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Reinforced Dissimilar Friction Stir Weld of Polypropylene to Acrylonitrile Butadiene Styrene with Copper Nanopowder

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ABSTRACT

The widespread application of thermoplastic polymers in different aspects of industries has motivated researchers and companies to improve and upgrade their forming, joining and assembling processes to overcome their limitations. The aim of this study is to investigate the reinforcement of the dissimilar joints of Polypropylene and Acrylonitrile Butadiene Styrene by incorporation of copper powder to the weld zone. The effects of process parameters such as rotational and traverse speeds and the heater temperature on the mechanical properties and the macrostructure of the joints were studied comprehensively. Rotational and traverse speeds and heater temperature of 1600 rpm, 16 mm/min and 80 °C, offered the best mechanical properties of the joint. In this condition, reinforced welded joint with strength equal to 91.2% of Polypropylene and hardness equal to 94.1% of Polypropylene was obtained. The results showed that adding the copper powder to the joint increased the tensile strength and hardness of the joint prepared at the optimum welding condition for about 36% and 30%, respectively.

1. Introduction

Modern thermoplastic materials are used in an expanding range of engineering applications, such as in the automotive industry, due to their enhanced strength-to-weight ratios and toughness. Even though plastics offer a high degree of design freedom and processing ability, the fabrication of large and complex parts usually requires joining technologies [1], such as laser welding [2], vibration welding [3], friction stir spot welding [4] and friction stir welding [5] are considered to be effective in different areas of industry. As a relatively new method, friction stir welding (FSW) invented in 1991 at the welding institute (TWI) has turned out to be a promising way of solid-state joining of difficult-to-join materials along with great mechanical properties [6]. The method can guarantee high quality, efficiency, energy saving, and environmental protection [7].

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 the tool along the joint line intermixes the work-pieces mechanically and forges the softened material by the mechanical pressure [8]. The FSW process was first utilized for Aluminum alloys [9], but as the time went on, FSW showed large potential for joining magnesium alloys [10], steel alloys [11], titanium alloys [12], copper alloys [13], metal matrix composites [14] and dissimilar materials [4]. A simple schematic of FSW process is shown in Fig. 1 [15].

2. Background

Recently, some researchers have studied the application of FSW on the thermoplastics polymers.

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 [4]. Rezaee Hajideh et al. [16] carried out dissimilar joining of PE/PP polymers using stationary shoe FSW, while four different tool pin profiles (threaded cylindrical, squared, triangular and straight cylindrical) were employed. Utilizing the threaded cylindrical pin provided more uniform material flow than the other pins. Rahbarpour et al. [17] performed FSW of wood/polymer composites by a stationary shoe with a heating system to eliminate the problems of voids and poor mixing.

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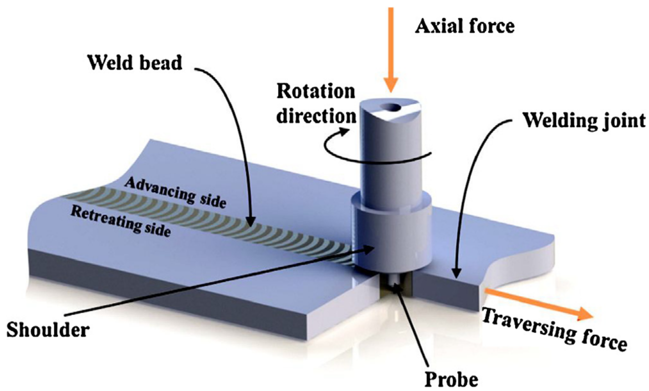

Fig. 1. Schematic view of the FSW process.

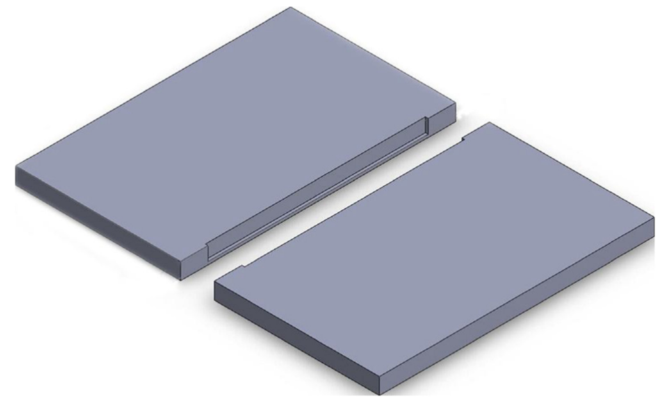

Fig. 2. Schematic view of the profile made adjoining side of a strip.

