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Improvement of Hardness of Aluminium 7075 Metal Matrix Composite with Silicon Carbide Powder by Friction Stir Processing

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ABSTRACT: *The aim of this experiment was to improve the mechanical properties of aluminum alloys Al 7075 by friction stir processing, a solid-state technique for microstructural modification using the heat from a friction and stirring. The parameters of friction stir processing for aluminum alloys Al 7075 were studied at constant travel speed was 20 mm/min under rotation speed 1120 rpm. Silicon Carbide particles were uniformly dispersed into an Al7075 matrix which promotes grain refinement and microscopic structure and hardness properties were increased by this technique. The hardness of friction stir processing was 83.67 HV which was higher than the base metal 71 HV. Additionally, the Silicon Carbide particle upon Al 7075 region showed fine grains even at elevated temperatures (~400 ºC) resulting in the pinning effect by the silicon carbide for Friction Stir Processed (FSPed) Al 7075 particles Consequently, the application of the friction stir processing is a very effective method for the mechanical improvement of semi-solid metal aluminum alloys.*

KEYWORDS: Friction stir processing; Al 7075 Aluminium Alloys; Silicon Carbide, Hardness Test.

INTRODUCTION: Friction stir processing (FSP) is a method of changing the properties of a metal through intense, localized plastic deformation. This deformation is produced by forcibly inserting a non-consumable tool into the work piece, and revolving the tool in a stirring motion as it is pushed laterally through the work piece. Friction stir processing (FSP) was developed based on the principles of friction stir welding (FSW) which was developed and patented by TWI Ltd, Cambridge, UK in 1991. FSP is a solid-state welding, microstructural modification technique using a frictional heat and stirring action, has recently attracted attention for making aluminum alloys with an excellent specific strength, and its studies have been actively performed [1-9]. Friction stir processing is a special technique to improve the microstructure in the solid state by using the heat from friction for the aluminum-casting alloy, which has a higher specification [10-13]. The mechanical properties of friction stir processing are improved due to the grain refinement of the microstructure [14-18]. The Semi-Solid Metal (SSM) is the one of potential technology for die casting, but there is not much developed in the past decade. Aluminum alloy 7075 is an aluminum alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys. However, aluminum casting is limited by mechanism such as hardness, tensile, elongation and fatigueness, which cause from porosity. Friction stir processing is effective for improving the mechanical properties and microstructure of aluminum alloy castings. For this research, we use the technique to improve the mechanical properties and the microstructure of a friction stir process of aluminum alloy castings, investigate the variable in the stirring which affects the structure of the microstructure and mechanical properties of the area to stir zone, and improve the processes used to enhance the mechanical properties as well as terms of research and to extend the results to the industry.

SILICON CARBIDE (SiC) CERAMIC PROPERTIES:

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing.

EXPERIMENTAL PROCEDURE: Material used in the experiment is an aluminum alloy 7075, cut into bite size 100×20×4 mm Commercially available SiC powder (mean diameter: 1micrometer, 99% pure) was used. The SiC powder was filled into a groove (100mm×2 mmx1mm) on the Al7075 plate before the FSP was carried out. The FSP tool made of h13 has a columnar shape (Ø6 mm) with a probe (Ø3 mm Pin diameter, length: 6 mm shown in Fig 3). The probe was inserted into the groove filled with the SiC powder. A constant tool rotating rate at 1120 rpm was adopted and the constant travel speed was 20 mm/min with tool tilt angle of 1º was applied.

