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A Study on the Fabrication of Surface Composites by Friction Stir Process

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Abstract— Friction Stir processing is among the latest methods which are used to produce the surface composites. Surface composites are used to improve the surface property of the material. Friction Stir process is employed in the grain refinement as well as the processing of various materials by creating surface composites. Friction Stir Processing is an emerging technology which showed significant advancements in recent times. It was developed from the Friction Stir Welding. Since then, various advancements has seen in this process. Various types of elements like aluminum and magnesium can be easily processed by this method. Recently, elements like tungsten has also been reported to be processed by this method. In this study, the existing understanding and the current status of work by Friction stir processing are discussed.

Keywords—Aluminum Alloys; Friction Stir Processing; Material processing; Super plasticity; Surface composites.

I. Introduction

Since the development of the Friction Stir Processing (FSP), the process of modifying the microstructure become easy. FSP is an emerging technology which is showing its significance at the industrial level. FSP is a useful process with the help of which, the homogenizing and refinement of the grain structure can be done easily. Friction Stir processing is based on the principle of the Friction Stir Welding which was invented by "The Welding Institute" (TWI) in 1991[1].

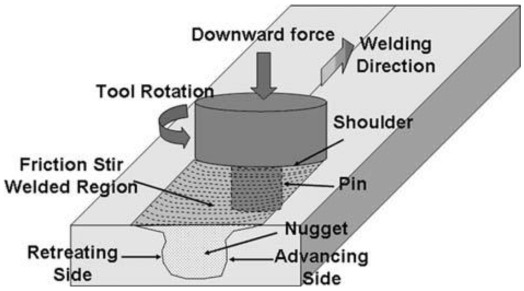

Fig. 1.Illustration of Friction Stir Welding technique.[2]

The Friction stir processing is known as the solid state process due to the reason that in this process the material is heated at the temperature below its melting temperature and hence the material remains at solid state at any given point. The FSP consist of the shoulder and a pin arrangement which are specially designed in proportion to the thickness of the work piece. The pin is intended in the work piece while the shoulder provides the specific rotation [3]. The contact between tool and work piece produces the friction which ultimately produces heat. When the shoulder contacts the surface of the work piece, it provides the excess heat due to friction. The shoulder-pin arrangement is provided with a specific transverse speed in a desired direction. This heat softens the work piece below its melting temperature. The pin cause the mechanical stirring which helps in the formation of the intense plastic deformation of the processed and produce recrystallized fine grain microstructure. Friction stir processing can increase the micro hardness as well as grain structure of the material. Various Aluminium alloys show an increase in the hardness from 2 to 3 times the base material. In many aluminium alloys the super plasticity has been reported. [4]–[8]

The traditional techniques for grain refinement includes the process which are time consuming, costly and are not environment friendly due to the reason that it consumes high energy [9]. Due to this reason, an alternative method is required for the grain refinement. Friction Stir Process helps to produce the homogenized structure with ultrafine grain structure.

Over conventional methods and other new material processing methods, Friction Stir processing has many advantages. Other processing techniques require multi steps for the processing whereas Friction Stir Processing can perform the same processing in single step. The simple vertical milling machine can be employed in this processing. The tools required in this process are cheap as compared to the other processing methods. These advantages of FSP make it easier, cheaper and preferable over other processing techniques.

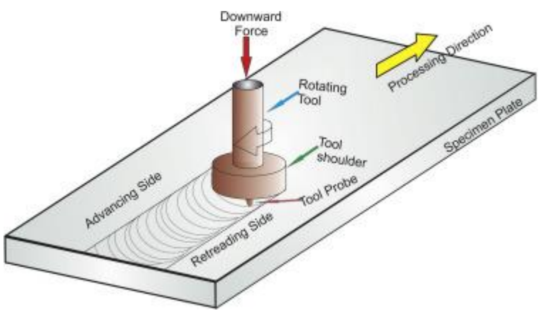

Fig. 2. Illustration of Friction Stir Processing technique.[10]

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II. Fabrication of Surface Composites

In friction Stir processing, reinforcement is the important agent to increase the property of the material. By using the reinforcements in the material by either grooving or holes methods, the hardness and other properties shows a significant advancements. The size of the reinforcement can also alters the result. A fine grain sized reinforcement provides a better result than bigger sized reinforcement. Other factor which also plays a vital role in process is the number of passes used. Various researchers has performed the Friction Stir Processes on various parameters and concluded different results.