The maximum tensile strength of the welded wood-polymer composites was 92.95% of base material, at a condition of medium rotational velocity, low temperature and high welding speed. Gao et al. [18] added multi-walled carbon nanotubes (MWCNTs) into the weld zone during FSW of HDPE and ABS, and found that the addition of MWCNTs could increase thermal conductivity and improve sufficient material flow and material mixture, reducing inside crack defect. Shaikh et al. [19] investigated the effect of SiC, SiO2, nano Al and graphite on mechanical property of HDPE joint. Compared with conventional FSW joint with tensile strength of 20.7 MPa and elongation of 60%, maximum tensile strength of SiC-reinforced composites reached 17.7 MPa, while elongation of graphite-reinforced composites obtained up to 100%.

Yusof et al. successfully joined A5052 aluminium alloy and polyethylene terephthalate (PET) via mimicking the FSSW technology [20]. Singh et al. [21] studied the experimental investigations for mechanical and metallurgical properties of friction stir welded recycled dissimilar polymer materials with metal powder reinforcement. The results showed that the reinforcement of Fe metal powder produced a metal bonding at the joint interface of LDPE and HDPE that provided a good joint strength. Kumar et al. [22] studied the microstructure and mechanical properties of FSP in-situ Cu/PDC composites. The results showed that the polymer derived ceramic nanoparticles (10–30 nm) are successfully dispersed in a friction stirred composite zone uniformly without any agglomeration of these nano sized particles. Employing FSW, not only metal matrix composites were successfully fabricated, but also promising results were reported for polymeric work-piece. Azarsa and Mostafapour successfully fabricated polymer matrix composites. They observed good distribution of copper particles in the high density polyethylene matrix after one pass [23].

In this work, another step was put forward and the effects of applying copper powder on the properties of the dissimilar FSW-ed joints are investigated as well. Copper powder possesses high strength versus the employed polymers. In the present study, the influences of rotational and traverse speeds, heater temperature and application of copper powder reinforcements on the macro-structure and mechanical properties of the dissimilar PP- ABS joints are studied.

3. Materials and Methods

In this paper, the Polypropylene (PP) and Acrylonitrile Butadiene Styrene (ABS) sheets were used as the base material. 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. It provides better results in terms of ductility fracture toughness and fatigue compare to other plastics materials [15]. On the other hand, acrylonitrile butadiene styrene has extensive application and excellent weldability as a very common commodity thermoplastic. ABS is amorphous and therefore has no true melting point [24]. Due to the widespread application of these two types of thermoplastic polymers in different aspects of the industries, the investigation on their dissimilar joining, using friction stir welding, provides valuable insight to further development and application. The summary of the physical properties of PP and ABS is presented in Table 1.

Rectangular plates of PP and ABS sheets with dimensions of $160 \times 60\,mm^2$ with thickness of 8 mm were used in this study. After cutting the PP and ABS plate, for half of the specimens a cavity with 0.2 mm width, 7 mm depth and required length was machined on the adjoining side of the sheets. To apply the reinforcing copper powder to the stir zone (SZ), the cavity was filled with the copper powder. The schematic view of the machined cavity is shown in Fig. 2.

Putting two machined pieces near each other formed a groove that enabled us to add copper powder into SZ. In the last two decades, polymer matrix composites that exhibit the global properties of both fillers and polymers have been the subject of extensive research. Physical and mechanical properties of polymer matrix composites are very important and remarkably influenced by the structures and compositions of the molecular layers. The filler materials such as CNTs and Cu particles easily agglomerate in polymer, which are difficult to be separated due to van der Waals force [25,26]. Therefore, the dispersion of fillers in polymer is the key issue to enhance the properties of polymer matrix composites. Currently, the primary techniques of preparing polymer matrix composites are in situ polymerization [27], solution mixing [28] and melt blending [28], respectively. Copper powder particles with size <45 μm and purity over 99% is used. The copper powder was packaged by Pourian Chemical Company. The specification of the

Table 1
The physical properties of polypropylene and acrylonitrile butadiene styrene polymers.

Material	Physical state	Tensile Strength [MPa]	Durometer Hardness [Shore D]	Melting point Temperature [°C]	Elongation [%]	Density [g/cm^3]
Polypropylene (PP)	Semi-crystalline thermoplastic	33	77	130-171	515	0.855
Acrylonitrile butadiene styrene (ABS)	Amorphous Plastic	41	110	217-237	20	1.05