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To Study Various Parameter's Effect on Mechanical Properties of AA6063/B4C Composite by Friction Stir Processing

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***Abstract*—AA6063 has good surface finishing, high corrosion, and resistance, is readily suited to processing and can be easily anodized, has high strength to weight ratio but low hardness and wear resistance properties. Friction stir processing (fsp) is a novel technique used for the enhancing the mechanical and metallurgical properties of the material and also to make composites of the material. It eliminates the porosity and micro structural defects in the material. In this study, manufacturing of composites AA6063 and boron carbide particles with 5 µm particle sizes were added as reinforcement. The tool shoulder is varied from 16 mm to 20 mm. the other parameters such as tool rotational speed of 1400 rpm and transverse speed of 50 mm/min are kept constant. The friction stir processing tool is made of high chromium high carbon steel with a pin length of 4 mm and pin diameter of 6 mm is used. The 18 mm shoulder diameter produces much finer grain size with boron carbide reinforced particles rather than the tools having shoulder 16 mm and 20 mm diameter, this is due to the fact that tool with 18 mm diameter produces sufficient amount of heat to properly plasticize and flow of the material during the FSPed process thus producing finer grain size within the nugget zone and possesses higher tensile strength and high micro hardness of the material. The maximum tensile strength and micro hardness achieved is 236 N/mm^{2}and 135 Hv respectively. In case of the tool having 16 mm diameter produces less amount of heat due to lesser contact with the work piece and the tool having 20 mm diameter, over heat the work piece due to more contact area with the work piece and causes improper plasticization and flow of the material within the processed zone by friction stir processing and produces courser grains. The tensile strength, yield strength and micro hardness values of composite fabricated with cylindrical left hand threaded pin tool were higher as compared to other selected tool pin profiles 18 mm produces finer grains than the others.**

Keywords*— FSP, microstructure, nugget zone, aluminum, plasticize, micro hardness, tensile strength, AA6063/B4C

I. Introduction

Friction stir processing (FSP) is a processing technique based on the principle of friction stir welding process (FSW), where a non-consumable rotating tool is plunged into the surface of a work piece,with a tool shoulder and pin and is moved forwarded in the direction perpendicular to the plunged and it was invented by The Welding Institute (TWI) of United Kingdom in 1991. [1] It is a surface modification technique and recently it has become an efficient tool for homogenizing and refining the grain structure of metal sheet. [2]

Friction stir processing (FSP) is a solid-state joining process. A tool is specially designed for the processing whichis in cylindrical shape and it comprises of a pin and shoulder that have dimensions proportional to the sheet thickness. The pin of the rotating tool is plunged into the sheet material and the shoulder comes into contact with the surface of the sheet and then tool is moved in the desired direction. When the rotating tool comes in contact with the sheet, it generates heat which softens the material and material is softened below the melting point of the sheet. Due to the mechanical stirring action caused by the pin of the tool and the material, undergoes intense plastic deformation, within the processed zone yielding a dynamically-recrystallized fine grain microstructure. [3].

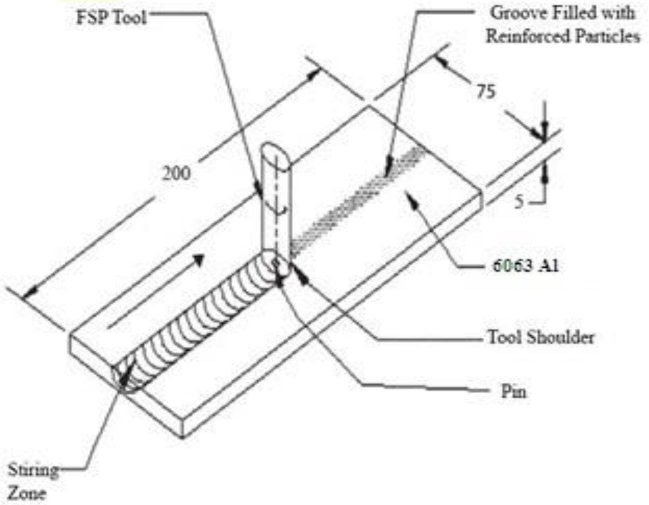

Fig. 1. Friction Stir Processing.

