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Morphology and Mechanical Behavior of Friction Stirred Aluminum Surface Composite Reinforced with Graphene

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Abstract: Al-6063 Surface Composites (ASCs) fabricated using Friction Stir Processing (FSP), which enhances the hardness and tensile strength prodigiously appropriate for automotive applications, for example, piston skirts in the cylinder chamber. This covers the way for the examination of multi-pass impacts of graphene nano-powder filled in Al-6063 SCs for investigation of microstructure, hardness, tensile strength, and grain size. The microstructural analysis uncovers the homogenous dispersion of graphene nano-powder particulates in the Al-6063 alloy, and on escalating the numbers of passes during FSP, uniform dispersion of graphene nano-powder in matrix material was observed due to a reduction of grain size in the produced Aluminum metal matrix composites (AMMCs). The results revealed that the superior microhardness of 106.4 VHN along with maximum tensile strength (217 ± 2 MPa) is achieved after the third pass of the tool. The minimum grain size of 23 µm was also observed in 3P- FSP-ed ASCs during friction stir processing.

Keywords: Al-6063, Friction stir process; graphene nano-powder; surface composites; hardness; tensile strength; microstructure.

1. Introduction

The goal of this research is to create Aluminum Surface Composites (ASCs) with increased mechanical properties by incorporating graphene nanoplatelets into the aluminum alloy. The Piston skirt, a critical component in the automotive industry, was redesigned to employ a different material, which was to be replaced by Al-6063 surface composite that had been created [1)]. High tensile strength and hardness are desirable characteristics for the produced material, and this is only achievable in composites that have been fabricated without flaws [2)]. The use of aluminum surface composites is expanding rapidly. Composites can be fabricated using a variety of liquid-state manufacturing techniques, including stir casting and infiltration [3–5)]. There were no intermetallic phases formed with this processing method, yet the mechanical characteristics were still enhanced. However, these flaws can be fixed by employing a solid-state processing technique known as friction stir processing (FSP), which modifies the intermetallic phases and boosts the mechanical characteristics of the manufactured ASCs in comparison to the base material [6)]. During friction stir processing, friction is generated between the FSP tool and the workpiece, which also softens the base metal (Al-6063). Furthermore, the parameters like tool rotation and transverse speed, plasticize the material and then transfer the material from Advanced Side (A.S) to Retreating Side (R.S). These outcomes in the development of three distinct areas specifically the stir / Mix Zone (SZ), Thermo-Mechanically Affected Zone (TMAZ), and Heat Affected Zone (HAZ). ASCs with the addition of ceramic reinforcements exhibit high strength, hardness, and elasticity character owing to the microstructural improvement [7)]. The previous literature shows the incorporation of numerous reinforcements like B_4C, TiC, Al_2O_3, SiC, TiB_2, ZrB_2, and TiO_2 to matrix material (Aluminum alloy) to get the as-wanted properties of the fabricated composites [8–12)]. Bourkhani et.al considered the interfacing of Al_2O_3 particulates as reinforcement with FSP tool pin in AA1050 aluminum alloy as a matrix using friction stirs processing technique. The author observed the agglomeration of reinforcement particles during the first pass but after the second pass improvement in tensile strength, hardness, and wear resistance was noticed. The homogeneity of microstructure also confirms the uniform distribution of reinforcement and matrix material after the second pass in the FSP technique. The hardness and tensile strength play a vital role in the verdict of the enhancement of properties for the fabricated FSP-ed surface composites [13)]. Rathee et. al observed the grooving method during FSP fabrication technique is better than direct pasting and filling blind holes with reinforcement. The defect-free surface composite was produced when the offset center tool was used towards the retreating side (R.S) of the workpiece. The optimized value was achieved at 1.5mm offset which is half the radius of cylindrical tool probe [14]. Khodabaksh et.al demonstrated the fact of strengthening in grain enhancement in fabricating AA5052/Graphene composites [13]. Patil et.al fabricated the surface composite of Al7075-T6 encapsulating with graphite and TiC as reinforcement using FSP technique. The EDS analysis confirms the traces of graphite and TiC particulates in the FSP-ed surface composite. The uniform reinforcement distribution in the fabricated composites also confirms with FESEM analysis [15]. Abushanab and Moustafa produced the Al6063/Al2O3 surface composite utilizing FSP technique and revealed that adequate dynamic recrystallization and frictional heat can be accomplished particularly after third pass and form equiaxial fine shape of the grains [16]. Suganeswaran et.al created the surface composite of Al7075 with reinforcement of SiC particles utilizing FSP method. The 15% and 22% enhancement in hardness (VHN) and tensile strength (MPa) was seen in created FSP surface composite. The uniform scattering of the reinforcement particles and critical grain refinement was seen from SEM investigation of FSP surface composites [17].

