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Surface Composites Preparation of AL5052 Reinforced with Al_2O_3 by Friction Stir Processing

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Abstract*: Friction stir processing is a modified form of friction stir welding process which is introduced to prepare the surface composites or to repair the defects in the surface to enhance the mechanical properties. The process is a green and environmental friendly process, where the required heat is produced by frictional action. In the present work, Surface composites were prepared using Al 5052 as base material and Al2O3 as reinforcement particles. Parameters such as number of passes, spindle speed, feed rate and tool pin profile were taken in three different levels. Six tools were made, three tools with 3:1 and remaining three with 4:1 D to d ratio. Totally 18 experiments were conducted with two group of tools. The results were analyzed to study the influence of above mentioned parameters on mechanical properties like tensile strength, hardness. The results were compared for different D/d ratios. The experimental results revealed that 3:1 D/d ratio tools were given better results than 4:1.Tool with square pin profile given better hardness and strength than the other profiles. This is because of the pulsating effect of the square pin profile. The other parameters have directly proportional relationship up to certain level, after which further increase of parameters reduces the tensile strength and hardness.

Index Terms*: Al5052 with Al_2O_3, Different pin profile , Friction Stir Processing, Number of passes, Surface composites,

I. INTRODUCTION

The life span of the any components is mainly depends on the surface properties the products. A combination of low surface wear rate and more toughness of the interior bulk material are required to prolong the lifespan, where the remaining properties are not achievable in monolithic materials. It has developed as one of the advanced engineering materials having prospective application in numerous areas of automobile, nuclear, electronics and aerospace components.
In the present scenario, to improve the surface properties of the materials several surface modification techniques are developed such as high energy laser melt treatment [1], plasma spraying [2], cast sintering [3] and casting route [4].

Among the different techniques, to modify the surfaces Laser Surface Engineering (LSE) is widely applied. Though various other techniques are also employed to modify the surface properties, the traditional method is based on the liquid state processing at higher temperature. During the liquid state process, it is difficult to avoid the formation of the certain deleterious phases and matrix reinforcement interfacial reaction. During the process controlling the process parameters is also a challenging task.

An economical process was developed to overcome the drawbacks of liquid metallurgy route which is named as Friction Stir processing. The process works well below the materials melting point which avoids interfacial reactions and porosity. Based on the process parameters employed, the process ensures the homogeneous distribution of ceramic particles and refines the grains [5].

Mishra and his team had invented the process as variation of friction stir welding (FSW), a process developed at The Welding Institute (TWI), UK in 1991. FSP was primarily used for fabricating superplastic aluminium alloys with ultra-fine grain size. The basic concept of FSW and FSP are same. In both the processes the material undergoes severe plastic deformation leading to a homogeneous refined microstructure [6].

The major methods of surface composite fabrication through FSP are by a] By Groove method, b] By drilled holes, c] By using cover plate. The schematic diagram of drilled holes method is shown in the figure 1. Surface composites are a group of materials where the core of the material remains untouched and surface comprises of dispersed secondary phase. Chemical or Physical vapor deposition, plasma spraying; laser treatment and centrifugal casting are few methods have been developed to produce surface composites. [7] FSP has many advantages over traditional material processing technologies especially relative to low melting nonferrous materials normally difficult to process. In the last two decades the FSP technology has been extensively studied and has evolved in to many new application directions including superplastic materials and surface composites. [11]. The problems associated with melting and solidification can be addressed by making surface composites using Friction stir process. The mostly used matrix materials are Aluminum, copper, titanium, magnesium, et. , and SiC, Al2O3, B4C, TiC, Ni particles, carbon fibres.

