EFFECT OF TOOL SHOULDER DIAMETER ON AA6101/B_4C COMPOSITE FABRICATED BY FRICTION STIR PROCESSING

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Abstract- **Aluminum 6101 alloy is a light weight structural material with high specific strength, good damping capability and machinability, most attractive material in applications of automobile, aircraft and aerospace structures, boat building and ship building etc. In 1991 a solid state processing named friction stir processing (FSP) was developed and this technique has attracted considerable interest from the aerospace and automotive industries, since it is able to produce defect free composite materials by doping reinforced particles in alloys i.e. Magnesium and aluminum alloys. In this investigation an attempt has been made to study the effect of processing parameters on mechanical properties of AA6101/B_4C composite material fabricated by friction stir processing. Composite material was fabricated by varying tool shoulder diameter (18 mm, 20 mm and 22 mm) with single pass FSP at constant transverse speed and tool rotational speed of 50 mm/min and 1600 rpm respectively. After mechanical and micro structural testing , results revealed that the tensile strength and micro hardness of AA6101/B_4C composite was improved. Doping of B_4C particles imparts better tensile and micro hardness properties to AA6101/B_4C fabricated composite material. Tool shoulder of 20 mm diameter causes homogeneous distribution of reinforced particles rather than tool having shoulder diameter of 18 mm and 22 mm due to proper heat generation and proper material flow from advancing side to retreating side. AA6101/ B_4C composite material exhibited hugher values of tensile strength (236 N/mm^2) and micro hardness (135 Hv) fabricated with FSP using 20 mm tool shoulder diameter as compared with base material.**

Keywords: Friction Stir Processing, Mechanical Testing, Metallurgical Testing, Boron Carbide,

I. INTRODUCTION

Friction stir processing (FSP) is a materials processing technique based on the principle of friction stir welding (FSW) process, where a non-consumable rotating tool having a shoulder and pin is plunged into the surface of a work piece 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 cylindrical tool which is specially designed for the processing 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]

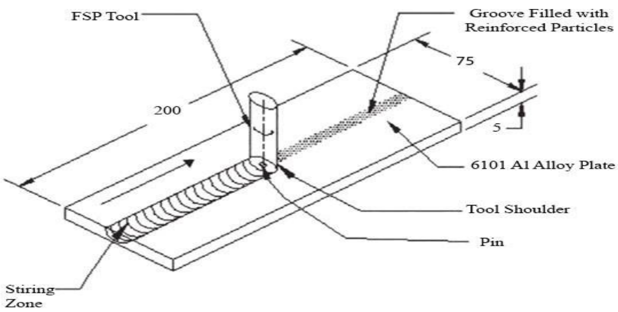

Fig. 1: Friction Stir Processing

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 B4C 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 aluminum 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 AA6101in the form of rolled plates of 5 mm thickness. Three specimens of size 200 mm 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. Grooves were filled with B_4C particles of size approximate 20 µm. A tool made up of High Chromium High Carbon Steel is used for the processing. Three tools of different tool shoulder diameters 18 mm, 20 mm and 22 mm with cylindrical threaded pin profile were used. The diameter of tool pin was 4 mm and length of the pin was 6 mm used. Tool rotational speed and processing speed was 1600 rpm and 50 mm/min respectively used for friction stir processing .Tool profile used in study is shown in Figure 2.

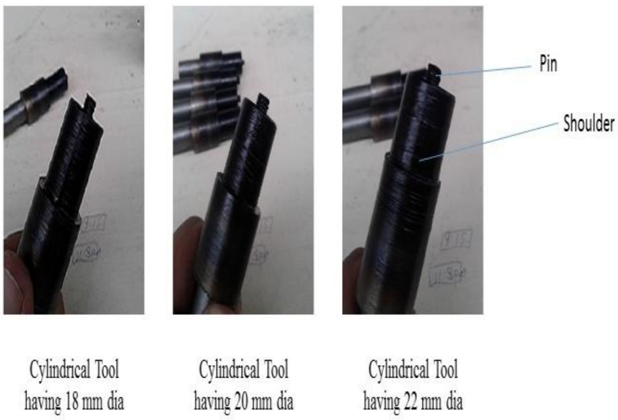

Fig. 2: Processing Tool Pin profiles

The machine used for the fabrication of composite was CNC vertical milling machine. In this process, the fixture was first fixed on the machine bed with the help of clamps and then plate was held in the fixture for processing as shown in figure 3. Tool pin is plunged vertically into the plate with groove of 2 mm diameter and 4 mm depth, while the tool is rotating. Due to velocity difference between the rotating tool and the stationary work piece, heat produced by frictional work and material deformation is started and to accomplish the processing, the rotating tool is traversed along the line, while the shoulder of the tool is maintained in intimate contact with the plate surface. The temperature rises and material softens without reaching the melting point. The pin is moved in forward direction leading the face of pin which forces the plasticized material to the back of the pin and thus applying the force for the processing. When the processing distance is covered, the tool is pulled out of the work piece leaving behind an exit hole as a foot print of the tool.

