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A STUDY ON THE INFLUENCE OF REINFORCEMENT VOLUME ON AA5083/(SiC-Gr) HYBRID SURFACE COMPOSITE DEVELOPED BY FRICTION STIR PROCESSING

In this study, a hybrid surface composite of AA5083/SiC-Gr was produced by Friction Stir Processing (FSP). Reinforcement material each in 50:50 proportion was filled in the base matrix using holes method. Three different hybrid reinforcement volumes of 301.6 mm^3, 452.4 mm^3, and 603.2 mm^3 were prepared for surface composite. Optical and Scanning Electron Microscopy was used to check the quality of the prepared surface composite and homogeneous distribution of reinforcement was observed in the images. It was observed that due to better uniform distribution of reinforcement particles during 3 pass FSP, specimens with 301.6 mm^3 reinforcement volume showed enhanced microhardness and wear properties in comparison with the other specimens.
Keywords: Surface Composites; Multi-pass; Friction Stir Processing; Reinforcement; Hybrid Composite

1. Introduction

Aluminum Alloy 5083 (AA5083) is recognized for its enhanced ratio of strength-to-weight and its lightweight properties [1]. Due to these reasons, they are used in the marine and automotive industries. However, these alloys lack hardness and tribological properties, due to which they are generally mixed with reinforcement particles to make a composite material. There are various techniques to develop composite materials [2-7]. However, constructed on the basic principle of Friction Stir Welding, FSP is one of the best-known techniques to develop surface composites [8]. In FSP, a tool with a pin is used which is provided with a rotating speed and is inserted in the base matrix, and then traverse movement is given to the tool. This movement produces enough heat in the base material to reach severe plastic deformation. The grain refinement in the microstructure takes place, and the material properties get enhanced due to the FSP [9].

Various researchers developed surface composites by the FSP technique. Suganeswaran et al. investigated FSP on AA7075 alloy and produced a surface composite with Al_2O_3 and SiC reinforcement particles [10]. It was observed that the produced hybrid surface composite contains better microhardness and wear properties. Jain et al. [11] investigated FSP on A5083-B_4C/SiC/TiC and observed that the FSP assisted the material to increase its tensile, wear, and microhardness properties. Pan et al. analyzed FSP on AISI 420 martensitic stainless steel and concluded that the processed material had enhanced hardness in comparison with the conventionally hardened material [12]. Similarly, Amra et al. [13] investigated FSP on Al5083/CeO_2-SiC and observed that the composite showed enhanced wear resistance properties to the base material.

Various published studies focused on the production of surface composite by using reinforcement materials. Most of the literature work emphasized investigating the influence of change in the ratio of the hybrid reinforcement during the FSP. However, the influence of reinforcement volume in the base matrix has not been investigated thoroughly yet. In this paper, different volumes of SiC-Gr Hybrid reinforcement were used to develop the AA5083 hybrid surface composite by using 3 pass FSP. Three specimens were prepared to analyze the influence of reinforcement volume on AA5083/SiC-Gr Hybrid Surface Composite. In specimen "A", 301.6 mm^3 of SiC-Gr Hybrid reinforcement material was used in the experiment. Similarly, 452.4 mm^3 and 603.2 mm^3 of reinforcement material were used for specimens "B" and "C" respectively. The ratio of hybrid reinforcement SiC-Gr was kept at 50:50 constantly in all specimens A, B, and C. The specimens were investigated for their microhardness, microstructure, and wear resistance.