In such manner, Kavery et al produced composite of AA-6063 filled with TiC using FSP technique and concluded that hard reinforcement particles of TiC and fundamentally increases the hardness. The Aluminum composite reinforced with Mg_2Si after successive number of FSP passes, which results in decrement in the porosity and actuate the molecule discontinuity that upgrades the hardness value [18]. In the meantime, expanding the number of passes in FSP process results in uniform dispersion of the matrix and reinforcement particles which correspondingly enhances the mechanical properties of the fabricated composites [19]. Mehmood Khan et. al also reported the increment in hardness due to incorporation of TiB2 particles to the AA-5083 alloy using FSP route [20]. The hardness and wear resistance were analyzed in surface composite of A380-SiC using FSP route. The optimum values of hardness (177 Hv) at 1460 tool rpm during FSP-ed surface composite and wear rate (4x10-8 gm/cm) was noted at 15 N loading conditions as concluded by Maryam and Akeel [21]. To the authors knowledge, few reports are explored to fabricate the Al6063/graphene nano powder SCs using FSP technique. Al-6063 alloy is viewed as inferable from its brilliant explicit strength and decreased weight character [22–24]. For these previously mentioned reasons, this study focusses on creating the Al6063/graphene nano powder SCs through taking on the different pass methodology particularly for cylinder skirt material as an automotive application.

2. Experimental methods and materials

In the current research, Aluminum surface composite was prepared using friction stir processing technique. The Al-6063 alloy plates of size 120 mm x 50 mm x 6 mm was taken as base material and graphene nanoplatelets powder was used as reinforcement for the ASCs fabrication. The reinforcement was purchased from Nano shell Intelligent Material Private Limited, Derabassi, Punjab, India. Figure 1 represents the EDS and XRD of Al-6063 FSP-ed SCs.