Micro hardness of A1050 h24 plates of 5mm thickness was observed to be increased from 23 HV to 60 HV with FSP by MahnoudEt. al [11]. They showed the effect of tool used and its size in the process of friction stir process by adding the particles of SiC in the layer of A1050 h24 plate. The tool probe of diameter 3, 5 and 7mm was used with a length of 3.5mm. Various different types of tool profiles were used in the process. The Friction Stir Process was carried out at the transverse speed of 1.66mm/sec and having rotational speed of 1500 rpm to 2250rpm. The SiC reinforcement was used and placed in the plate groove of 1.5 mm depth and 3mm width. After that the aluminium sheet of 2mm was used to cover the groove. The tool tilt angle was of 3 degree. Three passes were used in the process. After the process, Transmission Electron Microscopy (TEM) was carried out to observe the homogeneity of the SiC in the material. The process showed that the rotational speed of 1500 rpm was the optimum speed and the best nuggets were produced at 5mm diameter. In the same study, it has been observed that the profile of the tool and the welding torque has a relationship in them. High torque of welding was observed by using the flat edge probe as compared to that of the circular probe The Rotation speed have a greater effect on the torque whereas travelling speed have also its effect on torque.

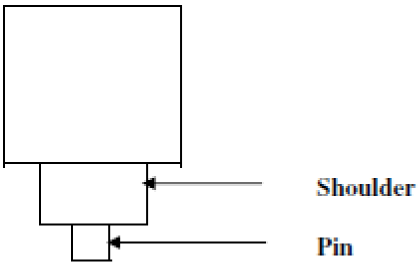

Fig. 3. FSP tool profile.[12]

Micro hardness of AZ31 was observed to be increased to 80 HV by MorisadaEt. al[13]with the help of FSP. They studied the effect of FSP on the hardness of AZ31 by using SiC as reinforcement. The reinforcement of SiC with a size of 1 micro meter was used over the base plate of magnesium alloy. The grooving method was employed for mixing the reinforcement. The groove of 1mm width and 2mm depth was made. The tool was made with the SKD61 material. The shoulder was kept at a diameter of 12mm and the tool pin was used with a height of 1.8mm and diameter of 4mm. The Friction Stir Processing was performed at a transverse speed of 25 to 200 mm/min and rotating speed of 1500 rpm. The tool was tilted at an angle of 3 degrees. The homogeneity of SiC in the work piece was observed with the help of Transmission Electron Microscopy (TEM) and Scanning Electron Microscope (SEM). The grain structure of the FSPed work piece was observed with the help of Optical Microscopy. The micro hardness seemed to be increased from 48.1 HV to 69.3 HV. The grain size of Friction Stir Processed AZ31/SiC was observed to be finer than that of without Friction Stir Processed. When the material was heat treated at above 300 degrees, then the micro hardness was observed to be decreased to 40 HV.

ShivramanEt. al [14] observed that the presence of the PZT ceramics in the NAB alloy helps to increase the hardness and the strength of the overall alloy. In this study the Barium Titanate was taken as the reinforcement and NAB material was taken as a work piece. The NAB plate had a dimension of 6 mm thickness , 100 mm width and 150 mm length. The reinforcement was added by using the holes method. Holes of 2 mm depth and 2 mm diameter were drilled in the plate. These holes were then filled with the BaTiO3 PZT ceramic powder. The rotational speed was carried out at 931 rpm while the transverse speed was 30mm/min. The tool pin was threaded in profile and had a shoulder diameter of 18mm and shoulder length of 3 mm. The microhardness of 180 HV was observed in the as-cast surface. On the other hand, without reinforcement FSPed surface was observed to have the microhardness of 228 HV and FSPed surface with reinforcement showed the hardness of 265 HV. Tensile properties were also seemed to be increased after the process.

