side of the stationary shoulder. So the effective length and working area of the stationary shoulder was increased. The geometrical dimensions and the image of the stationary shoulder are shown in Fig. 3. The arrows in the presented tool assembly show the direction of tool rotation and tool advances.

### 3.3. Welding procedure

The experimental studies were performed using commercial $160 \times 60 \times 8$ mm sheets of Polyethylene (PE) and Polypropylene (PP) [26]. All the samples were fabricated from a same sheet to eliminate the effects of material changes in this study. PE and PP

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