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Effect of feed rate on shear strength and macrostructure of friction stir welding dissimilar high-density polyethylene-polypropylene joint

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Abstract

The connection of dissimilar materials is complicated, too. This connection is due to differences in physical and mechanical properties, but with the development of technology, dissimilar materials can be joined using solid-state welding methods. Dissimilar joints can produce a good combination of structure and mechanical properties. One of them is friction stir welding, which is used to connect sheet materials. The welding process of this research uses a conventional vertical milling machine. This study aims to determine the maximum shear strength and welding defects against variations in the feed rate of lap joints dissimilar high-density polyethylene with polypropylene. The machining parameters used in this experiment were 4 mm pin tool diameter, 2360 rpm rotation speed, 9 mm/min, 12 mm/min, and 16 mm/min feed rate. The results showed that the highest shear strength was obtained using the 12 mm/min feed rate variation of 3.11 N/mm. It can be seen in the macrostructure that the incomplete defects produced are less than the other welding process variations.

Keywords:

High-density polyethylene, polypropylene, feed rate, lap joint, shear strength, macrostructure.

1 Introduction

Welding is the process of joining two or more materials utilizing heat energy so that materials can be connected [1]. Welding is often used in everyday life to make simple to complex products, such as fences, building construction, and others. Along with the development of technology, the demands for materials that have special properties are needed such as the connection of different materials. Various companies have developed and applied dissimilar connections because dissimilar connections can produce a good combination of structure and usability properties to get engineering benefits and be more economical [2]. However, differences in the thermal, physical, and mechanical characteristics of the materials to be joined, cause problems when joining different types of materials [3].

Welding of different materials is usually done using solid-state welding methods, one of which is Friction Stir Welding (FSW). Research on FSW has been found using aluminium material. However, as technology develops, FSW is currently used for non-metallic materials such as polymers and composites. FSW has advantages, including being environmentally friendly and does not cause harmful rays, gases, or smoke [4]. Friction stir welding is one of the welding processes used to connect various materials. This is because joining other materials using FSW has advantages

such as low welding temperatures that reduce distortion, a Heat Affected Zone (HAZ), and low porosity defects [5]. Polymers have difficulties when joined; this is because polymers are insulators, so they have low thermal conductivity [6]. Polymers are metal substitutes that are often used in various industries. Polymers have several advantages that metals do not have, including lightweight, corrosion resistance, and lower price [7]. The use of lightweight materials has expanded throughout time in response to the need for engineering goods to be lighter. Low-cost thermoplastic materials are becoming more and more popular in the industrial industry because of their high specific strength and lightweight [8], [9].

Several studies on dissimilar polymer connections, such as high-density polyethylene polypropylene [10] and high-density polyethylene acrylonitrile butadiene styrene [11], have been successfully conducted. Previous research examined the effect of tool geometry on the mechanical properties and microstructure of polypropylene using variations in tool rotation speed, and feed rate. According to the results, the process parameters of the threaded cylindrical tool profile, rotational speed of 1860 rpm, and feed rate of 12.5 mm/min produced the best tensile strength of 23.7 MPa [12]. Other research on FSW process parameters with HDPE material. This study uses variations in rotational speed parameters (500 rpm, 600 rpm, 800 rpm) and feed rate (10 mm/min, 20 mm/min, 30 mm/min). The results showed that the highest tensile strength was 14.3 MPa with a rotational speed of 800 rpm and a feed rate of 10 mm/minute [13].

The study of variations in feed rate (30 mm/min, 45 mm/min, 60 mm/min) and spindle speed (1200 rpm, 1800 rpm, 2400 rpm) had an impact on the mechanical properties of polypropylene. The highest tensile strength value is 12.3 MPa with parameters 1800 rpm and 45 mm/min [14]. Other research on the effect of feed rate variations (20 mm/min, 60 mm/min, 120 mm/min, 180 mm/min) and tool rotation 1500 rpm, 2500 rpm, and 3600 rpm on the hardness and tensile strength of aluminium 5052 showed that a feed rate of 60 mm/min obtained the highest tensile strength of 187 MPa. The faster feed rate will result in a lower tensile strength value. In addition, the feed rate and tool rotation can increase the hardness value [15].

