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Investigation on the effect of different friction stir machining tools shape on the mechanical properties of magnesium alloy work piece

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Abstract. Friction stir process (FSP) is a method of solid-state consolidation that uses an inexhaustible tool to increase the modification of work piece structural. This current work presents a study of friction stir process on magnesium (Mg) alloy work piece using different design of pin profiles tool. Experiments were conducted in dry condition where tool progression was monitored carefully in every milling passes, then the effect and quality criterion were measured. Result shows that the dominant tool of friction stir process mechanism of mild steel tool is the strength intensity increased at higher speed and lower plunge length due to the superiority of friction stirred region on the magnesium. Furthermore, the hardness of the stirred friction of Mg alloy also increased by using a triangle pin profile design.

1. Introduction

In recent years, aluminium alloys have been the popular materials used in cars to reduce weight but magnesium-based alloys have become well known in recent years because of their good strength to weight ratio and their low density compared to aluminium alloys [1]. Magnesium and its alloys have recently been evaluated as excellent material for automotive and aerospace industries owing to its low density, high specific strength (158kN-m/kg), responsive cast-ability, great weld ability and formability properties, strong damping, and superior machinability [2].

Recent studies have implemented friction stir processing (FSP) to modify the upper surface of the metallic materials. In FSP, determination of tool parameters specifically as the tool traverse speed (v) and the rotational speed of tool (ω) in conjunction with the probe and shoulder diameter ensures the amount of heat required on the work piece [3]. The material surface is altered by embedding a cylindrical rotating tool containing a small probe at the tip and plunged into the material, so that the shoulder comes into contact with the sheet surface along the required length in the traverse direction by applying a suitable load during FSP [2,4-7]. Subsequently, the connection between the shoulder rotating tool and the material sheet generates heat that softens the material and with the mechanical stirring induced by the probe, the material within the processed zone undergoes strongly plastic



deformation resulting a dynamic recrystallized fine grain structure [8-11]. Thus, this study aims to developing prescient tools that can predicate microstructure and properties of the processed material. Hence, one can select the suitable and acceptable tool shape to achieve and attain the desired microstructure modification and mechanical properties.

2. Material and experimental method

The samples of Mg alloy AZ91A were prepared with the dimension length 40 mm, width 40 mm and thickness 30 mm. The composition of the Mg alloy AZ91A is provided in Table 1. The FSP experiments were carried out on a milling machine (MAKINO KE55). All the samples were subjected to single pass of FSP using four different design of pin profiles. The work piece and the FSP tool were clamped and setup on the machine as shown in Figure 1. The FSP tool was made from ASTM A-36 mild steel with a body diameter 20 mm, shoulder diameter 15 mm, pin length of 3 mm and pin diameter of 6 mm. The FSP tool pin profile designs were varied to cylindrical, taper, square and triangle shapes (Figures 2 – 5).

Table 1. Chemical composition of Mg alloy AZ91A.

