

The Effect of Tool Pin Shape of Friction Stir Welding (FSW) on Polypropylene

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Abstract. This experiment deals with similar joining of polypropylene (PP) with thickness of 3 mm was carried out by using friction stir welding (FSW) technique. The process parameters, rotational speed, welding speed and tilt angle were fixed of experiments. The tool geometry shapes were the main parameters which were taken into consideration. The optimum designs of tool geometry shape were determined with reference to tensile strength of the joint. During the tensile testing experiment, the results show that all fractured occurs in the heat-affected zone (HAZ) on the polypropylene (PP). Results show that the optimum design can be obtained with same rotational speed, welding speed and tilt angle.

1. Introduction

Magnesium Friction Stir Welding (FSW) is a welding method under solid state joining that involves no melting that is welding below melting point [1]. The advantages of FSW compared to another method are excellent mechanical properties in fatigue, tensile and bend test, no arc or fume, can weld in all position, no filler wire needed, weight reduction because no usage of filler and uses consumable tools which means that the tool can used for many times [2]. FSW tool consists of two parts, namely shoulder and pin. The functions of pin are the primary source for material deformation and the secondary source for heat generation in the nugget [3]. The pin is designed to disrupt the faying or contacting surface of the work piece, shear material in front of the tool and move material behind the tool [4]. Shoulder is the main source of heat generated during the process, the primary constraint to material expulsion and primary driver for material flow around the tool [3]. Tool shoulder is designed to produce heat to the surface and subsurface regions of the welding material [4]. They are several types of tool profile such as cylindrical, threaded pin and taper pin profile. However, each uses different uses different pin tool shape geometry and it affects the strength, macrostructure and microstructure of the specimen. This study investigates the effect of tool pin shape of friction stir welding (FSW) on polypropylene.

2. Experimental Procedure

2.1. Material

The base material used in this study was polypropylene (PP) with 3 mm thickness. The dimension of base metal to be welded was 60 mm (width) × 100 mm (length) × 6 mm (thickness). The plate was longitudinally butt welded using PARTNER VMM3917 conventional milling machine. Polypropylene is a linear hydrocarbon polymer, $(C_3H_6)_n$. Polypropylene is a gaseous compound obtained by the thermal cracking of ethane, propane, butane and the naphtha fraction of petroleum. Table 1 shows the mechanical properties of polypropylene (PP).



Table 1. Mechanical properties of polypropylene (PP) material.

Material	Density	Yield Strength	Melting Point
Polypropylene	0.855g/cm ³	12.43 MPa	130-171°C

2.2. Welding Setup

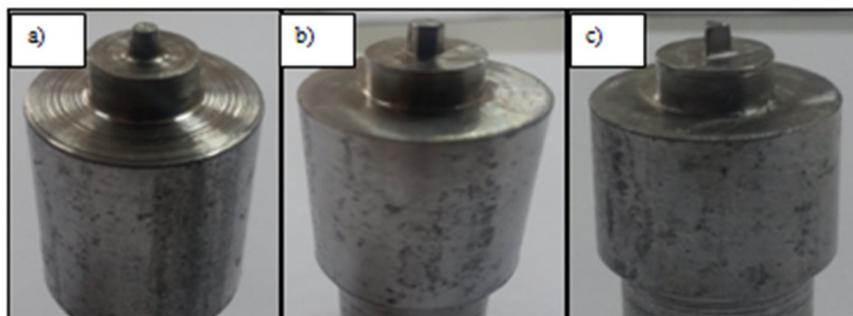
The process parameters used for this experiment are given in Table 2 and the parameters are set from a defect free specimens. These parameters; welding speed, rotational speed and tilt angle were kept constant throughout the process. The welding tool material used is H13 steel. The tool pin shapes used in this study were cylindrical tapered, hexagon and triangle. Detailed tool specifications are presented in Table 3.

Table 2. Welding parameters for FSW.