II. Literature Review

Kwon et al. (2003) obtained the hardness and tensile strength of the friction stir processed 1050 aluminum alloy. The hardness and tensile strength increased significantly with decreased tool rotation speed. The results showed that at 560 rpm, the hardness tensile strength increased as a result of grain refinement by up to 37% and 46% respectively compared to the as-received material. The hardness was higher on the advancing side than that of the retreating side. Kwon et al. concluded that the results demonstrate that the friction stir processing technique is highly effective for creating improved mechanical properties resulting from grain refinement. [14]

S.R. Babu et al. (2014) observed the role in producing a defect free processed zone. There are various tool shoulders was used, which is the main source of heat generation, either flat or tapered in shape. The typical shape of the shoulder aids in material consolidation during processing by forcing the softened material to be retained in the processed zone, as the tool traverses along the length of the work piece. Irrespective of the tool shoulder diameter, FSP can refine and homogenize the grains at the selected region within the material. The various defects and tensile strength of the friction stir processed material depends upon the combination of tool axial force, tool rotational speed, tool traversing speed and tool shoulder diameter. To eliminate the defects in the processed region, tool shoulder diameter is more significant and for the maximum tensile strength and microhardness, tool traversing speed is the most significant parameter. The tool shoulder diameter of 18 mm produced the defects such as tunnels, voids and pin holes in the processed region for different parameter variations in 6 mm thick plate. With increase in the tool shoulder diameter beyond 18mm but less than 24 mm, a defect free processed zone was observed for variation in the process parameters in 6mm thick plate. As the thickness of workpiece is reduced, the defects in the friction stir processed zone of 1.5 mm thick plate is completely eliminated. A fine grain of average grain size less than 10μm was observed in the nugget region. Curves demonstrate that it is feasible to predict the maximum FSW temperature in an alloy if the thermal diffusivity, welding parameters, and tool geometry are known [4].

R. Sathiskumar et al. (2014) observed effect of parameters on microstructure and micro hardness of boron carbide particulate reinforced copper surface composites and they produced defect-free and sound surface composites within the range of selected parameters. The area of the surface composite increased when tool rotational speed was increased and reduced when processing speed was increased due to increase in frictional heat generation and the area of the surface composite reduced when groove width was increased. The distribution of B_4C particles in the surface composites was influenced by tool rotational speed and processing speed and the micro hardness was found to be 175 Hv at 800 rpm and 132 Hv at 1200 rpm. [5]

A. Kumar et al. (2014) observed the influence of tool shoulder diameter on the mechanical properties of friction stir welded dissimilar aluminium alloys 2014 and 6082. The tool shoulder diameter produces a great impact on the strength and quality of friction stir welded joints. The joints fabricated by using tool having 18 mm shoulder diameter provided superior mechanical properties than the other tool shoulders. This is due to the fact that there is sufficient amount of frictional heat generation in the stirred zone and proper plasticized flow of material in the stirred zone.[6]

R. Srinivasu et al. (2014) the friction stir processing of cast A356 Aluminium alloy is done to improve the surface properties of the aluminium with B_4C particles. The microstructure of the material is improved significantly and form hard surface composite by reinforcing boron carbide particles in the aluminium matrix. The size of boron carbide powder particles affects the hardness and wear resistance of the alloy and there was improvement in wear resistance when the boron carbide and molybdenum disulphide powders of 40 nm size was added during friction stir surfacing. The higher wear resistance of friction stirred surface alloy is correlated to lower values of friction coefficient and change in wear mechanism as evident from scanning electron microscopy. [7]

N. Yuvaraj et al. (2015) the friction stir processing (FSP) is used to fabricate AA5083 aluminum alloy with reinforced layers of boron carbide (B4C). The Micro and nano sized B_4C reinforced particles were used. The microstructure of specimens with nano B_4C particles exhibits fine grain size, higher hardness (124.8 Hv), ultimate strength (360 Mpa) and wear rate (0.00327 mg/m) as compared to the base material hardness (82 Hv), ultimate strength (310 Mpa) and wear rate (0.0057 mg/m). The micro hardness of the Al/B_4C nano composites is higher than B_4C micro particles. The presence of nano size B_4C particles produces ultrafine grain size. The tensile strength of the specimen exhibited better mechanical properties than the base metal. The wear properties were improved by addition of B4C nano particles in comparison with B_4C micro particle. [8]