Element	Al	Zn	Mn	Si	Cu	Ni	Mg
Content%	9.7	1.0	0.5	0.5	0.1	0.03	91.2

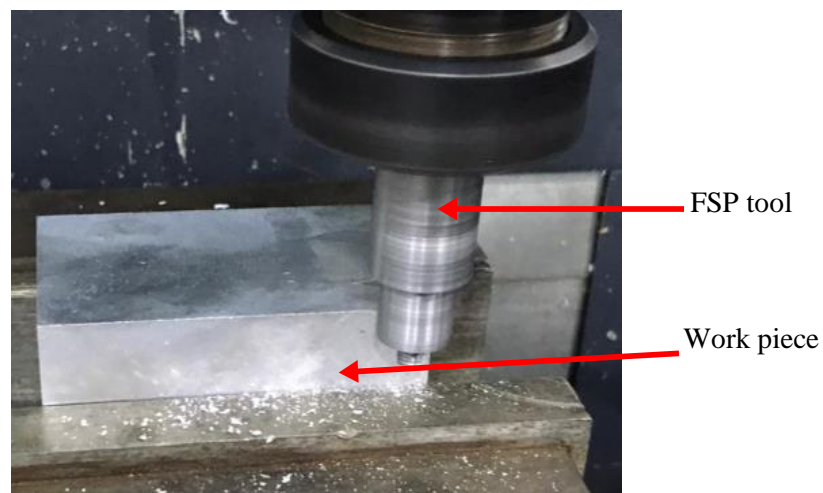


Figure 1. Apparatus setup on the milling machine

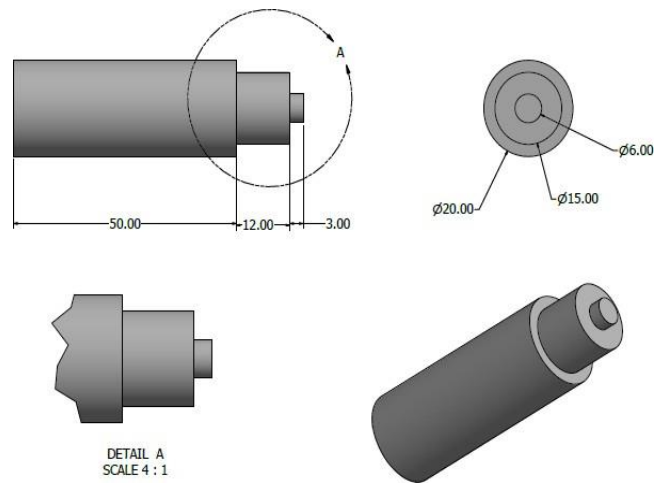


Figure 2. The design FSP tool with cylindrical pin profile (dimensions in mm)

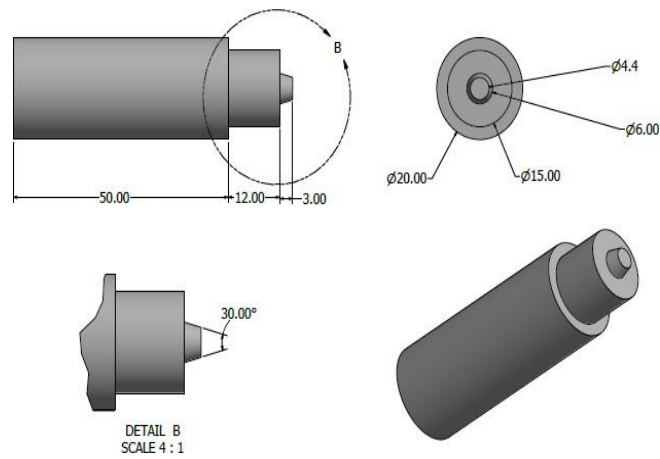


Figure 3. The design FSP tool with taper pin profile (dimensions in mm)

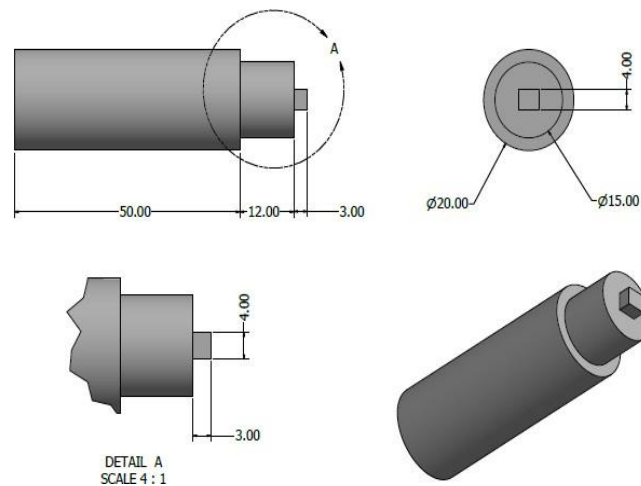


Figure 4. The design FSP tool with square pin profile (dimensions in mm)

