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Multi-axis force measurements of polymer friction stir welding

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A R T I C L E I N F O

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A B S T R A C T

In this study, high-molecular-weight-polyethylene sheets were welded in the butt-joint configuration in order to investigate the effect of welding parameters on the generated forces during welding. The welding procedure was performed using newly developed clamping device with the ability to measure and acquire the forces during welding in X, Y and Z directions (F_X, F_Y and F_Z). Using a welding tool with a stationary shoulder and position control, the applied force is kept approximately constant during the entire welding extension. The obtained results enabled the identification of the influence of each individual welding parameter on the applied forces. The axial force is the most influential force during this process, which is responsible for forging pressure and frictional heat, while traverse and rotational speeds have the main effect on the traversing and lateral forces. The developed sensitized clamping system was used in support of welding process optimization to produce quality welds without resourcing to costly force control sensors. Using this device, it was possible to use force as a welding parameter and produce strong welds with mechanical behavior close to the parent materials'.

1. Introduction

Taking into consideration the increase of global need for consumption of lightweight structures, more adaptable and environmental friendly joining methods are desired to keep up with the fast-growing industrial demand. The applicability of Friction Stir Welding (FSW) technique is not limited to metallic materials, and it was verified that polymeric materials can benefit from this welding method. Since the invention of FSW, the majority of the studies have focused on metallic materials butt-joints, and very few investigations have focused on polymeric materials, and in particular on the active forces during welding. The schematic representation of a butt-joint welding process for polymeric materials is illustrated in Fig. 1. A conventional FSW tool consists of two rotating parts attached together: "shoulder" and "probe". The shoulder generates most of the frictional heat under the axial force, while the probe penetrates into the base materials and stirs the soft materials together along the welding direction. As stated by Eslami et al. (2015), polymeric materials behave differently than metallic ones and strong welds are very hard to obtain using the same tool design concept. Nelson et al. (2004) reported that the conventional FSW tool is not suitable for welding polymers due to low melting point, thermal conductivity and hardness of polymers. The main problem of polymeric FSW using a conventional tool is the formation of flash defects, which causes the soft materials to be pushed out of the weld bead. For welding polymeric materials, instead of using a rotating shoulder, a stationary shoulder shown in Fig. 1 is required, to push the material down and avoid the flash defect formation, creating strong welds with good surface quality.

The FSW process can be categorized in three main stages: heating, deforming and forging. When the tool advances in the parent materials, the friction between the FSW tool and the base material generates heat, which leads to plastic deformation of the materials, and forges the soft material into the weld bead under the axial force. The applied forces play a critical role in this process, and as Eslami et al. (2016) reported, this issue is even more pronounced in polymeric materials, due to formation of the flash defect and the necessity of a stationary shoulder to forge and avoid material ejection. Atharifar et al. (2009) informed that during this process linear and rotational movements of the welding tool generate forces in different directions due to the inertial and viscous forces, as shown in Fig. 2. The axial force (F_Z) is one of the main parameters which affects the weld quality directly, and is responsible for forging pressure and frictional heat. The axial force direction defined in this study is in the downward direction (-Z) due to the negative value of the axial force in the original coordinate system. The applied force in the same direction of the welding direction is called traversing force (F_X). When the tool advances along the weld seam, the traversing force pushes the tool to penetrate the welding materials. The lateral force (F_Y) appears as a result of the FSW tool rotational movement. The direction of the lateral force is defined from the retreating side of the weld to the advancing side, as implemented by Mendes et al. (2016),

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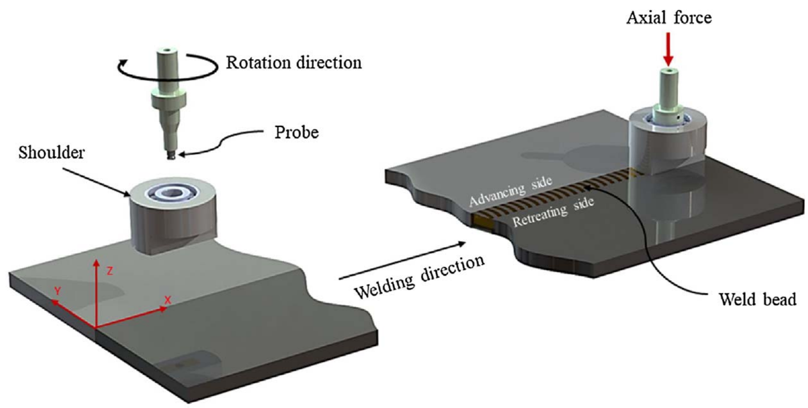

Fig. 1. Schematic of FSW butt-joint using stationary shoulder.