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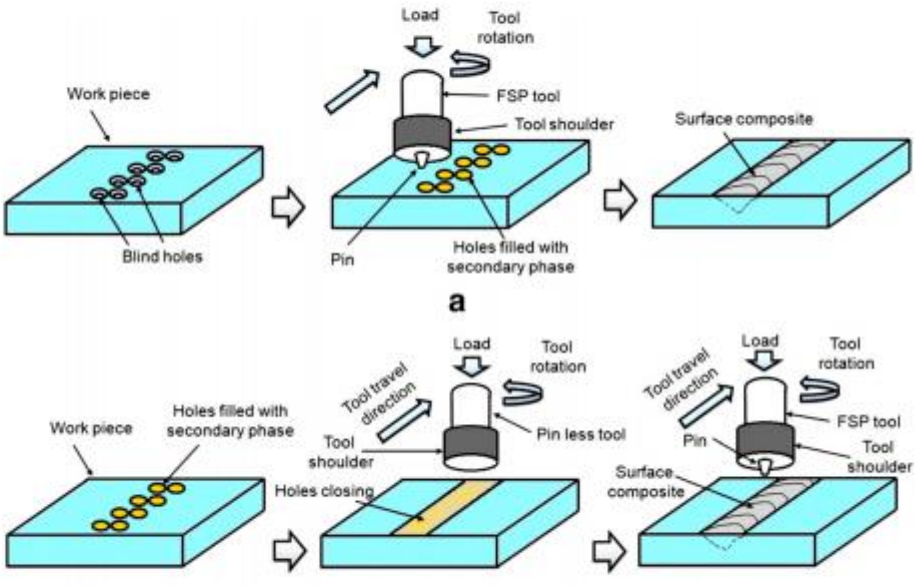

Figure 1 : Drilled Hole Method [7]

To develop the surface composites numerous other approaches have also been applied. Friction stir surfacing was used by many researchers to fabricate surface composite coating over the substrate. In this method, a consumable tool is packed with strengthening particles and is expended to form layer of composite on the work piece.

This is process has several advantages like easiness in controlling the depth of the processed zone by changing the pin length, and this process is considered as energy efficient and green technique due to heat input from friction and plastic deformation.

Bahrami et al [8] investigated the pin geometry on microstructure and mechanical properties of AA7075/SiC nano-composite fabricated by friction stir processing technique using five geometrically different pin tools. Other welding parameters were unchanged. The most uniform particle distribution was found in the case of using threaded tapered pin tool.

Mahmoud et al [9] had done an investigation on the surface composites fabrication of homogenously dispersed SiC particles of size 1.25 µm into aluminum plate surface using friction stir processing technique. Process parameters such as tool rotational speed, traverse speed, size of the groove and its position relative to the tool probe, were considered to analyze the distribution of SiC particles in the stir zone.

Mishra et al [6] using FSP process successfully incorporated SiC particles with different volume fractions into the aluminium matrix. It was established that the homogenous distribution of SiC particles within aluminium alloy matrix resulted better interface bonding.

Devanathan.C et.al [10] made an attempt to analyze the hardness and microstructure of Al 5052 reinforced with cupric oxide surface composites. Because of the pulsating stirring action the best hardness value of 92 and 87 was obtained by the tool having square pin profile and cylindrical profile respectively.

Hardness results showed that, increasing the number of passes increases the hardness value due to better stirring of reinforcement particles.

Kan et.al [11], reviewed the research growths in terms of principle, process and application of FSP technology as well as its upcoming research directions and developments prospects. The feasibility of FSP has been demonstrated extensively via experiments, but the current process is not sufficiently mature. Although the tools used in FSP are in principle, non-consumable they do experience severe wear during this process. Frequent replacement not only affects the efficiency but also increase the production cost.

This process has been successfully utilized by several researchers to produce surface composites and microstructure modification on aluminium, magnesium, titanium alloy.

II. EXPERIMENTAL PROCEDURE

A. Workpiece Material Selection

Aluminium is the abundant material in the world which is the most commonly used material next to steel due to its flexibility. In this work, Aluminum 5052 alloy were purchased and machined to size of 150 X 75 X 6mm. In order to fill the reinforcement, zig-zag holes of 3mm diameter for 3mm depth was drilled centrally. Al_2O_3 reinforcement particles were filled in the drilled holes and clamped tightly to perform the function.