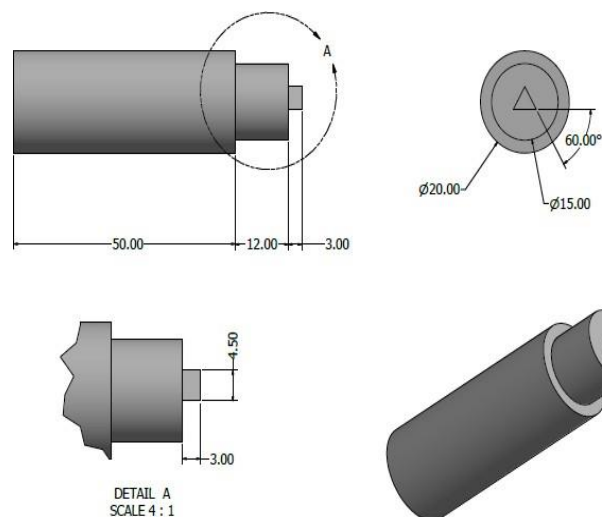


Figure 5. The design FSP tool with triangle pin profile (dimensions in mm)

The FSP experiments were conducted by using milling machining parameters in Table 2 and a repetition experiment was performed for each pin profile. These parameters are commonly used when machining Mg alloy material. All the samples were prepared for mechanical and microstructural characterizations. The hardness of the samples was determined by using a Rockwell indenter at 588.4 N. All the samples were cut, grinded and polished using metallographic technique and was etched by using glycol reagent.

Table 2. Milling machining parameters.

Parameter	
Spindle speed, rpm	1208
Feed rate, mm/min	10
Depth of cut, mm	3
Width of cut, mm	6
Work piece thickness, mm	30-50
Coolant	Dry
Tool material	Mild Steel, ASTM A-36

3. Results and discussions

Mg alloy AZ91A samples were successfully friction stirred using different pin profile designs, i.e. cylindrical, taper, square and triangle pin shapes. The mechanical characterization and microstructure of four FSPed sample are discussed below.

3.1. Friction stir processing quality

The friction stir processing quality was visually observed. Figure 6(a) represents the result obtained using straight cylindrical pin did not produce enough frictional heat to soften the material and allow the material to flow in the retreating zone. The presence of the groove was observed on the entire length of FSP area. It is suspected that the straight cylindrical pin profile design was not suitable under the process parameters it produced high pressure on z-axis and high temperature which resulted in groove existence. Figure 6(b) showed the FSP with taper pin profile was approximately same with the cylindrical pin profile result. However, the presence of the smaller grooves were observed on the FSP area, the other regions were partially closed. This was because the taper pin had a smaller clearance between the tool pin and the work piece. The square pin profile produced smooth worm shape of FSP. This was observed on the entire length of the stir zone as shown in Figure 6(c). However, at the end of the process Mg alloy material accumulated on the pin. Visible burnt marks also observed due to the colour changed of the specimen. The colour of Mg alloys material which filled the space of the stir changed to light brown colour. The triangle pin produced a completely closed FSP region with smoother worm shape formation as in Figure 6(d). Furthermore, there was no accumulated material after the machining was performed.

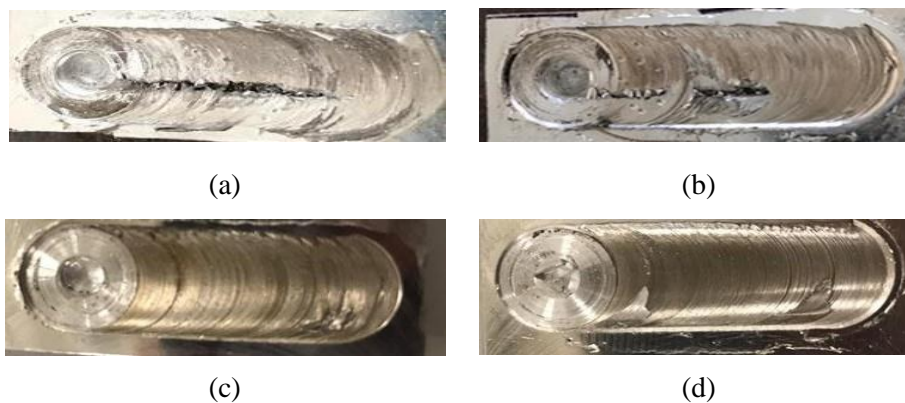


Figure 6. The friction stir processed quality with different pin profile; (a) cylindrical, (b) taper, (c) square and (d) triangle