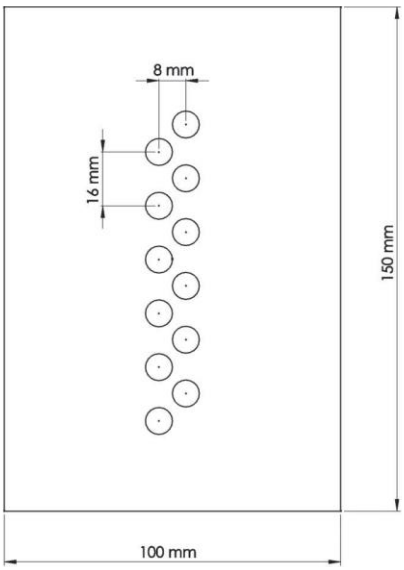

Fig. 4. FSP tool profile.[14]

K Oh-ishiEt. al [15]suggested that the NAB materials are not heat treatable . Therefore FSP can be used to strengthen the surface layer. In the experiment, Cast NAB was used as the work piece. The shoulder diameter was kept at 28.8 mm. The pin height was kept at 7.95 mm and pin diameter was 7.95 mm. The pin dimension was tapered with spiral grooves. Friction Stir Process was carried out at a transverse speed of 152mm/min and tool rotating speed of 800 rpm. It was observed that the Thermo Mechanical affected zone (TMAZ) was about 5 to 6 mm in depth and 20mm in width. In TMAZ,

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the variation in the microstructure was constant with severe strain, strain rate, high peak temperature and temperature gradient.

X C LuoEt. al [16] studied the tensile properties and microstructure of surface composites of AZ61 produced by multipass FSP. They suggested that the single pass friction stir process can refine the grains of AZ31 magnesium but the multipass FSP can further increase the refinement of the grains. In this study, plate of AZ31 magnesium alloy with dimension of 178 length, 170 width and 6mm thickness was used. The tool shoulder of 18mm diameter was used. The tool pin of 7 mm diameter and 5mm thickness was used. The Friction Stir Process was performed at a transverse speed of 600mm/min and rotating speed of 1000 rpm. The tool tilt angle of 2.5° towards the normal direction was used. The friction stir process was performed at 6 passes. In the study, it was also observed that the presence of inhomogeneous microstructures during the multi pass FSP and single pass FSP results in the decrease in the strength in the transverse direction. It has been concluded that the multi pass friction stir process can be used to produce the large scale of AZ31 magnesium alloy plates without any macro defects.

CI Chang Et. al [17]produced the nano based Mg-Al-Zn microstructure with the help of two step friction stir process. They used the grain size of 85 nanometers and produced it by solution hardened AZ31. The two step friction stir process was used in the process. In the first pass, shoulder of 10mm diameter was used. The pin had a diameter of 3mm while the pin length was 3mm. The second pass friction stir process used the pin with length of 2mm and diameter of 2 mm. The shoulder diameter was kept at 6mm. In both the passes, rotational speed of 1000 rpm and travel speed of 37mm/min was used. The tool tilt angle was 1.5°. The tests were confirmed by using the Transmission electron Microscope and Scanning electron Microscope. The micro hardness was carried out at a load of 200gf load for 10 seconds. It was observed that, before FSP the micro hardness of the material was 50HV, whereas after the first pass, the micro hardness was reached at 115 to 128 HV and on the other hand, after the second pass the micro hardness was observed at 130 to 155 HV. During the first pass, the micron or sub-micron scaled grains were produced in the FSPed processed plate. Due to the pre-existing microstructure and high strain rate, the copious nuclei were produced during the second pass. The liquid nitrogen cooling system was used to stop the growth of the recrystallized grains.

DolatkhahEt. al [18] performed the friction stir process on the Aluminum 5052 alloy. SiC of 5 micrometer and 50 nanometer size were used as the reinforcement. The study concluded that the hardness and the wear properties were increased with the change of tool rotating speed, increase in number of passes and decrease in SiC particle size. The work piece of dimension with 5 mm thickness, 100 mm width and 125mm length was used. The reinforcement was added in the work piece with the help of grooving method. The groove of 1mm width and 2 mm depth was used for the process. H13 steel was used as the tool material with the square pin profile. The shoulder with 18mm diameter was used. The pin with 3 mm height and 6 mm in diameter was employed for the process. The Friction stir process was performed with the rotating speeds of 700, 1120 and 1400 rpm and transverse speed of 40, 80 and 125 mm/min. The tool tilt angle was 3°. Four passes were used for the process. It was observed that the reinforcement was homogeneously mixed in the material at the rotational speed of 1120 rpm and transverse speed of 80 mm/min. In the process, the best results were observed by using the nano sized SiC powder. The wear rate was decreased to 9.7 times and the micro hardness was increased up to 55 % as compared to the as received Al5052.