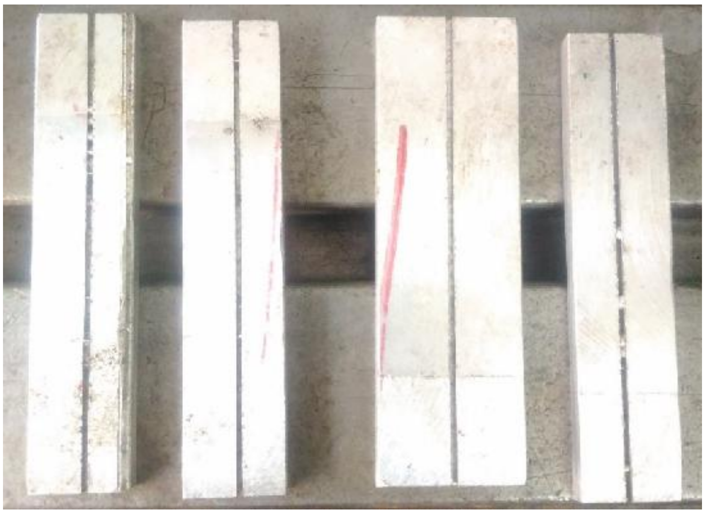

Fig 1: Base Metal Aluminium alloy Al7075

Fig 2: Silicon Carbide powder is filled through out the groove

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Table 1. Chemical compositions (% weight) of the base materials.

Materials	Zn	Mg	Cu	Si	Fe	Mn	Ti	Cr	Al
	5.6 – 6.1	2.1-2.5	1.2-1.6	0.5	0.5	0.5	0.5	0.5	Bal

Fig. 3. FSP tool used

Fig 4 (a) & (b) Specimen before & after Filling of Silicon Carbide Powder

Fig 5: Friction Srir Processing is carried out using Vertical Milling Machine

(a) The material used in this study was Silicon Carbide with 400 meshes. The chemical composition of the alloy is presented in Table 1.Aluminium7075 samples sized 100 mm x 20 mm x 6 mm machined from cast Al 7075 billets were subjected to FSP (processed in air). Prior to the FSP, the samples were polished and chemically cleaned with alcohol to eliminate surface contamination, and dried in air. The friction stir processing was done on a vertical milling machine. All samples were processed using a tool made of h13 tool steel, consisting of a cylindrical 10 mm diameter shoulder. A pin diameter was 3 mm, and a pin length was 6 mm. The surface of the stir tool was smooth and linearly traversed at v=20 mm/min. The rate at which the tool was immersed perpendicularly to the surface (r) was 2 mm for all samples. Then, after having achieved full immersion of the tool, the main movement of the tool was performed with the welding rate vs. the rotational speeds (n) were within the range of 1120 to 1200 rpm with 1degree tilt angle. Within the range of the adopted process parameters a heat plasticization of the silicon carbide was observed, and this was the precondition for carrying out the process of modification with the FSP method. The specification of the treatment parameters is presented in Table 2. The depth of structural changes was about 600–650 µm, and this approximately corresponded to the length of the working tool shank. The FSP pattern and the examples of the macroscopic effects of the treatment obtained at 20 mm/s traverse speed, using 1120 revolutions per minute.

(b) Fig. 6. Friction stir processing; a) scheme, b) sample- exemplary macroscopic effects. The structural research was carried out with the use of the Optical metallurgical light microscope. The phase composition of the samples was determined by X-ray diffraction (XRD) with a Seifert XRD-3003 diffract meter (rich. Seifert & co, Hamburg) using filtered co K α radiation (λ=0.17902nm) operated at 30 kV and 40 mA. The used exposure time was 186 min and the analysed spectra taken from 2θ range of 20-90°.

After the friction stir processing, the specimen is cut perpendicularly to the vertical stirring shown in Fig. 7. These sections were polished and etched using Keller's reagent: 190 ml H2O, 5 ml HNO3, 3 ml HCl, and 2 ml HF. The boundary stirring was checked by an optical microscopy (OM, Olympus: BH2-UMA). The sub-size tensile test specimens with gage length 25 mm, width 6 mm, total length 100 mm and fillet radius of 6 mm were machined and tested according to American Society for Testing and Materials (ASTM E8M-04) standard on an initial strain rate of 1.67×10-2 mm/s at room temperature. The tensile properties of the joint were evaluated using three tensile specimens in each condition prepared from the same joint.