B. Design and Fabrication of FSP tool

The tool design is the primary part of the process and the shape of the tool determines the heating, plastic flow, and consolidating pattern of the metal. The tool material determines the rate of frictional heating, strength of the tool, and working temperature. It was noted from the literature that the square profile gave good weld quality than the other profiles.

In the recommended work Tool steel with the hardness of 52HRC was selected as tool material. Three pin profiles such as cylindrical, square, cylinder taper with thread was selected as the pin profile. The dimensions and machined FSP tools are shown in the Figure.2

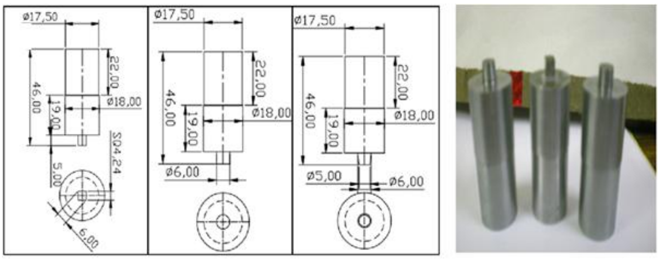

Figure 2. Dimensions and machined Tool

C. Selection of Process Parameters:

In the proposed work, Spindle speed, traverse feed, tool pin profile and number of passes are considered as process parameters. These parameters are taken in three different levels, which require 9 experiments to be carried out as per L9 Orthogonal array. The two sets of experiments were conducted by varying the shoulder to pin diameter ratio. For one set of experiments (9 Experiments) shoulder to pin diameter was maintained 3 and for another set it was maintained 4. Hardness and tensile strength of the weldment were considered for analyzing the effect of process parameters while performing Friction Stir Processing for preparing surface composites. For carrying out the tensile test, the prepared workpieces are cut as per the ASTM E8-04 standard. The table 1 gives the details of the process parameters and their levels..

Table 1 : Process Parameters and their levels

	Factor 1	Factor 2	Factor 3	Factor 4
Run	A:no of passes	B:pin profiile	C:feed	D:speed
	nos	Type	mm/min	rpm
1	2	Cylinder	100	1500
2	3	Square	50	1500
3	1	Cylinder	50	1000
4	2	Tapered Cylinder	50	1250
5	1	Square	100	1250
6	2	Square	150	1000
7	3	Cylinder	150	1250
8	1	Tapered Cylinder	150	1500
9	3	Tapered Cylinder	100	1000

D. **Conducting the Experiments**:

Surface composites were prepared using Computer controlled friction stir welding available in Material Joining Laboratory , Department of Metallurgical and materials engineering, IIT Madras. The prepared Friction Stir Processed specimens are shown in the Figure 3 & 4 for D/d ratio of 3:1 and 4:1 respectively. . The experiments were conducted as per the process parameters framed by L9 orthogonal array.

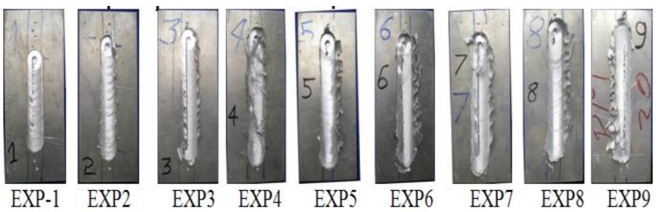

Figure 3. Tensile Specimen for D/d ratio of 3:1

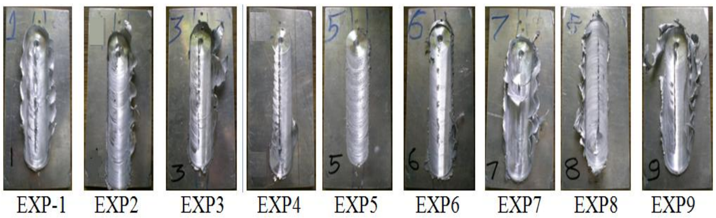

Figure 4. Tensile Specimen for D/d ratio of 4:1

III. Results and Discussion:

The prepared FSP components were tested for its properties tensile strength and hardness. The components were cut as per the ASTM standards and the tensile specimens before the test is shown in the figure 5 & 6 corresponding to 3:1 & 4:1