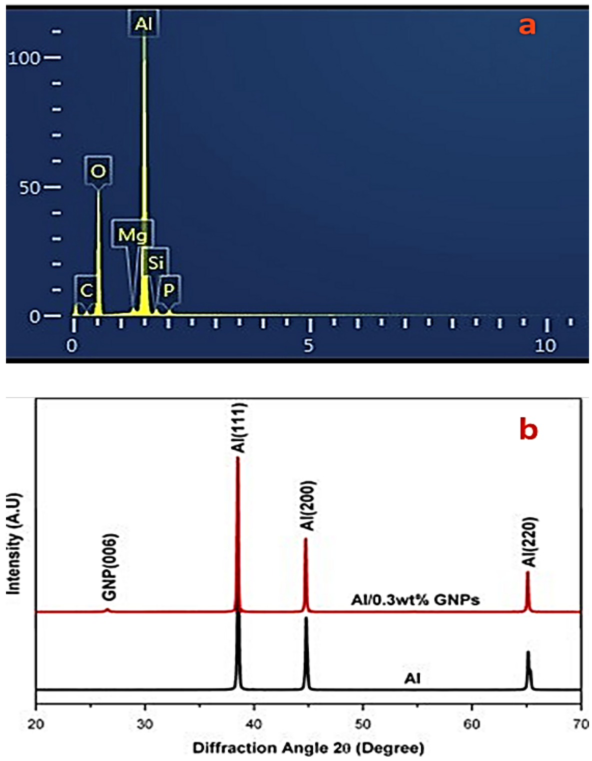

Fig 1: (a) EDS and (b) XRD of Al-6063 FSP-ed SCs

The graphene nano-powder was additionally processed by preheating at 300 °C to remove the moisture content from the reinforcement. A square groove was prepared in the base material with the dimension of 3 mm x 3 mm in the Al-6063 alloy plate, which is along the direction of FSP tool progression. A cylindrical shaped tool with 30 mm shoulder diameter, 5.8 mm, and 4 mm as height and diameter of shoulder pin were the dimensions of the H13 steel tool for the ASCs processing. The SIEMENS make vertical milling machine was used with maximum loading limit of 5 tons. The reinforcement was filled in the groove and the groove was closed using pin-less tool, in order to avoid the splashing of the graphene powder from the groove. To fabricate the ASCs specimens, the process parameters such as 1500 rpm (rotational speed), 45 mm/min (transverse speed), 1.5 mm (depth of cut), and 2° (tilt angle) were selected after pilot run to make the fabricated surfaces defect free. Figure 1 shows the steps involved in ASCs fabrication, which represents in graphical form. The range of numbers of passes were selected as (1-3) and after the third pass the enormous defects were generated and results in decrement of mechanical properties of the fabricated ASCs [25–27]. The 1P-FSP-ed ASCs, 2P-FSP-ed ASCs, and 3P-FSP-ed ASCs were designated after one, two, and third pass of the tool, respectively, and FSP-ed (Al-6063) specimen as no reinforcement for comparison purposes.

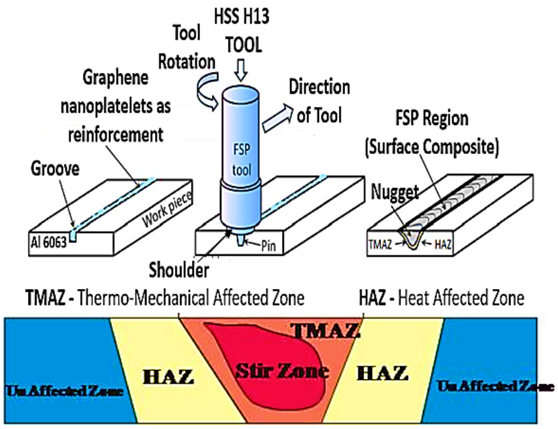

Fig 2: Friction Stir Processing Route

The experimental setup to produce the FSP-ed SCs is illustrated in figure 2. A groove of 4 mm width is prepared after machining, which is perpendicular to the direction of FSP route as represented in figure 1. After preparing the groove on the specimen, it is cleaned using acetone than it is polished using emery papers or sheets of different grit sizes. The polished specimen is now etched with killer reagent to give shining to the specimen. To observe the grain size of the distributed particulate in the FSP-ed SCs, DeXel-Imaging metallograph (Version SIGMA, UK) was utilized. ASTM E03-01 standard was used to reveal the microstructural behavior of the base alloy and FSP-ed surface composites. To analyze the morphology of Al-6063 alloy and FSP-ed SCs, (Model- JOEL, USA) Scanning Electron Microscope (SEM) was used (table-1). The hardness tests were performed on the Vickers hardness tester with precision of 0.01 mm and for load of 200 gf and dwell period of 15 seconds. According to the ASTM E92, three observations were recorded to find the average hardness value. The tensile strength of the specimens (75 mm x 10 mm x 5 mm) was observed in accordance to ASTM E8 standard. The Universal Testing Machine (Make- FASNE) was used for tensile tests.

Table 1: Details of test performed

Number of passes	Rotation Speed (rpm)	Transverse Speed (mm/min)	Tilt Angle (degree)
1P FSP-ed	1600	40	2
2P FSP-ed			
3P FSP-ed			

The mean of three readings was recorded for the tensile strength of Al-6063 alloy and FSP-ed surface composites. Figure 2 shows the graphical representation of prepared samples. The mean of three readings was recorded for the tensile strength of Al-6063 alloy and FSP-ed surface composites. Figure 3 shows the graphical representation of prepared samples.