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2. Materials and Methodology

For this work, Aluminum alloy AA5083 was used as the patent material. AA5083 sheets with dimensions of 50 mm width, 5 mm thickness, and 300 mm length were selected for the process. For producing the surface composite, hybrid reinforcement of Graphite (Gr) and Silicon Carbide (SiC) in the proportion of 50:50 was used for the process (i.e. SiC and Gr were mixed in equal volume proportion). To add the reinforcement particle into the base matrix, the hole method was used. To investigate the influence of reinforcement volume, three types of hole patterns were made into the workpiece with 2 mm diameter and 3 mm depth in a zig-zag pattern. Fig. 1 shows the hole patterns. It has been calculated that the reinforcement volume fraction in Pattern A (2 holes Pattern) is 301.6 mm^3, reinforcement volume fraction in Pattern B (3 holes Pattern) is 452.4 mm^3, and reinforcement volume fraction in Pattern C (4 holes Pattern) is 603.2 mm^3.

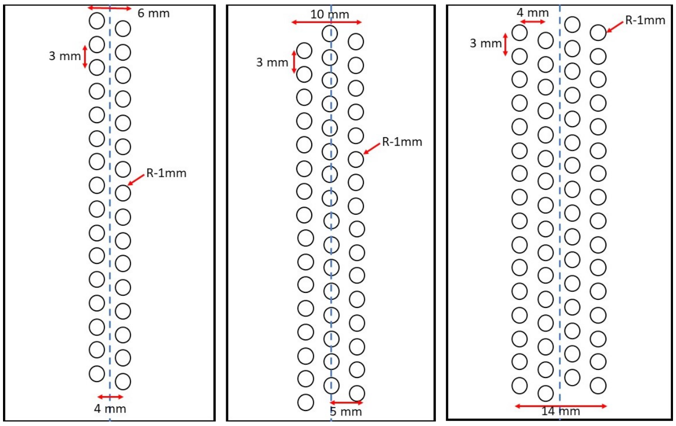

Fig. 1. Pattern A (2 holes Pattern), Pattern B (3 holes Pattern), Pattern C (4 holes Pattern)

The FSP was performed on a vertical milling machine. The parameters for FSP were selected based on the preliminary experiments and as per the previous literature review [14-17]. The tool's traverse speed of 31.5 mm/min and rotating speed of 500 rpm were employed for the process. A 2.5° of tool tilt angle was used for the process. A tool without a pin was employed during the capping pass, followed by a three-pass FSP with the tool having a cylindrical pin profile with a 4 mm pin diameter, 4 mm pin height, and 18 mm shoulder diameter.

The microstructure of the prepared hybrid surface composite AA5083/SiC-Gr was examined by Field emission scanning electron microscopy (FE-SEM) and Optical microscopy. The samples were cut from the cross-section area and were grounded using the emery papers. The grounded samples were then polished with the help of a diamond paste of 3 µm and 1 µm and Keller reagent was used on the surface of the samples to etch the grounded specimens.

The microhardness property of the prepared hybrid surface composites was studied with the help of the Vickers microhardness tester (HVS – Micro Hardness Tester – Daksh) as per the ASTM E384 norms. The microhardness test was done using a dwell period of 10 seconds and a constant load of 200 gf. The tribological properties of the prepared hybrid surface composites were analyzed on a "pin-on-disc tribometer". The Wear Rate and Coefficient of friction (COF) were measured during the test. The test was done according to the ASTM G99-17 criteria. A constant sliding distance of 1000 m, a track diameter of 80 mm, and a load of 10 N were used for the tribological study.

3. Results and Discussion

3.1. Microstructure

The distribution of the SiC-Gr reinforcement in the aluminum matrix is presented in the optical microscopy in Fig. 2(b-d) and in SEM micrographs in Fig. 3(b-d). The homogeneous dispersion of the reinforcement material was observed in the base matrix without any significant clustering or agglomeration. This is due to the continuous flow of material during the movement of the FSP tool and intense plastic deformation in the nugget zone during FSP. The three-pass FSP further assisted in the scattering of the reinforcement material and avoided any chances of agglomeration [18]. The presence of Gr in SiC-Gr hybrid surface composite worked as a solid lubricant particle and helped the reinforcement material to disperse more homogenously during the FSP. The FSP specimen without any reinforcement underwent recrystallization and therefore formed refined grain microstructure, as depicted in Fig. 2(a) and 3(a). Specimen A showed a better scattering of the reinforcement material in the base matrix followed by specimen B and then specimen C. The lower reinforcement volume in base material helped in the homogeneous stirring of the matrix material and thus helped in better material flow during the FSP. The same result can be