Fig. 3 Work piece set up during FSP

Table no. 1 Parametric design adopted for Friction stir processing

Specimen no	**Tool Shoulder Dia. (mm)**	**Reinforced Particles**
S1	18	B_4C
S2	20	B_4C
S3	22	B_4C
S4	Without Processing	Without

Specimens for the tensile strength analysis cut from the processed zone.Tensile test specimens were prepared 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 1600 rpm, processing speed 50mm/min and tool shoulder diameter of 20 mm with B_4C reinforced particles shows better surface finish rather than other parameters.

IV. RESULTS AND DISCUSSION

The FSP is used to improve the properties of the material. This is very effective process for the automotive and aerospace industries where the new materials needed to be developed to improve resistance to wear, creep, and fatigue [9]

A. EFFECT OF TOOL SHOULDER DIAMETER ON TENSILE STRENGTH OF STIR ZONE-

The tool shoulder produces the effect on the tensile strength because tool shoulder 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 no. 2 Tensile Strength of AA-6101/B_4C composite

Specimen no	Tool Shoulder Dia. (mm)	Reinforced Particles	Tensile Strength (N/mm^2)
S1	18	B_4C	229
S2	20	B_4C	236
S3	22	B_4C	224
S4	Base Metal	Without	221

Figure5. 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 20 mm has high rather than the tools having shoulder diameters of 18 mm and 22 mm. This happens due to the fact that 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 as compared to the tool having 20 mm diameter. Tool having 22 mm shoulder diameter leads to have more surface area of contact and produces large 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]. High heat input in the work piece causes the production of defects like voids which deteriorates tensile strength. On the other hand, tool having 20 mm diameter produces sufficient amount of heat in the work piece which causes the proper material flow and improves the tensile strength of fabricated material. 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 [6].

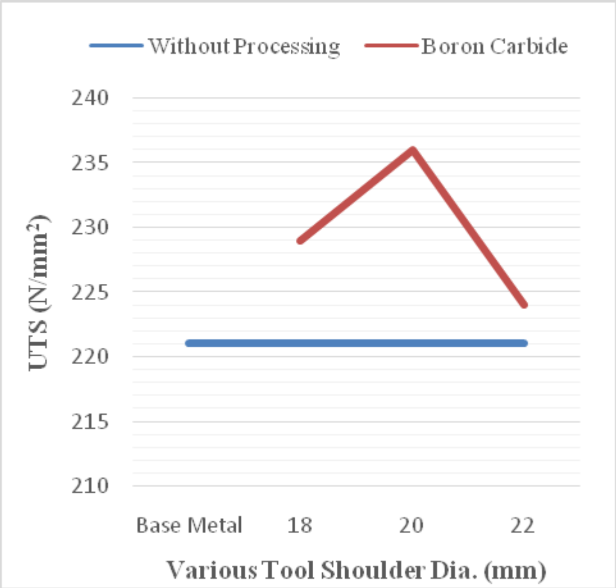

Fig. 5 Effect of tool shoulder diameter and reinforced particles on UTS

B. EFFECT OF BORON CARBIDE PARTICLES ON TENSILE STRENGTH-

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 number of high angle boundaries is produced [11]. More refinement of the grains increases the hardness of the material. Hardness is directly related to the tensile strength of the material. Increase in hardness of the material causes increase in tensile strength of the material. High value of tensile strength of 236 N/mm^2 was achieved with tool having 22 mm tool shoulder diameter. This happens due to the uniform dispersion of the boron carbide particles which makes the material harder.

C. EFFECT OF TOOL SHOULDER DIAMETER ON MICRO HARDNESS OF STIR ZONE OF AA-6101/B_4C COMPOSITE-

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 no. 3 Micro Hardness at Stir zone of AA-6101/B_4C composite

Specimen no	**Tool Shoulder Dia. (mm)**	**Reinforced Particles**	**Micro Hardness (Hv)**
S1	18	B_4C	107
S2	20	B_4C	135
S3	22	B_4C	120
S4	Base Metal	Without	75

Figure 6 shows that the tool having 20 mm shoulder diameter produced maximum micro hardness value than the tools having 18 mm and 22 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 friction stir processed zone which reduces micro hardness values [6]. Tools having 20 mm diameter produces sufficient amount of heat and uniform dispersion of reinforced particles in the stir zone. With 22 mm shoulder diameter homogeneous dispersion of reinforced particles is achieved. High heat input causes courser gain size which further reduces micro hardness [16].