Process parameters can affect joint quality, including feed rate, tool rotation speed, tool tilt angle, and depth plunge [16], [17]. The feed rate can affect the welded joint's heat input, plastic deformation, and microstructure [18]. Therefore, further research was conducted on the welding process parameters to obtain the desired mechanical strength. This research is to determine the maximum shear strength and welding defects that occur against the feed rate variation on dissimilar lap joint connection HDPE-PP.

2 Research Methods

This study used a vertical milling machine with its equipment and pin tool dimensions as presented in Fig. 1. The primary material of this research uses two polymer sheets with high-density polyethylene and polypropylene. The dimensions of the polymer sheet are 120 mm × 85 mm × 4 mm. Table 1 presents the physical and mechanical properties of high-density polyethylene material, while the physical and mechanical properties of polypropylene are presented in Table 2.

Table 1. Physical and mechanical properties of high-density polyethylene [19]

Physical properties of high-density polyethylene	
Density (kg/m ³)	950
Melting point (°C)	126
Thermal conductivity (W/m K)	0.46
Mechanical properties of high-density polyethylene	
Tensile modulus (GPa)	1.06-1.09
Tensile strength (MPa)	22.1-31
Yield strength (MPa)	26.2-33.1

Table 2. Physical and mechanical properties of polypropylene [19]

Physical properties of polypropylene	
Density (kg/m ³)	910
Melting point (°C)	160
Thermal conductivity (W/m K)	0.22
Mechanical properties of polypropylene	
Tensile modulus (GPa)	1.14-1.55
Tensile strength (MPa)	31-41.4
Yield strength (MPa)	31-37.2

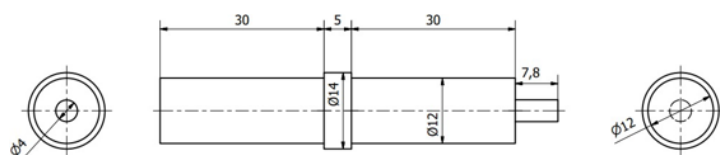


Fig. 1. Pin tool dimensions (unit in mm).

This experiment used the welding parameters: 4 mm tool pin diameter, 2360 rpm rotation speed, 7.8 mm depth of feed, and feed rate variations of 9 mm/min, 12 mm/min, and 16 mm/min to obtain optimal results. The selection of feed rate variations was adjusted to a constant feed rate on the FM-2SK chevalier vertical milling machine. FSW welding is carried out by installing the workpiece on the chuck, then turning on the milling machine, slowly lowering the tool pin, setting the automatic feed rate according to the parameters, and running the automatic feed rate until the welding point ends. After that, switch off the automatic feed rate if it has reached the end point of welding, then lift the pin tool. The welding process is presented in Fig. 2.

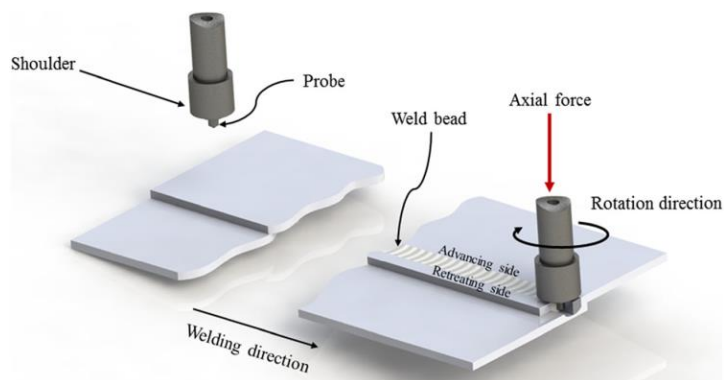


Fig. 2. Schematic of the FSW Process [8].