RESULTS AND DISCUSSION

Surface modification by FSP

Fig.5 Illustrates the surface of the stirring Al 7075 aluminum alloy at the rotation speed at 1120 rpm, and travel speeds at 20 mm/min. It showed that the surface of the skin is smooth and uniform mixing. The analyses of the stirred surface, after using friction stir processing, showed that the stirred surface area achieve great synchronized pattern in stirred zone at all condition of rotation speed and travelling speed. The bottom of it stirred a penetration well, no cracks in stirring zone. However, the end of the stirring has a hole due to the profile of the pin. Stirred roughness boundaries surface as a result of heat generated during stirring caused by rotation speed and travel speed. The less internal resistance of material can be observed because the weakening areas of material was stirred resulting in less surface roughness on the stirred area [20] which corresponds to with rotation speed. By increasing the rotation speed from 1120 up to 1200 rpm, the heat generated during the stirred will increased deformations, which also turn material to plastic deformation, less internal resistance of material, and less surface roughness on stirred area. However, heat generated from the friction stir processing is caused by both the rotation speed and travel speed. In the condition of rotation speed at 1200 rpm and travel speed 80 mm/min, the minimum roughness was about 8.85 µm, and found the flake of the retreating side due to heat accumulation in the boundaries stirred which is large enough to cause material in a state of plastic that the motion of the material easy to overflow out of the shoulder of the stirred as a the flake on the retreating side. This causes by the direction of the rotation speed opposite to the direction of the travelling speed [21].

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Table 2: Friction stir Processed (FSPed) at different speed Parameters

Rotational Speed	
1120 rpm	1200rpm

Fig.6 Surface of rotation speed at 1120 rpm and 1200 rpm

MACROSTRUCTURE

The analysis of macrostructure of the speed of Fig. 6. Showed three levels, three different travel speeds: 20 and 40 mm/min without any defects. Heat will accumulate in the stir zone in a state of the plastic flow around the tool that occurs due to heat, pressure, rotation speed, and travelling speed. This causes the flow of material is resolution than the base metal and the direction of flow in the certain of around tool. Furthermore, if the material is not heated enough, it will cause the void [22]. Moreover, the same depth of the stir zone can be seen in all the conditions because the same pressure was applied. The width of the area will get wider which has been stirred up as the heat of stirring.

MICROSTRUCTURE:

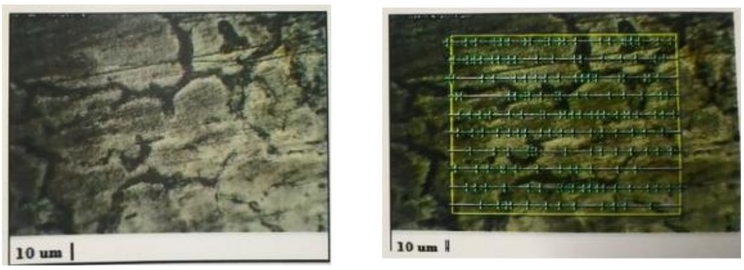

Fig 6: Microstructure of Base Metal Al 7075

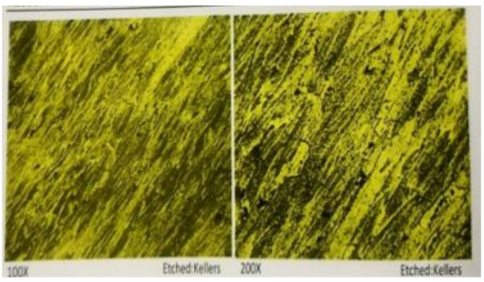

Fig 7: Optical Microscopic image of FSPed Al 7075

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The base metal is globular grains that have equal average size. Stir zone (SZ) area is occurred friction stir processing to fine grain structure more than base metal. The heat generated from stirred to silicon into the mixture in aluminum-metric (α) with eutectic (Mg2Si), homogenized and refine grain, and found that grain size decreases when the travel speed increase [20, 23] due to the high travel speed will be the distribution of silicon particles constantly more than low travel speed. The rotation speed is too high to result in grain larger [24] because increased rotation speed was stirred to the high temperature. As a result, grains is larger which cause the reduction of mechanical properties of the materials. So, the rotation speed threshold is appropriate, because it will produce enough heat and not too much plastic deformation which result in reduction of porosity and fine grain size in the stir zone [23, 25]. However, if specimen gets too little hot, it will appeared that void [22]. Boundary have been influenced by thermal on the advancing side resulting from the friction in the pull from rotation of tool, which is the same direction as the movement of the workpiece. Structural characteristics of grain is similar to pulled. The shape of grain was distorted in the direction of the tool movement. And found that, the high rotation speed has longer grain size than the grain size from low rotation speed because increased rotation speed to higher temperatures will result in more heat. At the retreating side, this results from the friction in the compression from rotation of the tool, which is in the opposite direction to the movement of the workpiece. Structural characteristics of grain are similar to compressed. The shape of grain was fine and narrow more than the advancing side [26]. Found that, the high rotation speed has smaller grain size than the low rotation speed because increased rotation speed to higher temperatures will result in more heat, shown in Fig. 7.