III. Experimentation

The material under investigation was a 6063Aluminium alloy under the form of rolled plates of 5 mm thickness. Three specimens of size 200mm x 75 mm x 5 mm with grooves of 2 mm diameter and depth of 4 mm were processed in the direction perpendicular to the rolling direction with single pass Friction Stir Processing doping with B4C particles of size approximate 20 μm. A processing tool made up of High Chromium High Carbon Steel made up of three different tool shoulder diameters 16 mm, 18 mm and 20 mm with cylindrical threaded pin profile were used. The pin diameter of tool was 4 mm and length of 6 mm used for present research work. The employed tool rotational speed of the cylindrical threaded tool and processing speed was1400 rpm and 50 mm/min respectively. Tool profile used in study is shown in Fig. 2.

Fig. 2. Processing Tool Pin profiles.

For Friction stir processing the plates are cut with the help of milling operation in the required proportion. The CNC vertical milling machine was used for the processing of plates. In this process, the fixture was first fixed on the machine bed with help of clamps and then plates were held in the fixture properly for Friction Stir Processing as shown in Fig. 3. Then the tool pin is plunged into the grooves of the plates doped with the reinforced particles. The tool is moved into the groves with constant rotational speed and transverse speed.

Fig. 3. Work piece set up during FSP.

TABLE I. PARAMETRIC DESIGN ADOPTED FOR FRICTION STIR PROCESSING IN CURRENT RESEARCH WORK

Specimen no	Tool Shoulder Dia. (mm)	Reinforced Particles
S1	16	B_4C
S2	18	B_4C
S3	20	B_4C
S4	Without Processing	Without

Specimens for the tensile strength analysis cut from the processed zone. Tensile test specimens were prepared from the Friction Stir Processing plate in accordance with ASTM specifications, E-8M-08, having specimen of 50 mm gauge length and 12.5 mm width [12] [13]. Tensile test was carried out at a constant speed of 2 mm/min at 16 KN load. The load was applied until the necking was there and specimen failed. Servo Control Universal testing machine. Tensile test specimens before and after tensile testing are shown in Fig. 4

Fig. 4. Specimens after testing.

Visual inspection was performed on all processed samples in order to verify the presence of macroscopic external defects such as surface irregularities, excessive flash, and lack of penetration, voids and surface open tunnel defects. It was observed in the visual inspection that specimens processed with tool rotational speed 1400 rpm, processing speed 50mm/min and tool shoulder diameter of 18 mm with B4C reinforced particles shows better surface finish rather than other parameters.

IV. RESULTS AND DISCUSSION

The FSP is used to enhance the properties of the material. This is an effective process for the automotive and aerospace industries where the new materials are developed to improve the resistance to wear, creep, and fatigue. There are many materials processed by fsp such as AA 2519, AA 5083 and AA 7075 aluminum alloys, AZ61magnesium alloy, nickel-aluminium bronze and 304Lstainless steel [9].

A. *Effect of Tool ShoulderonTensile Strengthof Stir Zone*

The tool shoulder produces the effect on the tensile strength because it produces heat to the surface and sub-surface region of the work piece. The FSP tool serves three primary functions i.e. heating of the work piece, movement of softened material and containment of hot metal beneath the tool shoulder [10].