The welding process has been completed. Then, specimen pattern-making refers to previous researchers with the configuration shown in Fig. 3 [9]. The lap joint configuration is used at the top of the joint with HDPE material and PP bottom. The specimen pattern measured in Fig. 3 is cut using the Ryu table saw.

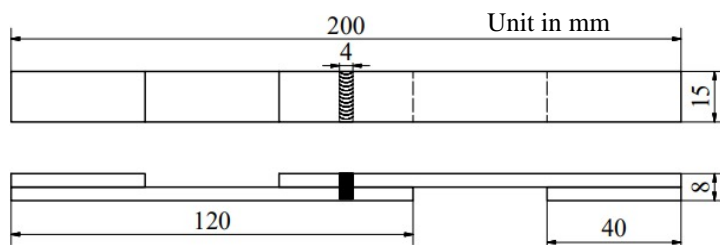


Fig. 3. Sketch of tensile test specimen

After cutting the specimens, the macrostructure was observed by looking directly at the joint interface using a visual optical macro test tool. This test aims to determine the defects at the joint interface of each welding process variation. Macrostructure observation uses a magnification number of 1.5 times. The tool used for this macro test is an Olympus optical microscope type SZ61-TR; the image results are connected to a computer, and the image can be saved on the computer.

Tensile testing was conducted to determine each welding parameter variation's maximum tensile load shear strength value. Tests were carried out on specimens of different types, namely HDPE and PP, by gripping the test specimens on a Zwick/Roell Z020 tensile testing machine. The tensile speed was set according to the previous researcher's reference of 1 mm/min [15]. Then, pull the specimen until it breaks.

3 Results and Discussion

The connection process using the friction stir welding method on HDPE and PP materials has been carried out, and the results will be seen along the weld joint path. This study uses constant parameters, including a rotation speed of 2360 rpm and diameter of 4 mm, while the parameters used are feed rate of 9 mm/min, 12 mm/min, and 16 mm/min. There are several influences on the weld area, such as the direction of rotation, welding direction, Advancing Side (AS), Retreating Side (RS), and exit keyhole. The friction stir welding results according to various parameters presented in Fig. 4.

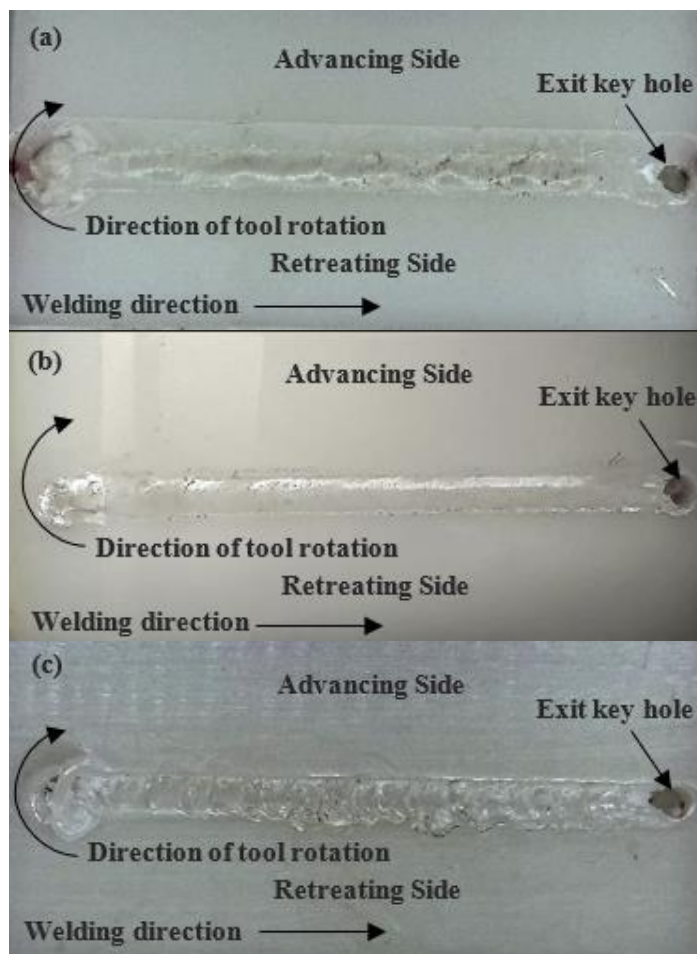


Fig. 4. Welding results of feed rate variations (a) 9 mm/min (b) 12 mm/min (c) 16 mm/min.