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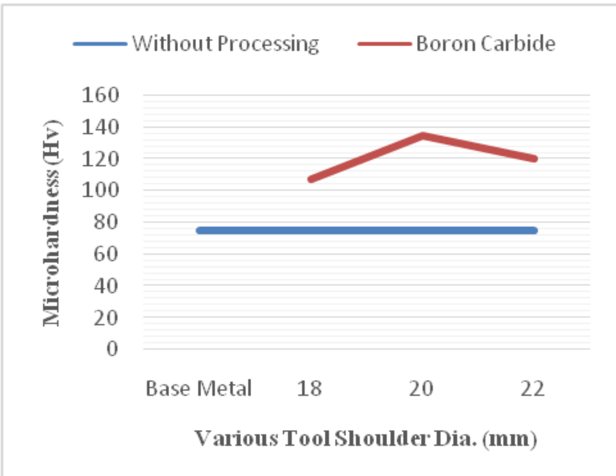

Fig. 6 Effect of Tool Shoulder Diameter and Reinforced particles on Micro Hardness

D. EFFECT OF REINFORCED PARTICLES ON MICRO HARDNESS OF STIR ZONE AA-6101/B_4C COMPOSITE

The average microhardness hardness of friction stir processed surface composite was 1.5 times 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 . 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 DIAMETER ON IMPACT STRENGTH OF FABRICATED AA-6101/B_4C COMPOSITE MATERIAL

Table no. 4 Impact Strength results

Specimen no	Tool Shoulder Dia. (mm)	Reinforced Particles	Energy Absorbed (J)
S1	18	B_4C	14
S2	20	B_4C	7
S3	22	B_4C	13
S4	Base Metal	Without	23

Figure 7 show that the tool having 22 mm shoulder diameter has the high impact strength. 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 22 mm shoulder diameter produces more heat in the nugget zone which causes increase in impact strength of the material.

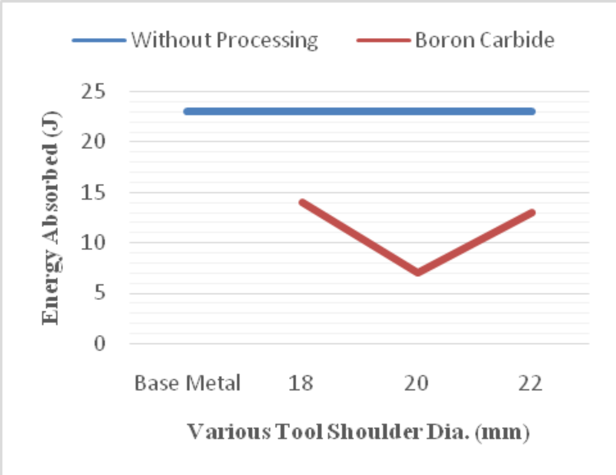

Fig. 7 Effect of tool shoulder diameter and reinforced particles on Impact Strength

F. EFFECT OF REINFORCED PARTICLES ON IMPACT STRENGTH OF AA-6101/B_4C COMPOSITE.

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. The impact strength of the material decreases with respect to the base metal. The impact strength of the B_4C particles also decreased this may be due to the fact the B_4C particles refines the grain size of material, this makes the material harder in nature [18]. The hardness causes decrease in the impact strength of the material.

G. MICRO STRUCTURAL CHARACTERISTICS OF STIR ZONE OF AA-6101/B_4C COMPOSITE.

The variation in the micro structure of 18 mm, 20 mm and 22 mm tool shoulder diameter with reinforced particles is shown in the Figure 7.

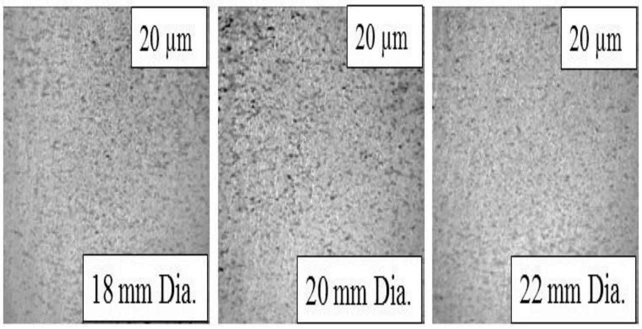

Fig. 8 Microstructure at Stir zone AA-6101/B_4C composite

The tool shoulder influences the area of friction stir processed zone. The tool having 20 mm shoulder diameter produces finer grains in the FSPed region. This happens due to the fact that the tool having 20 mm diameter produces sufficient amount of heat in the work piece which causes homogeneous dispersion of reinforced particles in aluminum matrix [20]. Tool having 18 mm diameter has smaller area of contact and produces lesser amount of heat in the work piece and hence there is improper flow of material in the processed region Non uniform distribution of the reinforced particles was observed in the processed region. Tool having 22 mm shoulder diameter causes high input in the processed region due to which size of grains were increased.

V. CONCLUSIONS

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 6101. Analysis has been carried out on AA 6101 alloy of 6 mm thick plates. 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 and micro hardness significantly.
- Tensile strength and Micro hardness is maximum in case of tool having shoulder diameter of 20 mm rather than 18 mm and 22 mm shoulder diameter due to proper heat generation and homogeneous dispersion of reinforced particles.
- Doping of B_4C makes the matrix harder as compared to base material. The Impact Strength is low as compared to base metal due to finer grain size produced after processing.

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