TABLE II. TENSILE STRENGTH AT STIR ZONE

Specimen no	Tool Shoulder Dia. (mm)	Reinforced Particles	Tensile Strength (N/mm^2)
S1	16	B_4C	229
S2	18	B_4C	236
S3	20	B_4C	224
S4	Base Metal	Without	221

To find the effect, the combination of FSPed tested specimens and all the results were plotted in the form of a line chart in the form of ultimate tensile strength v/s tool shoulder diameter as shown in Fig. 5. It is observed that the UTS (Ultimate Tensile Strength) of the material are influenced by the tool shoulder diameter. From the tests it is found that the ultimate tensile of the tool having shoulder diameter of 18 mm has high rather than the tools having shoulder diameters of 16 mm and 20 mm. This happens due to the fact that the tool having 18 mm shoulder diameter has smaller area of contact and produces lesser amount of heat in the work piece. This causes the poor processing of the material and producing the defects in the material and hence poor tensile stress of the material as compared to the tool having 18 mm diameter and in case of tool having 20mm shoulder diameter leads to have more surface area of contact and produces larger amount of heat in work piece due to friction subsequently it has wider TMAZ and HAZ regions and resulted in the decrease in tensile strength of the material [6]. Due to production of larger amount of heat in the work piece causes the production of defects like voids which causes the deterioration of tensile strength. On the other hand, tool having 18 mm diameter produces sufficient amount of heat in the work piece which causes the proper melting of the material and produces much finer surfaces rather than the other tools and gives excellent values of tensile strength. The heat produced in the work piece is due to the effect of tool shoulder i.e. bigger the tool shoulder more heat is produced and vice versa or it can have said as heat due to friction is directly proportional to the tool shoulder diameter [6].

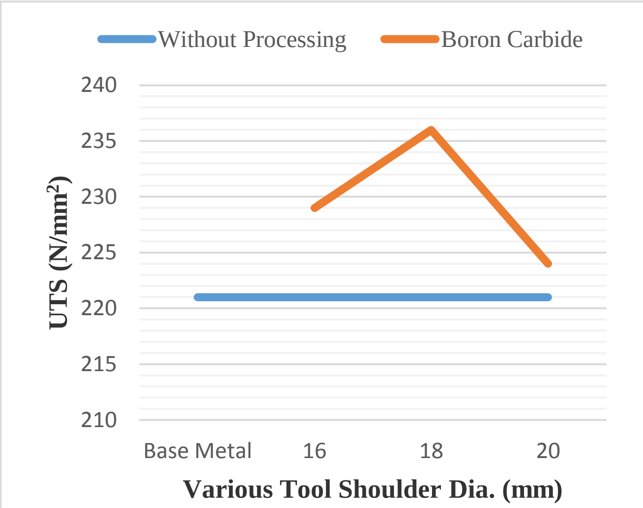

Fig. 5. Effect of Tool Shoulder Diameter and reinforced particles on UTS.

B. Effect of Boron Carbide particles on Tensile Strengthof Stir Zone

The reinforced particles increase the tensile strength of the material causing grain refinement of the material. It is generally used to alter the properties of the material. The boron carbide produced finer grains and gives more strength to the material than the other reinforced particles. The grain refining occurs due to severe deformation and that takes place during friction stirring and large numbers of high angle boundaries are produced [11]. More refinement of the grains increases the hardness of the material. Hardness is directly related to the tensile strength of the material. With the increase in hardness of the material causes increase in tensile strength of the material. This may be also due to the uniform dispersion of the boron carbide particles which makes the material harder. The values of tensile strength were plotted in the form of a line chart in Fig. 5.

C. Effect of Tool Shoulder on Micro Hardness of Stir Zone

The two main reasons are responsible for the hardness improvement in the stirred zone.

- The size of the grains present in the processing zone, if the grain size in the processing zone is finer then the base metal plays an important role to provide strength in the material. According to the Hall-Petch equation, hardness of the material increases as the grain size decreases.
- The small particles of inter-metallic compounds are useful for the hardness improvement according to the Orowan hardening mechanism. The hardness of the stirred zone was higher than the base metal irrespective of the reinforced particles and tool shoulder used [6].

TABLE III. MICRO HARDNESS AT STIR ZONE

Spec imen no.	Tool Shoulder Dia. (mm)	Reinforced Particles	Micro Hardness (Hv)
S1	16	B_4C	107
S2	18	B_4C	135
S3	20	B_4C	120
S4	Base Metal	Without	75

Fig. 6. show that the tool having 18 mm shoulder diameter produced maximum micro hardness value than the tools having 16 mm and 20 mm shoulder diameter. This happened due to the fact that the tool having 18 mm shoulder diameter has lesser contact area caused insufficient heat and there is clustering of the precipitates in the fsp zone which reduces micro hardness values [6]. But in case of tools having 18 mm diameter produces sufficient amount of heat and uniform dispersion of reinforced particles in the stir zone. With 20 mm shoulder diameter homogeneous dispersion is achieved but associated heat involved in the process is high because of more surface area contact. High heat causes courser gain size which further reduces micro hardness values.