Parameters	Values
Rotational speed	1500 RPM
Welding speed	45 mm/min
Tilt angle	1°

Table 3. FSW tool specifications.

Items	Values (mm)
L, length of pin	2.80
d, diameter of pin	3.00
D, diameter of shoulder	10.50

**Figure 1.** (a) Cylindrical tapered (b) Hexagonal (c) Triangle.

Tensile test was performed to evaluate the mechanical properties of the joints. The tensile test was prepared according to the ASTM B 557 M – 07 standards. The tensile test was conducted with one sample have three repetitions and the average values were presented in result and discussion. The data from the tensile test was recorded and analyzed accordingly. A metallographic specimen was performed to analyze the microstructure of welding area. To analyze the microstructure the cross-sectional specimens were then cut and mounted. The mounted samples were grinding manually using different grades sand papers; 240, 320, 600, 2400. The microstructure of the weld specimens was observed using an optical microscope.

3. Results and Discussion

3.1. Weld Appearance

The FSW weld appearance of polypropylene (PP) of different pin tool geometry shown in Figure 2. The inset in each sample shows a closer view of the weld scan. Figure 2(a) is the sample of FSW plate by using cylindrical tool profile with parameter 1500 rpm, 45 mm/min and 1° of tilt angle while Figure 2(b) is the sample of FSW plate by using hexagon tool profile with same parameter. The Figure 2(c) shows the sample using triangle tool profile also using with same parameter. All of the plates that show on that figures are defect-free samples. It also worth noting that from the tensile test conducted below, sample (a) has a higher joint strength compared to sample (b) and sample (c).

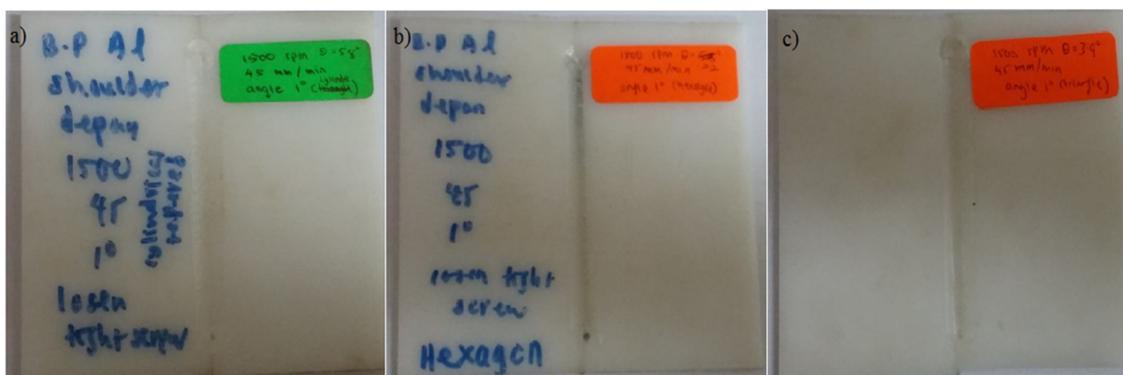


Figure 2. (a) Weld appearance cylindrical tapered pin shape (b) Weld appearance hexagon pin shape (c) Weld appearance triangle pin shape.

3.2. Tensile Test

Table 4 illustrates the tensile test data in table. The graph shows the sample number 2 for cylindrical using cylindrical tapered tool shape with parameter 1500 rpm, 45 mm/min and 1° of tilt angle has the highest tensile strength which is 8.95 MPa. The sample number 2 for triangle using triangle tool shape with same parameter has the tensile strength of 5.78 MPa. The third highest tensile strength is 5.62 MPa was obtained by sample number 1 for hexagon using hexagon tool profile with same parameter that are 1500 rpm, 45mm/min and 1° tilt angle.

Table 4. Result tensile test.