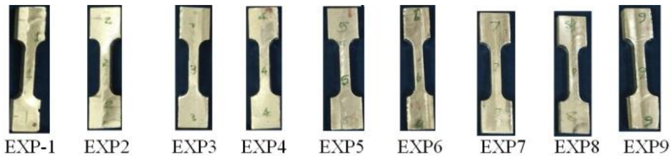

Figure 5. Tensile Specimen for D/d ratio of 3:1

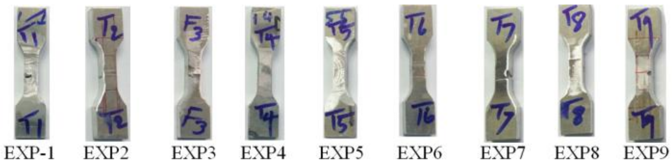

Figure 6. Tensile Specimen for D/d ratio of 4:1

The FSP components were also tested for its hardness and the results of the tensile test and hardness test, the effect of process parameters in output results is discussed below.

Table 2: Hardness and Tensile results (D/d ratio: 3:1)

S.No	Speed	Feed	Profile	No.of Pass	Average Hardness	Avg. UTS (Mpa)
1	1000	50	C	1	73	194.64
2	1000	100	TC	3	64	190.52
3	1000	150	S	2	65	190.35
4	1250	50	TC	2	73	186.16
5	1250	100	S	1	62	200.56
6	1250	150	C	3	76	192.86
7	1500	50	S	3	74	194.64
8	1500	100	C	2	63	191.50
9	1500	150	TC	1	72	191.72

From the samples, totally three readings were taken and the average of the results are given in table 2 and 3 for D/d ratio of 3: 1 and 4:1 respectively.

Table 3: Hardness and Tensile results (D/d ratio: 4:1)

S.No	Speed	Feed	Profile	No.of Pass	Average Hardness	Avg. UTS (Mpa)
1	1000	50	C	1	57	115.51
2	1000	100	TC	3	59	108.57
3	1000	150	S	2	59	158.71
4	1250	50	TC	2	56	110.52
5	1250	100	S	1	59	119.00
6	1250	150	C	3	61	152.60
7	1500	50	S	3	56	149.66
8	1500	100	C	2	61	159.86
9	1500	150	TC	1	56	108.84

A. **Effect of Spindle Speed***:*

The influence of spindle speed on tensile strength and hardness is given in the Figure 7. It also compares the effect of shoulder to pin diameter ratio. Increasing the speed, increase the tensile strength and hardness up to certain level, then decreases the value. This is because increasing the speed, will increase the heat generation which in turn increase the material distribution. But beyond the certain more heat input leads slow cooling, due to which coarse grains were formed. From the graph it was clear that 3: 1 ratio gives better results than 4:1.

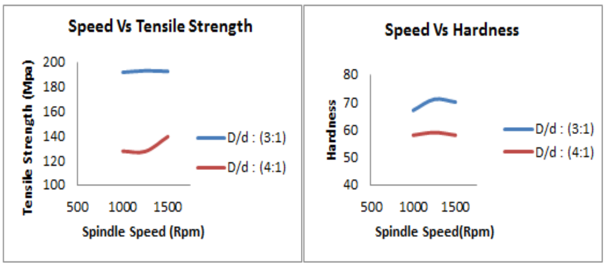

Figure 7. Effect of Speed on tensile strength and hardness

B. Effect of Feed:

The figure 8 depicts the effect of welding feed in tensile strength and hardness of the weldment. Tensile strength increases with increasing the feed, up to certain level, beyond which further increase in feed reduces the tensile strength. For hardness the results of the D/d ratio of the tool are exactly opposite. In general, slower welding feed results very slow process and more heat input. As a contrast, for higher welding feed, sufficient heat was not generated which will affect the properties. The tools which had 3:1 diameter ratio gave better results.