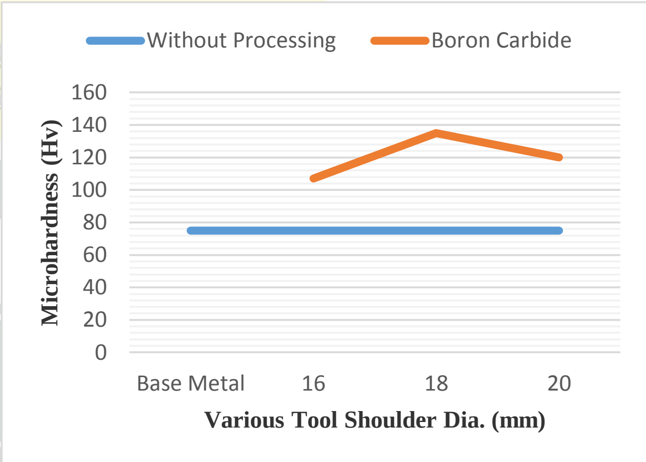

Fig. 6. Effect of Tool Shoulder Diameter and Reinforced particles on Micro Hardness.

D. Effect of Reinforced particle on Micro Hardness of Stir Zone

The average hardness of friction stir processed surface composite was 1.5 higher than that of the base metal. The increase in hardness was attributed to fine dispersion of B_4C particles and fine grain size of the Aluminum matrix. Microstructure of the composites has higher hardness because of fine dispersion of B_4C particles and fine grain size of the Aluminum matrix [26]. The micro hardness of the metal processed with boron carbide particles is higher than the base metal. This is due to the fact that the boron carbide particle breaks the grains into smaller size and it is completely dispersed with the aluminium matrix. Smaller the grain size higher will be the micro hardness value. The grain boundaries become the main obstacle to the slip of dislocations and the material with smaller grain size would have higher micro hardness or tensile strength as it would impose restriction to the dislocation movement.

E. Effect of Tool Shoulder on Impact Strength by FSPof Stir Zone

TABLE IV. IMPACT STRENGTH AT STIR ZONE

Specimen no	Tool Shoulder Dia. (mm)	Reinforced Particles	Energy Absorbed (J)
S1	16	B_4C	14
S2	18	B_4C	7
S3	20	B_4C	13
S4	Base Metal	Without	23

Fig. 7. shows that the tool having 20 mm shoulder diameter has the high impact strength as compared to other tool shoulder diameters. The impact strength is closely related to refinement and homogeneous distribution of the precipitate particles in nugget zone and reduction of the matrix grain size. The tool having 20 mm shoulder diameter produces more heat in the nugget zone due to the more production of heat there is production of less fine surfaces which causes increase in impact strength of the material. But in case of tool having 18 mm diameter there is proper production of heat that causes refined surfaces which makes the material brittle in nature. Similarly, in case of tool having 16 mm shoulder diameter has low impact strength but more has more impact strength than the tool having 18 mm shoulder diameter.

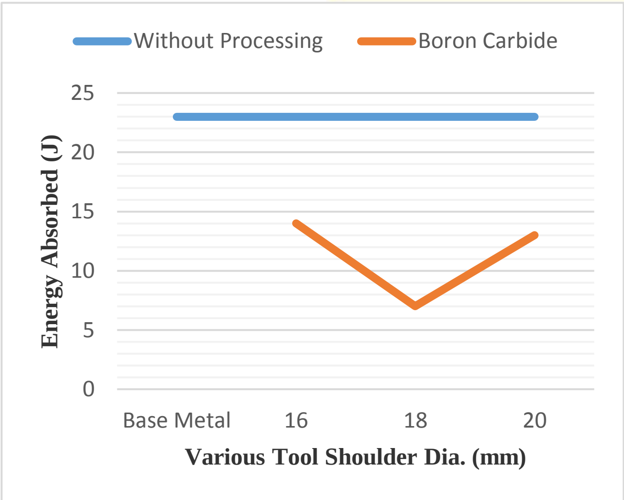

Fig. 7. Effect of Tool Shoulder Diameter and reinforced particles on Impact Strength.

