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Effect of reinforced particle on the mechanical and metallurgical properties of AA6101/WC

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Abstract: **Aluminium, due its properties, such as high stiffness to weight ratio, and high electrical and heat conductivity, it is used in automotive and aerospace industries. However, its use is limited due to poor surface properties and low abrasion resistance. So, in order to widely use this materials, researchers processed aluminum with the help of friction stir processing by doping it with various materials to improve its structure, but there is rare use of tungsten (WC) as a reinforcement particle. In this investigation, an attempt has been made to study the effect of tungsten carbide (WC) on the mechanical and metallurgical properties of AA6101. This composite was fabricated with single pass of FSP by using variable tool shoulder diameters (18mm, 20mm, 22mm) at constant transverse speed of 50 mm/min and at 1600 rpm rotational speed. After testing, it had been found that the tensile strength as well as micro hardness of AA6101/WC composite had increased after doping with tungsten carbide. Apart from that aluminum processed with tool having 20mm shoulder diameter had higher values of tensile and micro hardness as compared with other tools with 18mm and 22mm shoulder diameter owing to better homogeneous heat generation and flow of material.**

Keywords —Aluminium 6101, Friction Stir Processing, Micro Hardness, Tungsten Carbide, Tool Shoulder Diameter, Tensile Strength

I. INTRODUCTION

Aluminium is one of the most abundant material available on earth after iron, and due its properties, such as high stiffness to weight ratio, and high electrical and heat conductivity, it is used in automotive and aerospace industries e.g. foils and cans. However, aluminium and its alloys have limited use in the industry due to poor surface properties and low abrasion resistance. So, to improve its structure, it often processed with the help of state-of-the-art technology such as friction stir welding and friction stir processing by doping it with various materials like Ce, Cu, Zn, Ti and many more, but there is little to no use of tungsten carbide (WC) as a reinforcement material. Therefore, tungsten carbide is used with 6xxx series of aluminium to create a composite. The main reason to choose AA6101 is that the base material has moderate tensile strength and cheaper as compares with higher series aluminum. Moreover, it can be easily welded by GMAW and GTAW methods.

This material is then processed with the help of Friction Stir Processing (FSP) as it is based on the principle of friction stir welding. In this process, a non consumable tool is used to process the material by plunging it into the specially created grooves filled with reinforced particles moved forward in the perpendicular direction in which tool is plunged. It was invented by the welding institute (TWI) of United Kingdom in 1991.[1] This technique is used to refine the grain structure of the material so that its surface can be harmonized.[2] Basically, Friction Stir Processing (FSP) is a solid state joining process in which a specially designed cylindrical tool comprise of shoulder and pin is used to process the surface of the material. The tool pin has the dimensions proportion to the thickness of the surface, and it can be moved in desired direction. When this rotating tool comes in contact with the surface of the material, it produces heat in the region causes softening of the aluminium sheet below the melting point, and owing to intense plastic deformation within the processed zone creates a recrystallized refine-grain micro structure called nugget. [3]

Furthermore, different parameters, such as tool geometry, tool rotational speed, axial load, and axial load and grove width are used to calculate its effect on the surface of the material, so variable parameters are used in the experiment to find the effect of tungsten on the AA6101.

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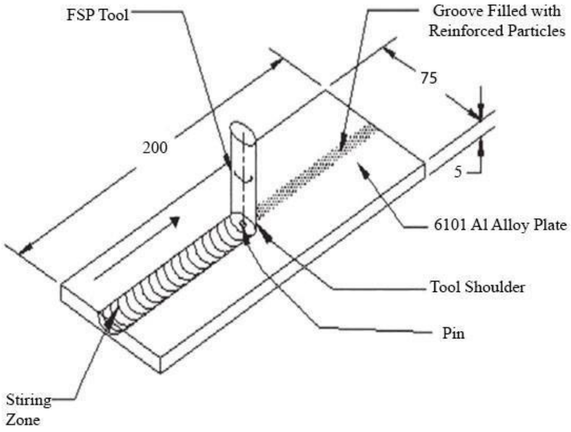