Number of samples	Ultimate tensile strength (MPa)	Tool geometry
C1	6.57	Cylindrical tapered
C2	8.95	Cylindrical tapered
C3	8.63	Cylindrical tapered
H1	4.73	Hexagon
H2	5.62	Hexagon
H3	1.50	Hexagon
T1	5.29	Triangle
T2	5.78	Triangle
T3	2.46	Triangle
Base metal	23.0	

Figure 3 show that the tensile fractured location. This test is done to find where the breakage occurs in the rear side of the welded polypropylene. This test concludes that there was lower strength on the back side of the weld, so the breakage was initiated from the point on the rear side of the welded specimen. According to experiment that conducted for the base metal tensile strength, the ultimate tensile strength for polypropylene (PP) is 23 MPa. The welding efficiency shows from equation for cylindrical tapered pin shape tool profile is the strongest, 35% compare to hexagon and triangle pin shape tool profile. The welding efficiency for hexagon and triangle pin shape tool profile is 23% and 24% respectively. On the other hand, hexagon pin shape tool profile is the weakest of tensile strength. The cylindrical tapered pin shape tool is the highest welding efficiency because the composition of polypropylene (PP) using this tool is concentrated may cause an inclusion defects in weld cross section [5]. After that, composition of polypropylene (PP) become low and may causes porosity in weld cross section [6]. Because of that, hexagon pin shape tool is the lowest welding efficiency.

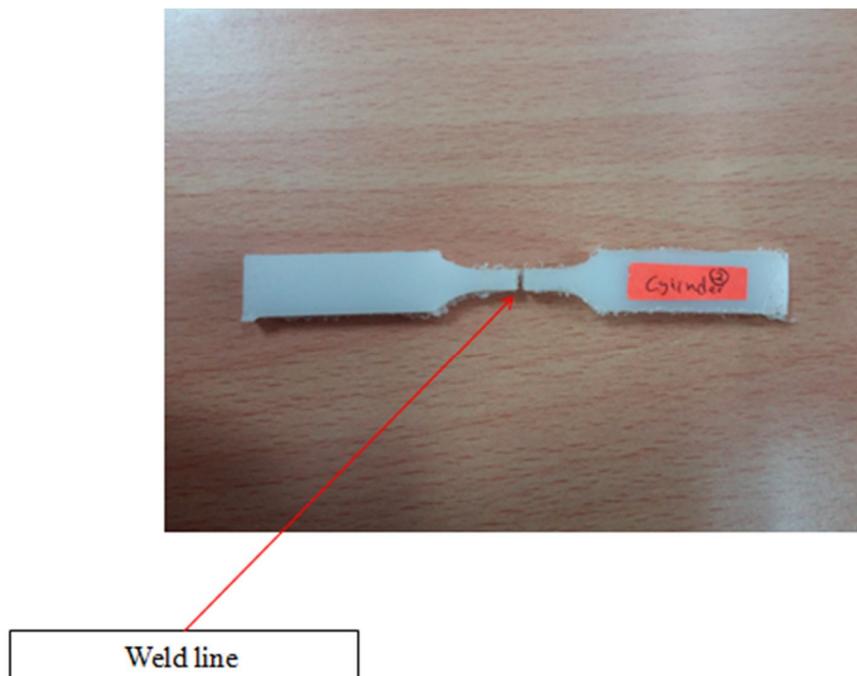


Figure 3. Tensile test fracture of polypropylene (PP).

3.3. Angular Distortion

Distortion is any unwanted physical change or departure from specifications in a fabricated structure or components, as a consequence of welding. In this experiment angular distortion was appeared. Angular distortion is weld tends to be wider at the top than the bottom causing more solidification shrinkage and thermal contraction [7]. The angular distortion occurs after the first run of weld cools, contracts and draws the plates together. The second run has the same shrinkage effect but its contraction is restricted by the solidified first run which acts as fulcrum for angular distortion.