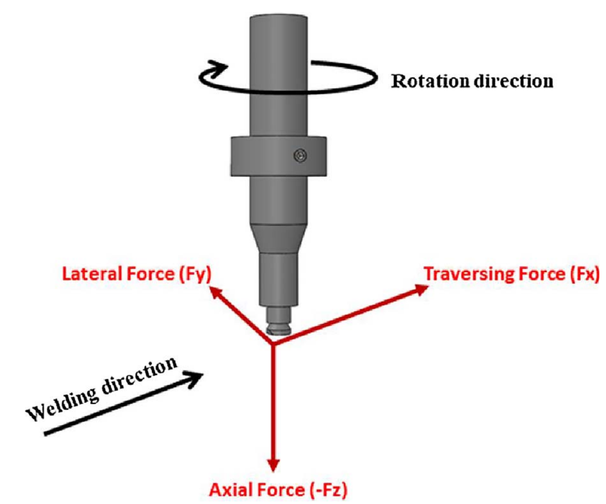

Fig. 2. Schematic of the defined generated forces directions during FSW process.

due to higher temperature of the advancing side than the retreating side, and consequently a higher applied force is required to deform the materials at the retreating side.

Various techniques were implemented in this field to measure the axial, traversing and lateral forces and the torque on the welding tools. Su et al. (2013) stated that the importance of the measuring force arises from the fact that the generated frictional heat is proportional to the applied force during welding. Most of the studies like Cui et al. (2010) focused on the measurement/control of tool torque because it is cost-efficient and easy to implement. Longhurst et al. (2010) claimed that using torque control is an attractive alternative to force control due to its sensitivity to the tool plunge depth. Recently, Pew et al. (2007) succeeded to measure the torque on the welding tool through the weld power, which is calculated by multiplying the spindle rotational speed to its torque. The weld power value has a direct relationship with the welding speed and spindle rotational speed, and an indirect relationship with the plunge depth. Similarly, Mehta et al. (2013) developed an inexpensive method to measure traversing force and tool torque using the input electrical current and power of each driving motor, then compared the obtained values for different welding parameters. Another approach for measuring the welding force was proposed by Trimble et al. (2012), based on a rotating cutting-force dynamometer with the ability to measure force and momentum in all directions. The use of such a device is highly expensive and major modifications on the welding equipment are necessary. Due to this fact, most researchers ultimately develop a customized device that may be used for a specific application. Gibson (2011) developed a low-cost force/torque measurement system by instrumenting a milling machine head with strain gages. The custom designed force platform used in this study is a cost efficient device consisting of 12 planar load cells to measure the axial, traversing and lateral forces during welding, which is described and depicted in the next section.

2. Materials and tools

Two 3 mm thick High-Molecular-Weight-Polyethylene (PE-HMW) 150 mm long were welded in the butt-joint configuration using position control FSW and the applied forces during welding were acquired and evaluated. The welding tool consists of a stationary shoulder made of Teflon with a highly heat conductive metal sleeve around the rotating probe. The 3D model of the FSW tool used in this study is illustrated in

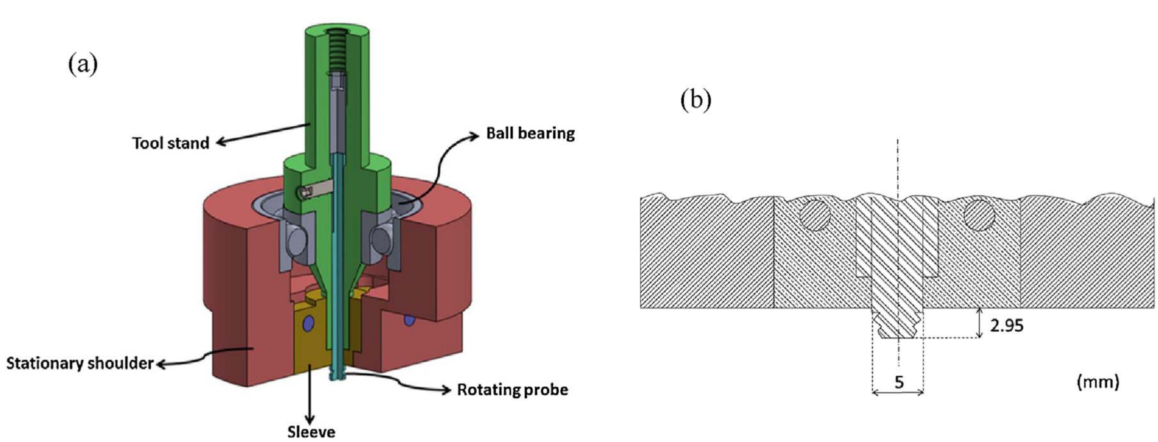

Fig. 3. FSW tool 3D CAD model (a); section view of the probe (b).