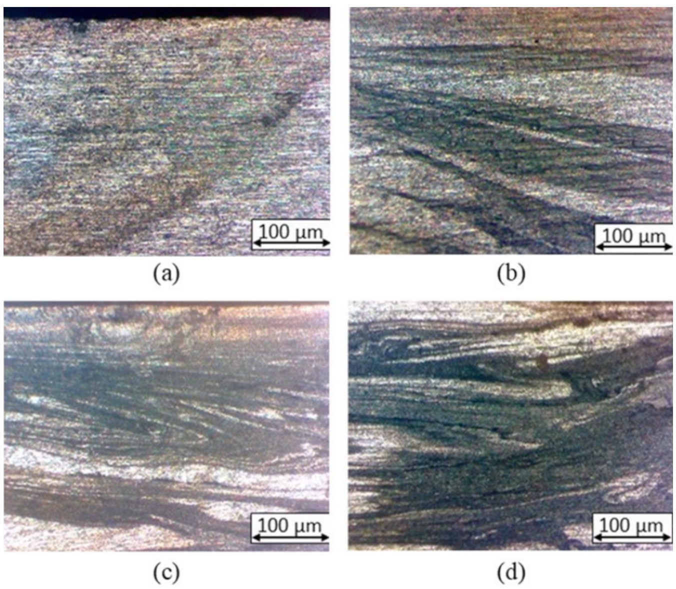

Fig. 2. Optical Microscopy from the nugget zone of FSPed specimen with (a) without reinforcement particles (b) Specimen A (c) Specimen B (d) Specimen C

verified from SEM image 3(d), in which the more homogeneous scattering of the reinforcement material can be seen.

The grain size was measured as per the ASTM E112/E1382-91 standards by using the line interception method with 10 no. of lines at 1 degree and 100 thresh hold. The average grain size of the prepared surface composite in specimen A was observed to be 3 μm in 3 pass FSP, 4 μm in 2 pass FSP, and 5 μm in 1 pass FSP, which is significantly smaller in comparison with the base matrix AA5083 with a grain size of 8 μm. This grain size refinement in the stir zone is because of the mechanical stress and thermal cycle which is experienced during the FSP, which causes dynamic recrystallization (CDRX) and thus produces fine grains microstructure [19].

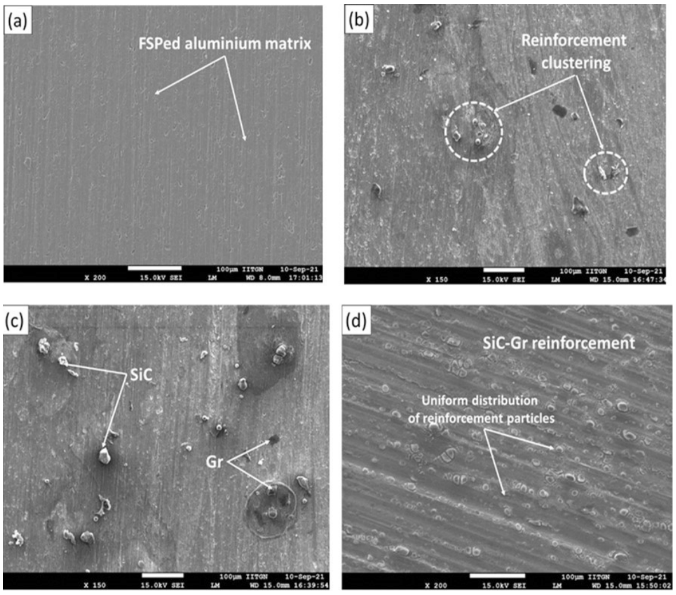

Fig. 3. SEM micrographs from the nugget zone of FSPed specimen with (a) without reinforcement particles (b) C-Specimen (c) B-Specimen (d) A-Specimen