Tensile testing in this study determines the strength value of friction stir welding HDPE-PP. The results of tensile testing and a comparison of the effect of variations in feed rate parameters on tensile load.

Fig. 5 comparison of the tensile load results in friction stir welding testing using feed rate parameters. The most considerable tensile load result was obtained from the 12 mm/min feed rate parameter of 193.97 N. It shows that a low feed rate will increase the mixing time in the stir zone and reach the thermoplastic temperature to be well connected. However, a feed rate that is too low will produce a very high heat input, causing the parent material to degrade. In addition, the stated decrease in feed rate results in much heating concentrated in the stir zone, causing defects [20].

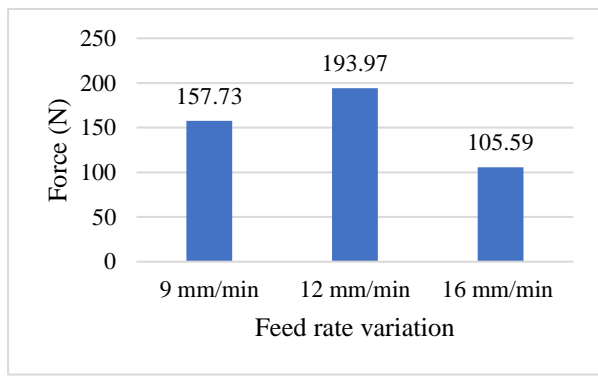


Fig. 5. Tensile load diagram for each feed rate variation.

Fig. 6. presents the shear strength results of each feed rate variation. The lowest shear stress result was obtained by the 16 mm/min feed rate at 1.80 N/mm². Because the pin tool does not have enough time to reach the thermoplastic temperature, the heat input generated is lower, thus reducing the weld nugget in the stir zone. In addition, the high feed rate makes it difficult to thoroughly soften the material in front of the rotating pin [10]. These factors cause the materials to not mix well, so the strength of the connection will decrease [14]. Therefore, selecting the proper feed rate will increase the mixing time in the stir zone and induce better mixing of materials. So, the feed rate can affect the shear strength value, and when viewed in the macrostructure in Fig. 7, the defects at each joint interface are different.

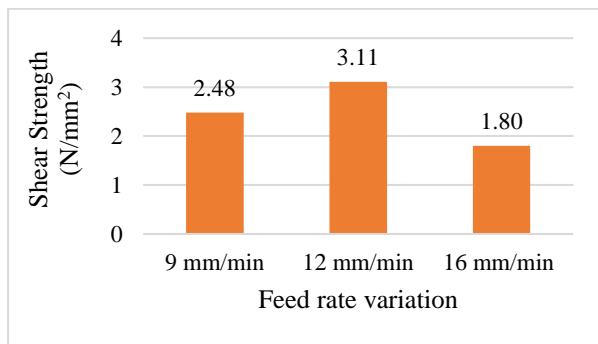


Fig. 6. Shear strength diagram for each feed rate variation.

The microstructural observations on the results of FSW welding using different HDPE-PP dissimilar materials with feed rate variations have been carried out. Fig. 6 shows the results of observations at the joint interface.

Fig. 7 shows the interface of the FSW joint. It can be seen that all three feed rate variations have defects. Most defects are obtained using a feed rate of 16 mm/min, as shown in Fig. 7(c). The primary stir zone, Advancing Side (AS), and Retreating Side (RS) have incomplete defects because the high feed rate does not allow sufficient time to soften the parent material. When compared to Fig. 7(b), there are fewer defects. Because the 12 mm/min feed rate produces good heat input, the mixing time of the two materials can reach thermoplastic temperatures, resulting in a homogeneous structure and the highest resulting tensile load or shear strength in this study.