Fig. 1: Friction Stir Processing

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. [11] **Itharaju et al. (2004)** observed the microstructure at different combinations of rotational and translational speeds and tried to relate the resulting grain sizes to the generated forces in friction stir processed 5052 aluminum sheet. The resulting average grain size of the FS processed AA5052 sheet were between 1.5 and 3.5 µm depending on the process parameters, compared to 37.5 µm for the unprocessed sheet, which mean that great refinement has been achieved. Itharaju et al also concluded that, in general, the plunging force increases with increasing rotational speed and it is almost independent of the translational speed. [14] **B.M Darras et al. (2007**) observed that the significant grain refinement and homogenization can be achieved in single FSP pass leading to improved formability, especially at elevated temperatures. FSP is a solid-state process where the material within the processed zone undergoes intense plastic deformation resulting in dynamically recrystallized structure. Most of the research conducted on FSP focuses on aluminium alloys. Despite the potential weight reduction that can be achieved using magnesium alloys, very little is reported on FSP of magnesium alloys. In this research, they had examined the possibility of using FSP to modify the microstructure and properties of commercial AZ31B-H24 magnesium alloy sheets. The FSP process was conducted on CNC vertical milling machine. A simple FSP tool was used in this work; the tool is made of H-13 tool steel and consists of a pin with 0.25 in. diameter, 0.12 in. height, and a 0.5 in. diameter shoulder. Several samples were friction stir processed with a single pass at different combinations of rotational speed (1200-2000 rpm) and translation (20-30 in./min) speeds. The results of microstructure of FSP sample are more homogeneous than that of as-received material. It is clearly illustrated that FSP refined the microstructure from an average grain size about 6. The result of the hardness clearly shows that hardness of the processed sheets is extremely sensitive to the processing parameters. [20] **M. Azizieh et al. (2011)** The AZ31Mg based nano composites with nano-Al2O3 particles were successfully fabricated by FSP. The Al2O3 particles distribution was improved with the number of FSP passes and the particles distribution was enhanced with increasing the rotation speed. Under higher rotation speed more grain growth occurred due to higher heat generation. The speeds used are 1200rpm, 1000rpm and 800rpm and as the speed decreases the composite hardness increases respectively. [17] **I. Sudhakar et al. (2012)** the current investigation was based on the fabrication of surface composite by incorporating boron carbide as reinforcement on AA7075 aluminium alloy using friction stir processing for wear resistant applications. When the tool feed rate is 50mm/ min and the rotational speed of 960 rpm and the plunging speed of the tool is 30 mm/minute with tilt angle of 2.5o resulted in formation of sound metallurgical SMMC. The EDX analysis supports the efficacy of friction stir processing and depicts the absence of dissolution of boron carbide and presence of boron carbide intact in SMMC and improved wear resistant of the material. [12] **J.M. Salman (2014)** observed significant grain refinement of the microstructure alloy and it was controlled by the rotation and transverse the tool. The microstructure and mechanical properties of cast aluminum alloy grade at three different transverse speeds viz. (116, 189 and 303) mm/min under two different rotational speeds 450 and 710 rpm. The HV variations was relatively small and there is improvement in tensile strength, yield strength and percentage elongation during FSP. There is also maximum tensile strength and percentage of elongation was observed with annealing process of the FSP. [2] **D. Amirtharaj et al. (2015)** in this investigation the surface property of aluminium alloy 6063 is modified by reinforcing Boron Carbide (B4C) powder particles via FSP. The distribution of B4C particles were examined for different reinforcing techniques, based on Hardness and Impact strength. The hardness is increased by reinforcing Boron carbide particles into the base metal surface. The maximum hardness and impact strength is achieved when the B4C particles are packed into the serial holes when it was with square pin profile tool. The Increase in hardness in the Stir zone shows the uniform distribution of B4C particles. [21]

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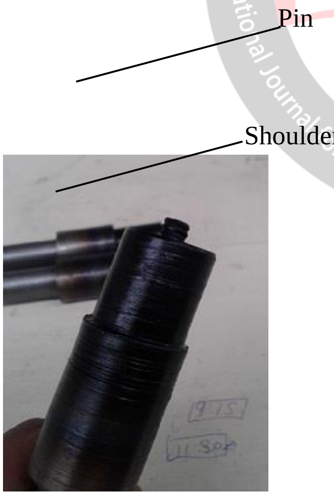
III. Experimentation