Cylindrical tapered is the highest of angular distortion occurred, 5.8° . After that, angular distortion occurred in 3.9° using triangle pin shape tool. Then, the lowest is hexagon pin shape tool that angular distortion occurred in 2.2° . The highest angular distortion occurred at cylindrical tapered because the pin profile is flat faces and associated with eccentricity. This eccentricity allows incompressible material to pass around the pin profile [8]. Because of that, the highest an angular distortion obtained using cylindrical tapered pin shape tool. After that, an angular distortion is lowest when using hexagon and triangle pin shape tool cause that profiles produce an energetic stirring action in the flowing material due to flat surfaces [8]. From the data, it can be concluding that the angular distortion effects the tensile strength. When the angular distortion is increase the tensile strength also increase.

3.4. Macrostructure analysis

In this experiment the polypropylene (PP) material through the process of Friction Stir Welding (FSW). The composite of polypropylene (PP) material is stir mix together to form a weld joint and the material can be joint. Figure 6 shows the reason why cylindrical tapered pin shape tool is the highest tensile strength. In cylindrical tapered the inclusion defect is appeared at cross section weld line. The inclusion occurs make the weld joint is become stronger and the tensile strength is the highest [9] compare to hexagon and triangle pin shape tool. Inclusion occurs because when the pin shape tool is plunge into polypropylene (PP) material the stir process between pin shape tool and polypropylene (PP) occurs and may cause the composite of polypropylene (PP) is concentrated. When the composite polypropylene (PP) concentrated, it was solidified at weld joint. The solidification of concentrated composite polypropylene (PP) called inclusion defect. After that, from Figure 7 the wormhole defect is appeared. The wormhole occurs at cross section weld line of hexagon pin shape tool. The effect of wormhole may affect the tensile strength of weld line [10]. These defect causes the hexagon pin shape tool is the lowest tensile strength. Wormhole occurs because the composite of polypropylene (PP) material is concentrated during stir when the Friction Stir Welding process occurred. Because of that wormhole defect occurs at the cross section of weld line on polypropylene material when using hexagon pin shape tool. On the other hand, the porosity is obtained in Figure 4. Porosity appeared using triangle pin shape tool. It is because insufficient of heat generated from the friction of tool and it not stir fully well during welding process. The effect of porosity causes the tensile strength become low.

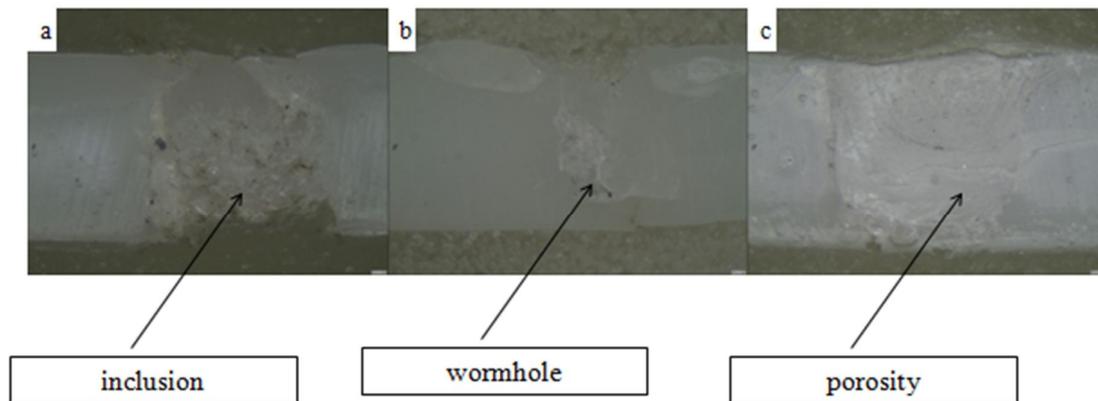


Figure 4. (a) Weld cross section cylindrical tapered pin shape tool (b) Weld cross section hexagon pin shape tool (c) weld cross section triangle pin shape tool.