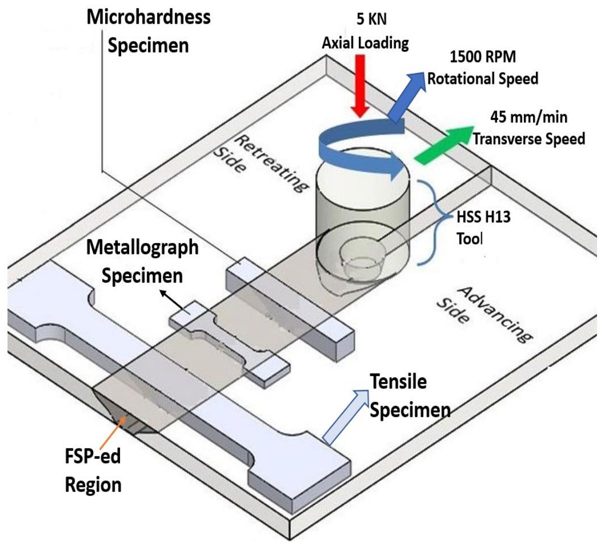

Fig 3: Representation of specimens for different testing

3. Results and discussion

3.1 Morphology Evolution

The graphene nano powder particulates dispersed over the matrix are identified through SEM which is represented in Figure 4. The figure 4(a) represents SEM analysis of Al 6063 alloy after friction stir processing.

The cracks, scratches, and dents were found in the figure 4a, which causes decrement in mechanical properties of the FSP-ed material. Clustering or agglomeration of the particulates are noticed on the outer layer of 1P-FSP-ed SC (Figure 4b) which also showed decrement of the mechanical properties of the fabricated surface composite. Similar behavior was noticed by Suresh Kumar et. al in Al6063/Si_3N_4/Cu composite after single pass processing. This occurrence is ascribed due to the deficient measure of frictional heat and plastic strain after single pass of the tool [22)].

Now, after the second pass of the tool, a better interface was observed between Al-6063 (base alloy) and fabricated Al-6063/Graphene nanoplatelets surface composite after 1P-Fsp-ed samples. This improved interfacing is results in formation of nucleation and less agglomeration of the particles as shown in figure 4(c).

Figure 4(d) represents the morphology of the FSP-ed surface composite after third pass of the tool. It is clearly seen from the figure 4(d) that smooth surface with homogenous dispersion of the reinforcement particles in the matrix material has been achieved. This reduction in grain size of 23 µm also confirm the strong bonding between graphene nano-platelet and Al-6063 alloy after 3P- FSP-ed surface composite.

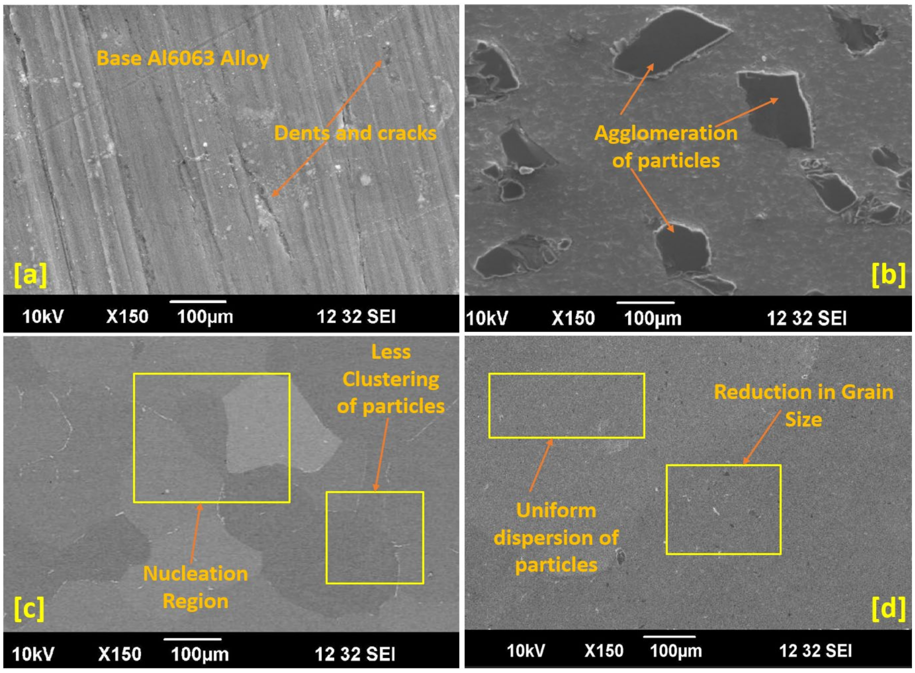

Fig 4: (a, b, c, and d): Microstructure of Al6063 and FSP-ed SCs at different passes

Table 2: Mean Values of Mechanical Properties of FSP-ed SCs Details of test performed