AA6101 was investigated under different conditions by using tungsten carbide (WC) as a reinforced particles. Firstly, aluminum sheets of 5 mm thickness were cut into smaller rectangular pieces of 200 mm x 75 mm and then grooves of 2 mm diameter and of 4 mm depth were made with the help of shaper machine. Secondly, different tools of variable shoulder diameter (18 mm, 20 mm, 22 mm) were used to process the material with cylindrical threaded pin profile having 4 mm diameter and 6 mm length. Basically, these are non consumable tools made of high carbon and high chromium alloy steel, and to increase their hardness, heat treatment had been given to them. Other parameters such as tool rotational speed and processing speed were kept constant at 1600 rpm and 50 mm/min respectively. The profile of tools have been shown in figure 2.

Cylindrical Tool having 18 mm dia

Cylindrical Tool having 20 mm dia



Cylindrical Tool having 22 mm dia

Fig. 2: Tools Pin Profiles

Thirdly, a fixture was made to hold the aluminium plates while processing. It was made of mild steel because it has high strength and toughness, which is required to withstand against the unbalanced forces and pressure during the FSP process. The size of the fixture is 300 mm x 300 mm x 15 mm, and it is shown in the figure 3.

Fig. 3: Friction Stir Processing Fixture

Finally, CNC vertical milling machine was used to fabricate the composite. The fixture was first fixed on the bed of the machine, as shown in the figure 4, with the help of clamps and the aluminium plate was attached with it. After fixing the plate, the grooves were filled with the tungsten carbide (WC) and then rotating tool was plunged vertically into the groove. When tool moved in the forward direction, started deformation in the region owing to velocity difference between tool and work piece. While maintaining intimate contact between tool shoulder and workpiece's surface, tool was moved along the groove caused rise in temperature due to friction between both surfaces softened the material below melting point. During the movement of the tool pin in the forward direction, the plasticized material was pushed backwards causing forward movement of the tool. After processing, the tool was pulled out of the aluminium plate.

Fig. 4: Attachment of Fixture and plate on Machine

After the process has been completed, specimens were cut from the processed zone to check their mechanical and metallurgical properties. Tensile test was conducted in the lab 2 mm/min speed with 16 KN load which was kept constant through out the testing. Besides, these specimens were created using set standard of ASTM, E-8M-08 that is

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50 mm gauge length and 12.5 mm thickness.[12][13] There are different specimen's list is given below in the table 1.

Specimen Number	Tool Shoulder Diameter (mm)	Reinforced Particles
S1	18	WC
S2	20	WC
S3	22	WC
S4	Without Processing	None

Table 1: Parametric design adopted for FSP

During the tensile testing load was applied continuously with the help of the Servo Control Universal Testing Machine until the specimen breaks. The image of specimens after testing is shown in the figure 5.

Fig. 5: Specimens after testing

Lastly, the visual inspection was performed to check any type of defect that might be present on the surface of the work-piece. Overall, it was found that the specimen S2 has highest values than other specimens.

IV. RESULTS AND DISCUSSION

After the processing, various values are obtained by doing tensile test, impact test, micro-hardness test and microstructure test and analyzed to come to a conclusion. It has been found that overall values are more then the base value of the material.

A. Effect of tool shoulder diameter and reinforced particles on tensile strength of AA6101/WC composite:

Tool shoulder is the one of the main reasons why heat is generated in the workpiece due to friction, and it is also responsible for the containment of hot metal below the tool shoulder.[10]

The ultimate tensile strength of the composite has been increased except when processed with tool having 22 mm diameter as shown in the figure 6, and it is also noticed that composite that was processed with tool having 20 mm shoulder diameter had more strength as compared to other tools (18 mm and 22 mm). This can be seen from the values given in the table 2.