3.2. Hardness profile of FSPed specimens

The hardness data of actual (as-received) Mg alloy and FSPed Mg alloy is shown in Figure 7. The hardness increased from 69.80 HRB to 77.62 HRB. The highest hardness data was recorded by FSPed specimen made using triangle pin profile. Observation also indicated that FSP had affected the hardness of the Mg alloy. The machining parameter and the design of FSP tool pin played an important role. From the hardness data it is evident that the value of the hardness for different pin profiles increased from cylindrical to the triangle pin. As the grain structure of the metal became smaller and finer, the hardness value of the FSPed Mg alloy was higher compared to the actual base metal hardness.

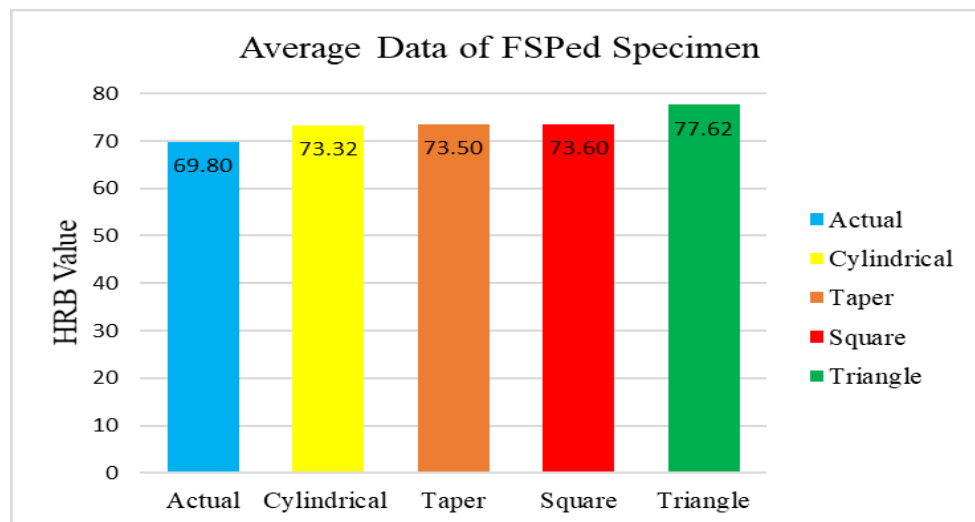


Figure 7. The average hardness graph of FSP by using different pin profile

3.3. Microstructure of FSPed with different pin profile

The micro structure of as-received Mg alloy is presented in Figure 8(a). Whereas, the micro structures of FSPed Mg alloy are shown in Figures 8(b) – (e), it is evident that grain size in the stirred zone (SZ) became finer. This was due to the effect of the pin that was used during the FSP. The mechanical properties of friction stirred Mg alloy are also dependent on the grain size at the SZ.

The pins were designed to disrupt the material's contact surfaces and affect deformation or frictional heating. They sheared the material in front of the tool and move it behind. Indeed, the depth of the deformation was governed by pin design of the tool. The FSP using cylindrical and taper pins are shown in Figure 8(b) and Figure 8(c). It showed larger grains in the SZ due to lesser generation of heat generation and higher load applied causing the melting of the material and inadequate moving of the metal, resulting less consolidation of the stirred material. The FSP using square and triangle pins are shown in Figure 8(d) and Figure 8(e) which revealed a mixture of finer grains. It is due to the shearing that occurred by the sharp pin profiles design. As the sharpness of the pin profile increased, the heat input of the stir enhances which it causes superior hardness of the metal and refined the grains.