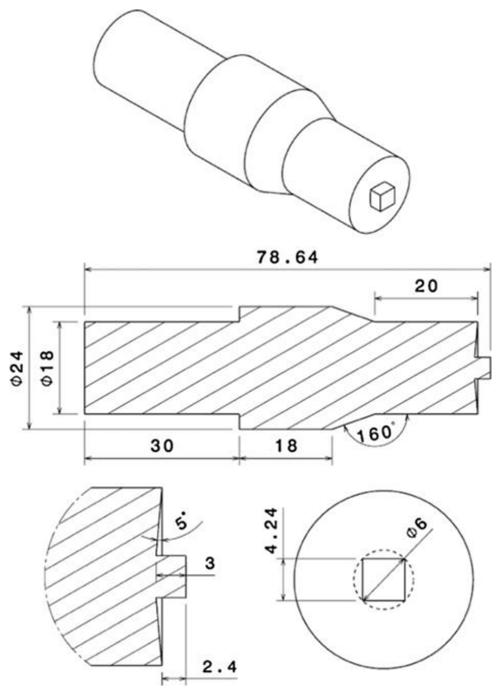

Fig. 5. Profile of FSP tool. [18]

Wang Et. al[19] produced the surface composites of the aluminum metal matrix by using the SiC powder as reinforcing agent. They used the commercial SiC as the reinforcement and 5A06Al aluminum as the base material. Tool material of High Speed Steel was used to perform the Friction Stir Process. The reinforcement was mixed in the work piece by using the grooving method. The grooves were produced at the advancing sides of the pin edge. Tool pin was 1 mm in thickness and 0.5 mm in width. SiC powder was poured into the grooves before proceeding the Friction Stir Process. The Tool had a screwed pin and columnar profile. The FSP was carried out at a transverse speed of 95mm/min and rotating speed of 1180 rpm. It was observed that the as-received material had a hardness of 88 HV. A 10% hike in the hardness was observed at the depth of 0.5mm and 1mm after the friction stir process due to the homogeneous dispersion of the SiC.

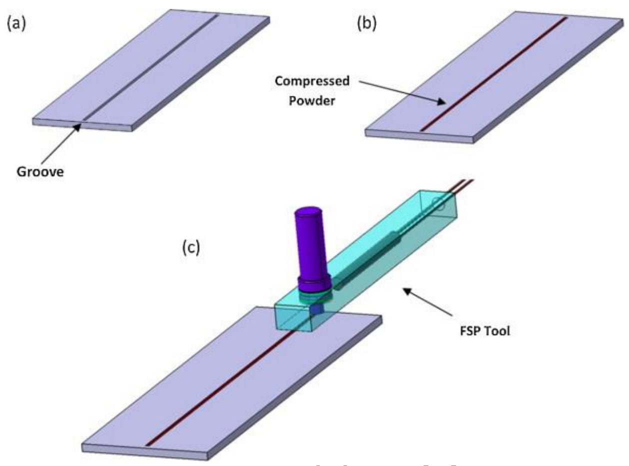

Fig. 6. Grooving method in FSP. [20]

III. Summary and Discussion

Friction Stir Process has emerged as a successful technique in the production of surface composites. The problem of mixing the reinforcement homogeneously has reduced a lot due to this process. Surface composites can now be made very easily due to this process. A simple Vertical milling machine is sufficient to perform the Friction Stir Process. But one have to be very careful in selecting the Tool geometry and dimension in this process. The selection of proper reinforcement is very important. The selection of optimum transverse speed and rotating speed also affects the production of sound surface composites. During FSP, the material is heated below its melting temperature, and all the heat which generates during the process is because of the friction between material and tool. Friction Stir Processing changes the crystal structure of the material and enhances its properties. In various studies it has been showed that Friction Stir Process has increased the micro hardness of the material up to 3 times to its base material micro hardness. The tensile strength has also showed a significant advancement after this process. Various different materials showed positive effect in response with this process. Further more research is required in this process in the commercialization of this process

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