Specimen Number	Tool Shoulder Diameter (mm)	Reinforced Particles	Tensile Strength (N/mm^2)
S1	18	WC	223
S2	20	WC	231
S3	22	WC	217
S4	Without Processing	None	221

Table 2: Values of tensile strength after testing

Higher values of tensile strength with 20 mm diameter is owing to appropriate production of heat in the work-piece causing easy flow of material thus little to no defects are produced on the surface of material thus resulted in higher values of tensile strength. When compared with the other situations where tool shoulder diameter is 18 mm and 22 mm, there is no proper generation of heat as well as flow of material caused some defects on the surface of the material there tensile strength is less. It is interesting to note that the value of tensile strength of S3 is even below than base metal due to production of more wider HAZ and TMAZ regions in the surface of the material.[6] Moreover, homogeneous dispersion of tungsten particles also caused higher values of tensile strength than base metal value.

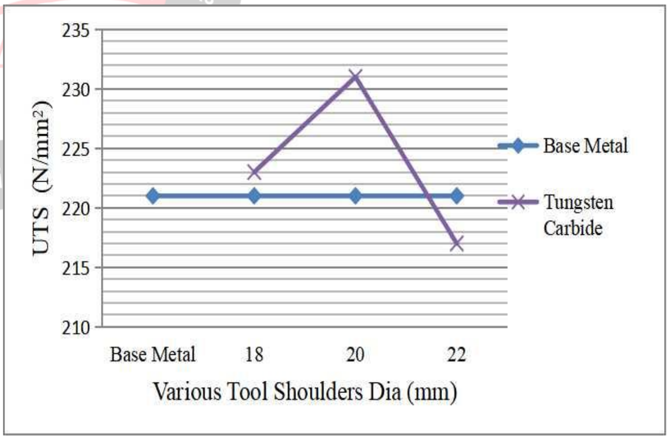

Fig. 6: Effect of tool shoulder diameter and reinforced particles on tensile strength

B. Effect of tool shoulder diameter and reinforced particles on micro hardness of AA6101/WC composite:

"The micro hardness of any material is directly proportional to its grain size means smaller the grain size more will be the hardness", according to the Hall-Petch equation.[6]

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Specimen Number	Tool Shoulder Diameter (mm)	Reinforced Particles	Micro hardness (Hv)
S1	18	WC	103
S2	20	WC	127
S3	22	WC	110
S4	Without Processing	None	75

Table 3: Values of micro hardness after testing

It can be seen from the table 3 that micro hardness of the composite is more than the base value owing to the creation of more finer grains after processing. However, material when processed with tools having 18 mm and 22 mm tool shoulder diameter have comparatively lesser values of micro hardness than 20 mm tool shoulder diameter. This is because tool with 18 mm diameter has lesser contact with the surface during the process caused lesser production of heat and reinforced particles within the region. Similarly, when material machined with 22 mm diameter tool has more surface contact area produced more heat resulted in heterogeneous flow of material as well as less uniform distribution of tungsten carbide particles. But, tool with 20 mm shoulder diameter caused homogeneous flow of material due to not only appropriate production of heat within the region but also homogeneous distribution of reinforced particles resulted in more finer grains. So, it has more micro hardness value than others as shown in the figure 7.

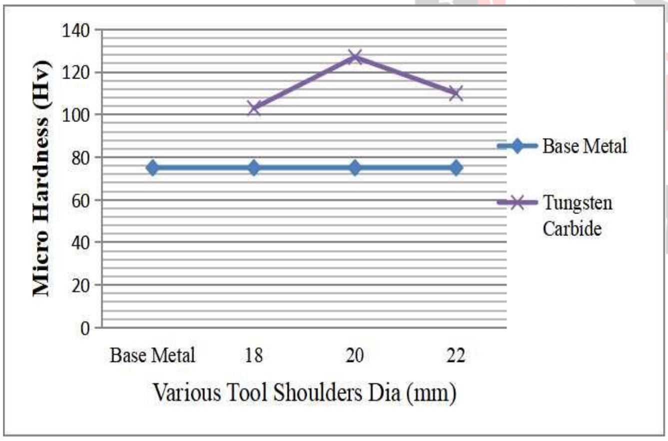

Fig. 7: Effect of tool shoulder diameter and reinforced particles on micro hardness