The AS zone experiences the most significant deformation due to its mechanical and thermal properties [20] (Fig. 7). This zone experiences a higher temperature and shear deformation rate than the RS. This is due to the combined effect of rotational speed and feed rate on the AS, which results in a higher heat generation rate due to frictional heating and shear deformation. Therefore, the AS side produces better plastic deformation and recrystallization than the RS side, resulting in a finer and more uniform microstructure. In addition, the AS side experiences a higher cooling rate than the retreating side due to the tool rotation direction. This results in a smoother and more uniform microstructure on the AS side due to the higher rate of new grain formation [18].

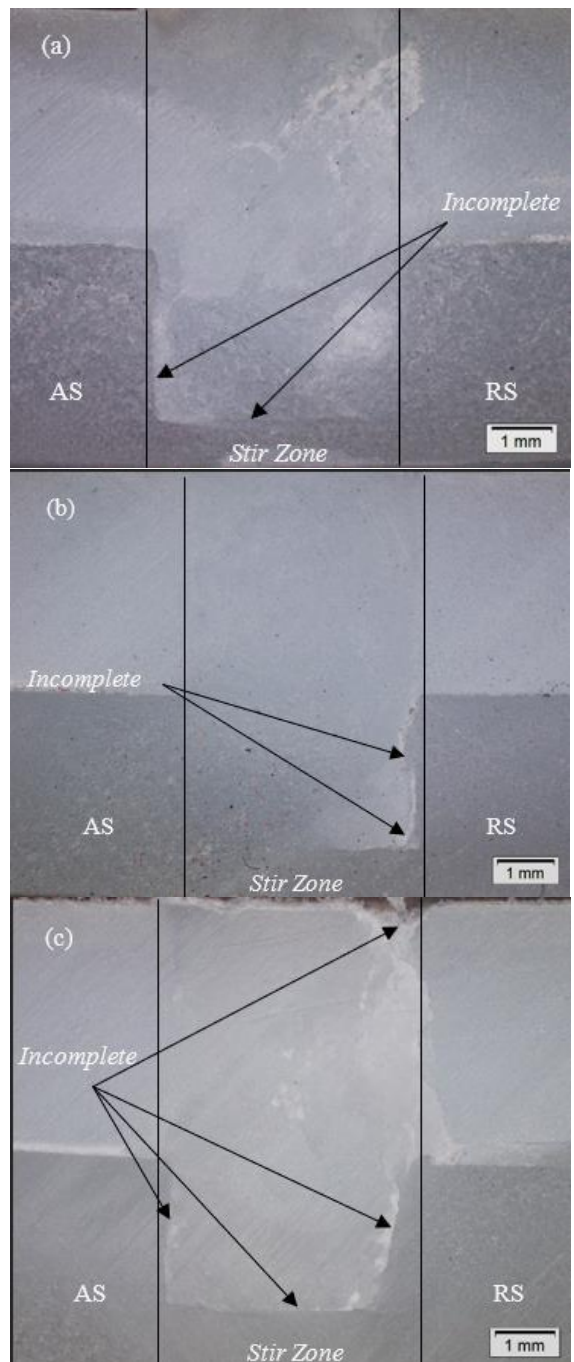


Fig. 7. Macrostructure interface of feed rate variation (a) 9 mm/min, (b) 12 mm/min, and (c) 16 mm/min.

4 Conclusion

The research results of friction stir welding dissimilar lap joint HDPE-PP using feed rate variations of 9 mm/min, 12 mm/min, and 16 mm/min, can be concluded: tensile load and shear strength increase with the increase in feed rate. The maximum tensile load and shear strength at 12 mm/min feed rate were 193.97 N and 3.11 N/mm², respectively. However, the tensile load and shear strength decreased when the feed rate was increased. Supported by the observation of macrostructure at 12 mm/min feed rate variation shows that the defects produced are less when compared to 9 mm/min and 16 mm/min feed rate variations. Therefore, the feed rate can affect the joint strength and incomplete defects.

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