No. of Passes	Hardness (VHN)	Ultimate Tensile Strength (MPa)	Average Grain Size (μm)
1P FSP-ed	82.3	188 ± 3	64
2P FSP-ed	98.7	203 ± 2	36
3P FSP-ed	106.4	217 ± 2	23
Base alloy	65.6	133 ± 1	98

3.2 Microhardness Evaluation

The values of hardness for FSP-ed surface composites and base Al6063 are addressed in Figure 4. The value of hardness (table 2) for as-received Al-6063 alloy was observed as 65.6 VHN, whereas after the addition of graphene nanoplatelet the enhancement in hardness value was noted in the range of (25.45 – 62.25 %) for subsequently (1-3) number of passes of tool. The maximum hardness (106.4 VHN) was achieved at 3P-FSP-ed surface composite [28–30]. The decrement in dents, pores, agglomeration of the particles, and grain size is the reason for improvement of hardness after 3P- FSP-ed of the tool in produced surface composite. The improvement in hardness worth of FSP-ed surface composites is attributable due to the accompanying reasons (I) The addition of graphene nanoplatelets in Al-6063 alloy which have the tendency to bear indentation load in the produced surface composite. (II) The three pass of the tool is used to produced surface composite, which increases the mechanical properties of the material due to uniform dispersion of the particles in the fabricated surface composite.

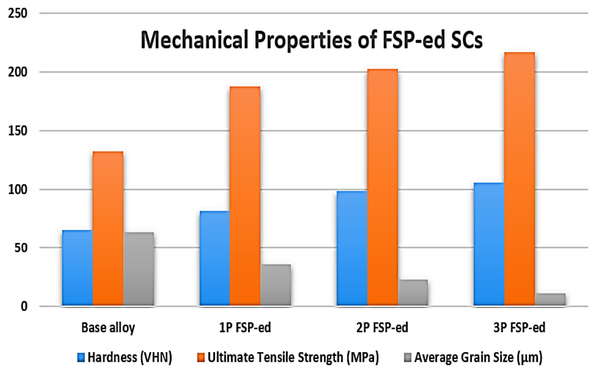

Fig 5: Mechanical Properties of FSP Surface Composites

3.3 Tensile Strength Measurements

To determine the tensile strength of the prepared FSP-ed surface composite, the specimens were observed at room temperature. During the tensile strength, the strain rate of 5 per second was kept constant for commercial importance. Table 2 shows the ultimate tensile strength of the specimens processed after number of passes and with addition of reinforcement particles also. The FSP-ed specimens have greater tensile strength compared to base material [31]. It has also been observed that the number of passes also affect the ultimate tensile strength. From the graph, it can be concluded that ultimate tensile strength is directly proportional to number of passes. The maximum tensile strength of 217 ± 2 was achieved with 3P FSP-ed surface composite specimens. The following facts can be the reason for the improvement in tensile strength: (i) Probable agglomeration of the graphene particles in FSP-ed surface composites. (ii) Addition of graphene particles which also enhances the hardness. (iii) The reduction in grain size and strong interfacial bonding of the matrix and reinforcement particulates. The afore-mentioned positive factors enhances the mechanical properties of the fabricated FSP-ed surface composite using FSP technique.

4. Conclusions

The present investigation examined hardness. tensile strength, grain size, and morphology of the FSP-ed surface composite reinforced with graphene nanoplatelets in Al6063 alloy using friction stir processing technique. The main outcomes are summarized as mentioned below:

- Aluminum-based surface composite reinforced with graphene nanoplatelets is successfully fabricated using friction stir processing.
- The maximum hardness and tensile strength of 106.4 VHN and 217 ± 2 MPa, respectively has been achieved after 3P-FSP-ed surface composites due to reduction in formation of dents, scratches, and cracks.
- The reduction in grain size of 23 µm has been noticed after three passes in friction stir processing due to strong interfacial bonding of the reinforcement and matrix material.
- Microstructural investigation discloses the homogenous distribution of graphene nanoplatelets particles in the Al-6063 alloy and on increasing the number of passes of FSP tool in the fabrication of Aluminum metal matrix composites (AMMCs).

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Nomenclature

ASC	Aluminum Surface Composites
FSP	Friction Stir Processing
AMMCs	Aluminum metal matrix composites
AS	Advanced Side
RS	Retreating Side
TMAZ	Thermo-Mechanically Affected Zone
HAZ	Heat Affected Zone

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