C. Effect of tool shoulder diameter and reinforced particles on impact strength of AA6101/WC composite:

Impact strength is directly related to the hardness of the material as it hardness increases impact strength reduces.[18]

Specimen Number	Tool Shoulder Diameter (mm)	Reinforced Particles	Impact Strength
S1	18	WC	17
S2	20	WC	9
S3	22	WC	15
S4	Without Processing	None	23

Table 4: Values of impact strength after testing

The table number 4 illustrates that the values of impact strength of specimens S1, S2 and S3 is low as compared with specimen S4 which is a base metal because when aluminium plate was processed by doping with the tungsten carbide (WC) particles, the grains of the metal refined causing rise in hardness value and fall in impact strength. Moreover, tools with 18 mm and 22 mm tool shoulder diameter has comparatively higher values of impact strength than remaining tool owing to not appropriate production of heat as well as dispersion of reinforced particles causing less hardness than tool 20 mm tool shoulder diameter as shown in the figure 8.

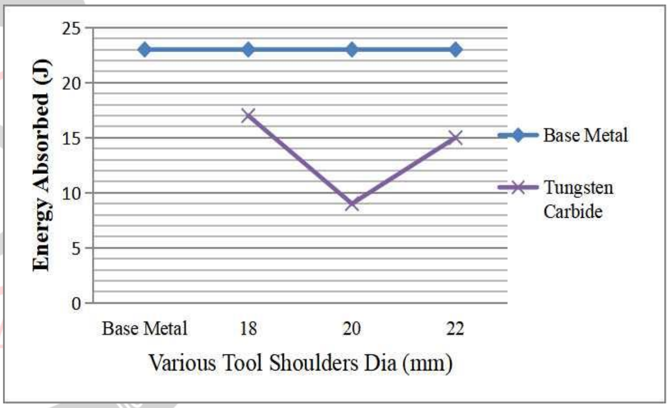

Fig. 8: Effect of tool shoulder diameter and reinforced particles on impact strength

D. Micro structural characteristic of AA6101/WC composite:

The micro structure of processed material is shown in the figure 9 below.

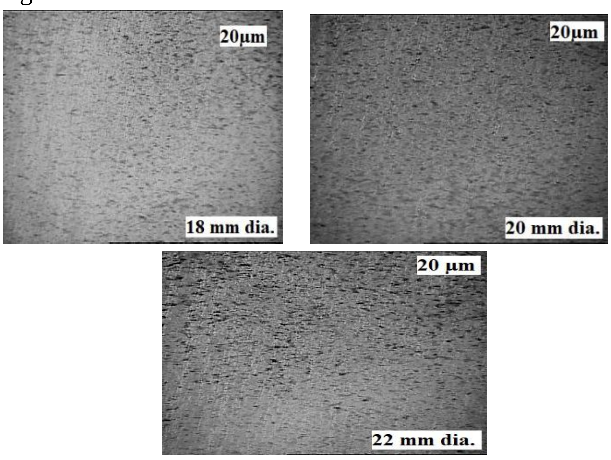

Fig. 9: Micro structures at the stir zone

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The diameter of tool shoulder clearly affected the dispersion of reinforced particles on the surface of the aluminium sheet in the processed zone. The tool with 20 mm shoulder diameter has dispersed the tungsten carbide particles more homogeneously than the other two tools because of appropriate area of contact as compared to others where non uniform dispersion of particles can be seen due to more or less area of contact between tool shoulder and work-piece.

V. CONCLUSION

The prime reason to conduct this experiment was to stimulate the properties of AA6101 so that it can be used in various applications like automobile and aerospace. After conducting experiment following conclusions are drawn:

1. Doping with tungsten carbide and by varying tool shoulder diameter considerably altered the values of mechanical properties, such as tensile strength, micro hardness and impact strength.

2. The values of different mechanical properties are maximum when material was processed with the tool having 20 mm shoulder diameter owing reasonable generation of heat in the stir zone than tools with 18 mm and 22 mm diameter.

3. However, the values of impact strength are lesser the base value of the material due to rise in the hardness.

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