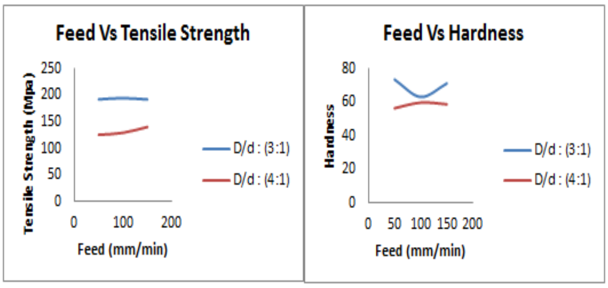

Figure 8. Effect of Feed on tensile strength and hardness

C. Effect of Pin profile:

In our experimental plan, three different tool pin profile were used, namely square pin, cylindrical and taper cylinder pin profile. Out of which square tool pin profile had given the better hardness and tensile strength. This is because of pulsating effect of the square edges results the better stirring action. This effect is shown in the figure 9.

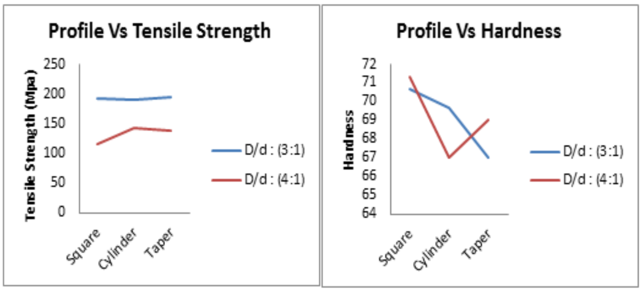

Figure 9. Effect of pin profile on tensile strength and hardness

D. Effect of Number of Passes:

In the case of number of passes, the mechanical properties increased as number of passes increased. When the number of passes is more, the materials in the stir zone become more distributed and finer, due to which mechanical properties were increased. The influence of number of passes on mechanical properties is shown in the figure 10.

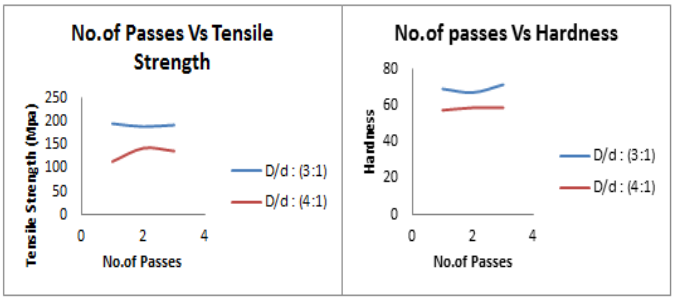

Figure 10. Effect of No.of Passes on tensile strength and Hardness

IV.CONCLUSION

Friction Stir processing is a fantastic adaptable procedure for processing of surface composites. In this work totally 9 experiments of two sets were conducted by changing four process parameters at three different levels. The results of the experimental work are given below.

The tools with D/d ratio of 3:1 have given better mechanical properties than the tools with 4:1 diameter ratio.

Among the three different profiles, square tool pin has given better mechanical properties followed by cylindrical profile. The parameters such as spindle speed, feed, and number of passes were directly influencing the mechanical properties up to certain levels, then further increase lead to decreasing the mechanical properties.

In future the work can be further extended for preparing hybrid surface composites with different layer thickness.

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