3.5. Microstructure analysis

In Figure 5 the microstructure using cylindrical tapered pin shape tool is showed. From that figure the tunnel defect is obtained. When the tunnel defect is obtained the angular distortion was formed because the deformation between polypropylene (PP) materials is occurred. The tunnel defect is occurred at weld line. Because of that it when using cylindrical tapered pin shape tool, it will more deform compare triangle and hexagon pin shape tool. The residual stress between these tools, cylindrical tapered pin shape tool is more residual stress.

In hexagon pin shape tool, the microstructure is same as like cylindrical pin shape tool. It showed in Figure 5. But, it a little bit different compare cylindrical tapered it is a porosity defect is appeared. The effect of porosity will affect tensile strength, the tensile strength become low and also the angular distortion is less compare to triangle and hexagon pin shape tool [11]. This reason hexagon pin shape tool is lowest tensile strength. After that, for triangle pin shapes tool it also same to cylindrical tapered and hexagon type pin shape tool. But in microstructure triangle pin shape tool the area of tunnel defect is smaller to cylindrical tapered pin shape tool. It had been showed in Figure 5. It is because triangle pin shape tool is less residual stress compare to cylindrical tapered pin shape tool. Inclusion and

porosity are also appeared in triangle pin shape tool. Inclusion make the tensile is high compare to hexagon but cylindrical tapered pin shape tool is the highest. In conclusion, the highest angular distortion using cylindrical tapered pin shape tools while the lowest angular distortion using hexagon pin shape tool.

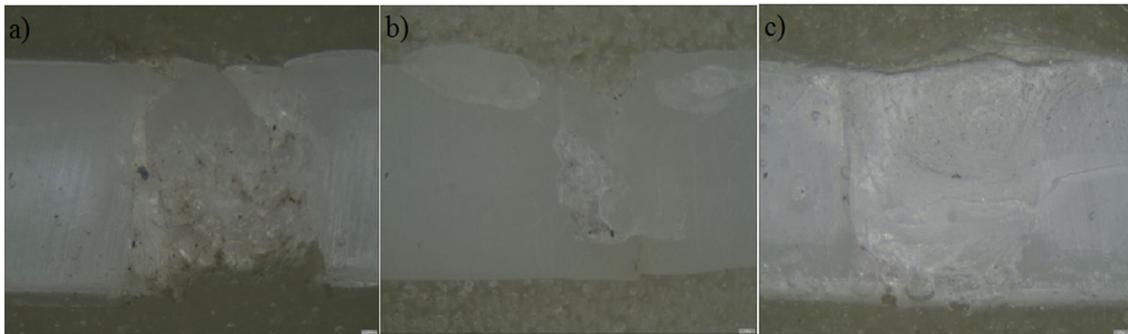


Figure 5. (a) Microstructure cylindrical tapered pin shape tool (b) Microstructure hexagon pin shape tool (c) Microstructure triangle pin shape tool.

4. Conclusion

The fabrication of joining 3 mm thick polypropylene (PP) plates were successfully done by using Friction Stir Welding (FSW) process with fix parameter of welding speed, rotational speed and tilt angle. It is also done by using different tool geometry and was butt joint. The highest tensile strength is 8.95 MPa using a cylindrical pin shape tool compare hexagon and triangle pin shape tool with tensile strength values of 5.62 MPa and 5.78 MPa respectively. The macrostructure analysis shows for cylindrical tapered pin shape tool an inclusion was obtained while hexagon pin shape tool wormhole defect was occurred and triangle pin shape tool porosity was observed. The microstructure analysis shows that polypropylene (PP) will produce tunnel defect at the welding cross section. This tunnel defect caused an angular distortion obtained for polypropylene (PP) material. The optimum for pin tool geometry in this research is cylindrical tapered pin shape tool because it is the highest tensile strength value. AZ31B magnesium alloy and AA6061 aluminium alloy without using filler ER5356 is about 67%. This show FSW with filler is better about 9% increases of joining efficiency.

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