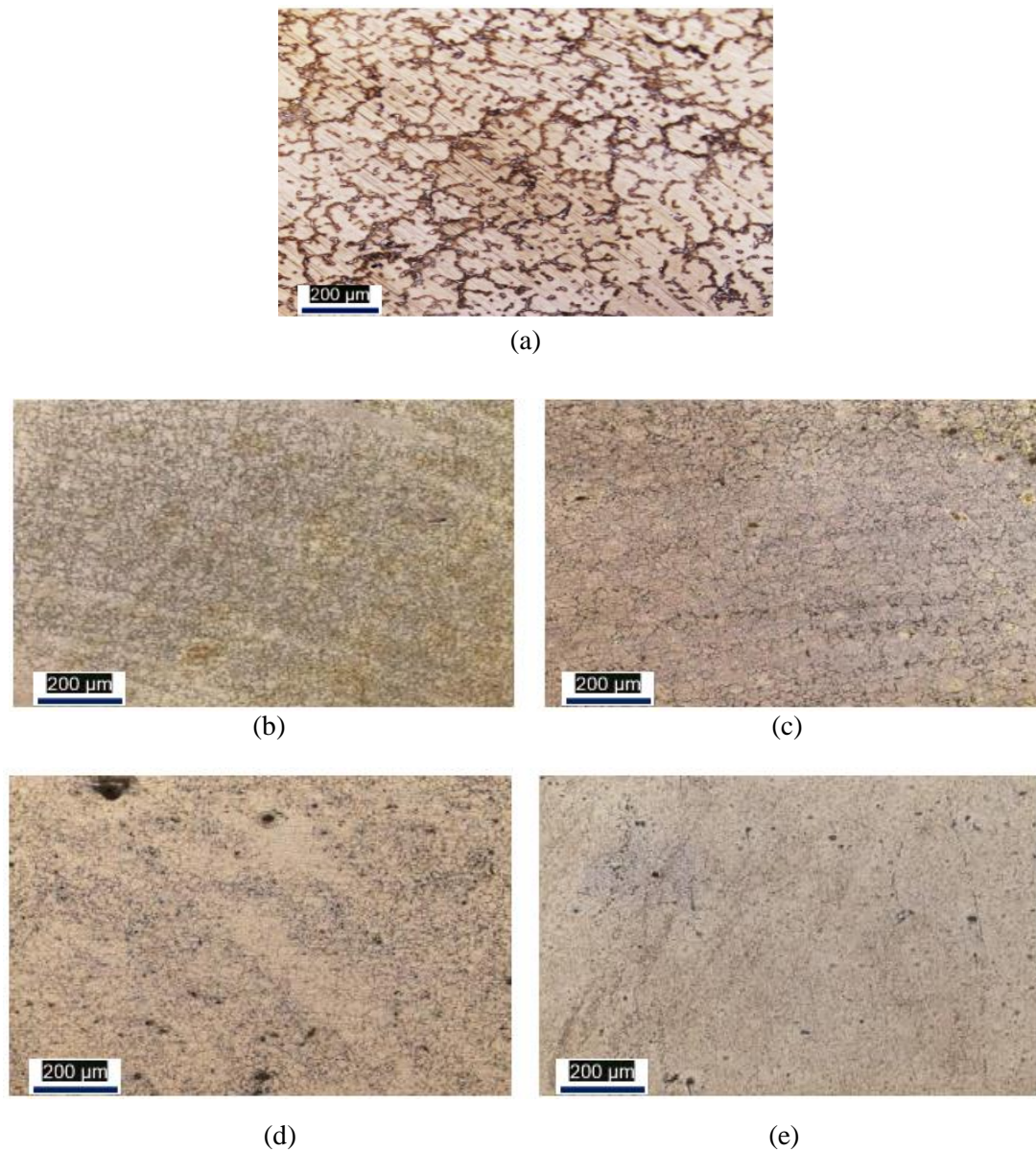


Figure 8. The grain structural of the AZ91A-Mg alloy (a) as received, after FSPed with b) cylindrical pin, c) taper pin, d) square pin and e) triangle pin.

4. Conclusions

Based on the obtained results, it can be concluded that the material flow of the Mg alloy material during FSP was influenced by the type of pin profile as well as the appropriate parameter setup for FSP experiment. It was observed that the highest hardness value of Mg alloy FSP was achieved by triangle pin profile. The grain structure for micro-structure result shown that the stir zone was far small than the other tools pin profiles. The FSP tool with triangle pin profile proved to produce a more desirable result as there no Mg alloy material accumulated at the tool profile. The material flow forms at the advancing side to the retreating side and produce small worm shape formation as it can be seen at the stirring zone, compare to other tools shape that produced few defects during FSP.

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