3.2. Microhardness

The microhardness study shows that the FSP helped to increase the microhardness property of all the processed specimens. The microhardness values of the FSPed specimens at every 1 mm distance are shown in Fig. 4. In the graph, it can be seen that all the FSPed specimens exhibit enhanced microhardness values in comparison with the base matrix. The SiC in the reinforcement material provided high microhardness and strength to the FSPed samples. The multipass FSP (3 passes) helps to enhance the heat dissipation during the FSP, which further assists in the uniform scattering and complete dissolution of the reinforcement material. This uniform scattering of the reinforcement particles provides high microhardness values in comparison with the base matrix.

The three passes FSPed sample without reinforcement exhibited an enhanced microhardness value of 16.18%. Similarly, an enhancement in microhardness value by 20.07%, 22.9%, and 28.65% was observed in specimens C, B, and A respectively. The FSP supported the dynamic recrystallization and decreased the average grain size in the prepared FSPed samples, which helped to enhance the microhardness value. This behavior agrees with the Hall-Petch equation, which says that with the decrease in the grain size, the microhardness property of the material enhances [20]. The grain boundary pinning effect and the refinement in the grain size assisted in the enhancement of the microhardness values in the FSPed specimens.

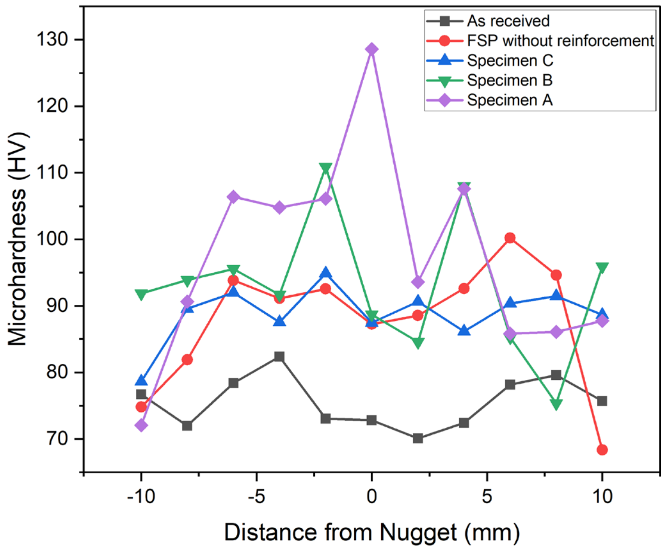

Fig. 4. Microhardness variation obtained after FSP

3.3. Tribological Behaviour

The tribological studies show that the FSP helped the specimens to increase their tribological properties. The presence of reinforcement material helped the specimens to reduce material loss during the pin-on-disc tribometer test. The maximum mass loss of 0.007 g was found in the as-received material, whereas the minimum mass loss of 0.005 g was found in specimen A after the test. The change in wear loss to sliding distance is shown in Fig. 5. The average wear resistance was 207.9, 131.8, 129.3, 113.7, and 91.8 μ/mm in specimens as-received, FSP without reinforcement, specimens C, B, and A respectively. Specimen A showed depicted the least wear loss in comparison with the other samples with the same tribological conditions, whereas the maximum wear loss of 207.9 μ/mm was observed in the as-received specimen. Due to the enhanced microhardness properties of the FSPed specimen, the tribological properties also seemed to increase in the same order. Fig. 6 depicts the SEM micrograph of the worn surface of the sample as received and specimen A. The deep abrasive grooves were observed in Fig. 6(a) in the base material due to its soft nature. However, in Fig. 6(b), the layer of reinforcement particles can be seen, which acted as the lubricant layer and thus assisted in decreasing the abrasive wear during the test. The AA5083/SiC-Gr hybrid surface composite layer helped the specimen to withstand the direct load during the tribological test, which further decreased the wear loss of the specimens. The more amount of reinforcement helps to enlarge the surface composite area and thus helps to increase the load withstanding capacity during the pin-on-disc tribological test.