F. Effect of Reinforced particle on Impact Strength of Stir Zone

Fig. 7. shows that impact strength of the impact strength value of FSP processed specimen gets decreased due to the reinforcement and increased hardness due to uniform distribution particles in the stir zone [27]. The impact strength of the material decreases with respect to the base metal. The impact strength of the B4Cparticles also decreased this may be due to the fact the B4C particles refines the grain size of material, this makes the material harder in nature. The hardness causes decrease in the impact strength of the material.

G. MicrostructuralCharacteristics of FSP

The variation in the micro structure of 16 mm, 18 mm and 20 mm tool shoulder diameter with various reinforced particles is given in the Fig. 7.

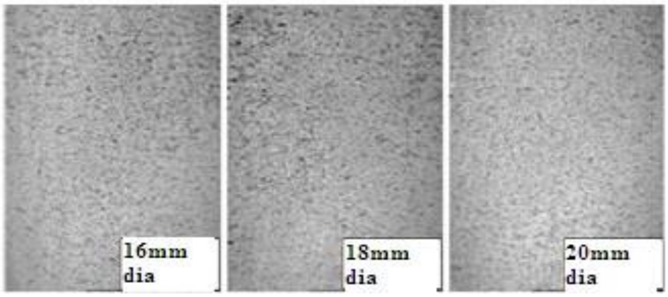

Fig. 8. Effect of Tool Shoulder Diameteron MicrostructurewithBoron Carbide Particles.

The tool shoulder influences the area of friction stir processed zone. The tool having 18 mm shoulder diameter produces finer grains in the FSPed region. This happens due to the fact that the tool having 18 mm diameter produces sufficient amount of heat in the work piece which causes the better material flow and results in homogeneous dispersion of reinforced particles in aluminium matrix. In case of the tool having 16 mm diameter has smaller area of contact and produces lesser amount of heat in the work piece and hence there is no proper flow of material in the processed region and there is non uniform distribution of the particles in the processed region. The tool having 20 mm diameter leads to have more surface area of contact and produces larger amount of heat in work piece due to friction subsequently wider TMAZ region and then resulted in the deterioration of tensile strength [6]. Due to production of larger amount of heat in the work piece causes the production of defects like voids. The boron carbide in the processed region produced the finer grains with the 18 mm tool shoulder diameter and their homogeneous distribution of processed boron carbide particles. There is more dispersion of the B4C particles in the processed region.

CONCLUSION

In the above investigation an attempt has been made to study the influence of tool shoulder diameter on the tensile strength of friction stir processing of aluminium alloy 6063. Analysis has been carried out on AA 6063alloy of6mm thick plates. The friction stir process was carried out at a constant tool rotational speed of 1400rpm with 50 mm/min tool rotational speed. The following are the conclusions drawn from the present research.

- The process parameters consisting of tool shoulders diameters (18 mm, 20 mm and 22 mm) and doping of micro sized B_4C particles affect the tensile strength significantly.
- Tensile strength and Micro hardness is maximum in case of tool having shoulder diameter of 18 mm rather than 16 mm and 20 mm shoulder diameter due to proper material flow from retreating side to advancing side.
- Tensile Strength and Micro hardness of the material is more in case of boron carbide reinforced particles due

to the homogeneous distribution of the reinforced particles in the processed zone.

- Highest value of Tensile strength and Micro hardness was236 N/mm^{2}and 135 Hvat Stir Zone is achieved with 18 mm tool shoulder doping with B_4C particles by FSP. Doping of B_4C makes the matrix harder as compared to Friction stir processing without B4C particles.
- The Impact Strength is low as compared to base metal due to finer grain size produced after processing. Finer grain size causes decrease in impact strength of the material.

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