DESTRUCTIVE TESTS: Brinell hardness test and Rockwell hardness test were conducted at plain area of Aluminium alloy 7075 before FSP and at stir zone after FSP respectively. The usual method to achieve a hardness value is to measure the depth or area of indentation left by an indenter of indenter of a specific shape, with a specific force applied for a specific time.

BRINELL HARDNESS TEST: It consists of indenting the test material with a 1/16” diameter hardened steel or carbide ball subjected to a load of 250 kg applied both at plain zone and stir zone i.e. Non-FSPed area and FSPed area. The diameter of the indentation left in the test material at plain zone and stir zone can be calibrated with a low powered microscope. The Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation.

Fig 8(a) Indentation upon Base metal

Fig 8(b) Indentation upon Stir Zone

$$BHN = \frac{F}{\frac{\Pi}{2}D(D-\sqrt{D^2-D_i^2})}$$

Where Load F= 250 Kg

Diameter of Ball Indenter D= 5mm

Diameter of Indentation at Non-FSPed zone D_i = 1.6mm

Diameter of Indentation at FSPed zone D_i = 1.4mm

Therefore, at Non-FSPed zone and at FSPed zone BHN are given as 1210 and 1591 respectively.

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Table 3: Various process parameters under Brinell Hardness Test

Zone type	Load	Rotational speed, rpm	Diameter of Indentation D_i mm	Brinell Hardness Number
Non-FSPed zone	250	1120	1.6	1210
FSPed zone	250	1120	1.4	1591 (Improved)

ROCKWELL HARDNESS TEST: This test is also similar to the Brinell test in that the hardness number found is a function of the degree of indentation of the test specimen by the action of an indenter under static load and it differs from Brinell test in that the indenters and loads are smaller. In this test, the use of diamond indenter enables the determination of higher ranges of hardness. In operation of the machine a minor load of 10kg is initially applied which causes an initial indentation that sets the indenter on the material and holds it in position. Then, a major load of 100 kg is applied over Non-FSPed area and FSPed area.

Fig 9(a) Rockwell Indentation upon Base metal

Fig 9(b) Rockwell Indentation upon Stir Zone

Table 3: Various process parameters under Rockwell Hardness Test

Zone type	Load, Kg	Rotational speed, rpm	Rockwell Hardness Number			
			Trail 1	Trail 2	Trail 3	Average
Non-FSPed zone	100	1120	72	70	71	71
FSPed zone	100	1120	79	85	87	83.67*

*Improved

Conclusions

The results of the specimen during the alloying aluminum, semi-solid, 400 grades Silicon Carbide used in this study can be concluded that:

(1) The surface of specimen is improved by the friction stir process.

(2) Macrostructure through a friction stir processing showed a homogeneous appearance as well. No defective part was found. The surface of stirred is smooth.

(3) The microstructure after the friction stir processing at all conditions have a very refined structure, which consists of a silicon particles in aluminum alloy matrix uniformly distributed throughout the area to be stirred. However, investigation did not find any defects with the stirred.

(4) The hardness of the area was influenced by the thermal both retreating and advancing with increased hardness for all experimental conditions compared to that of base metal. But for the stir zone, the hardness is increased. The condition that increased the hardness is travelling speed at 20 and 40 mm/min with any rotation speed. The highest hardness, obtained at 1120 rpm with travel speed at 20 mm/min, is equal to 84.67 HV, an increase of 18% compared to the base metal.

(5) The Brinell hardness number after using friction stir processing is equal to 1591, an increase of 24% compared to the base metal. It was found that the conditions providing strength to pull up the average is at the speed around the 1120 rpm and at the travel speed at 20 mm/min.

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