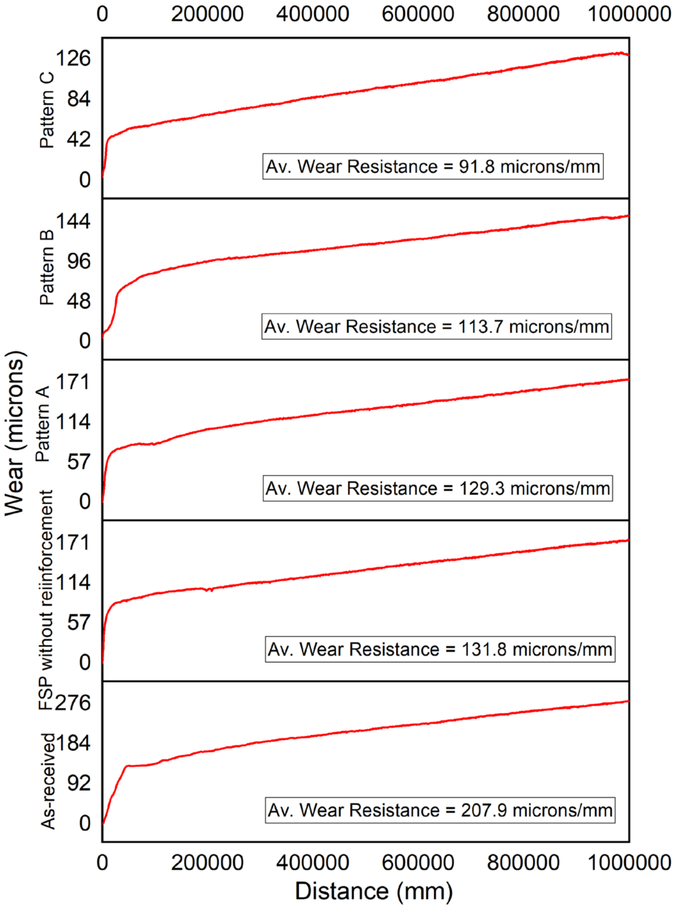

Fig. 5. Variation in the wear loss to sliding distance

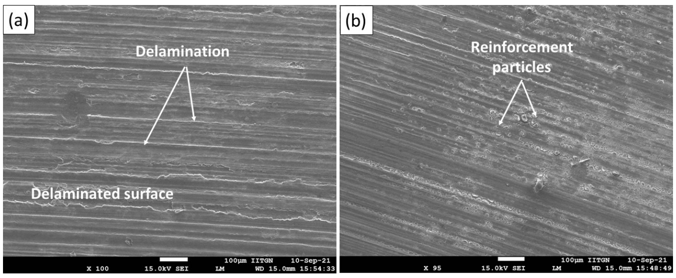

Fig. 6. Scanning Electron Microscopy of the worn-out surface of (a) As-received AA5083 (b) Specimen A (FSPed AA5083/SiC-Gr)

Fig. 7 depicts the COF for all the samples. It has been found that the average COF for specimens as-received, FSP without reinforcement, specimens C, B, and A are 0.42, 0.414, 0.403, 0.398, and 0.352, respectively. The least COF of 0.352 was observed for specimen A in comparison with the base matrix specimen with a COF of 0.42. This reduction of COF in specimen A can be understood with the presence of Gr in SiC-Gr hybrid reinforcement. The existence of Gr in the hybrid reinforcement particles produces a lubricant effect in the surface composite and the steel disc of the pin-on-disc tribometer. Due to the lubricant property of Gr, it helps in the proper mixing of SiC and Gr, which further helps in the prevention of contact between metal to metal and thus helps in the wear property of the produced surface composite.

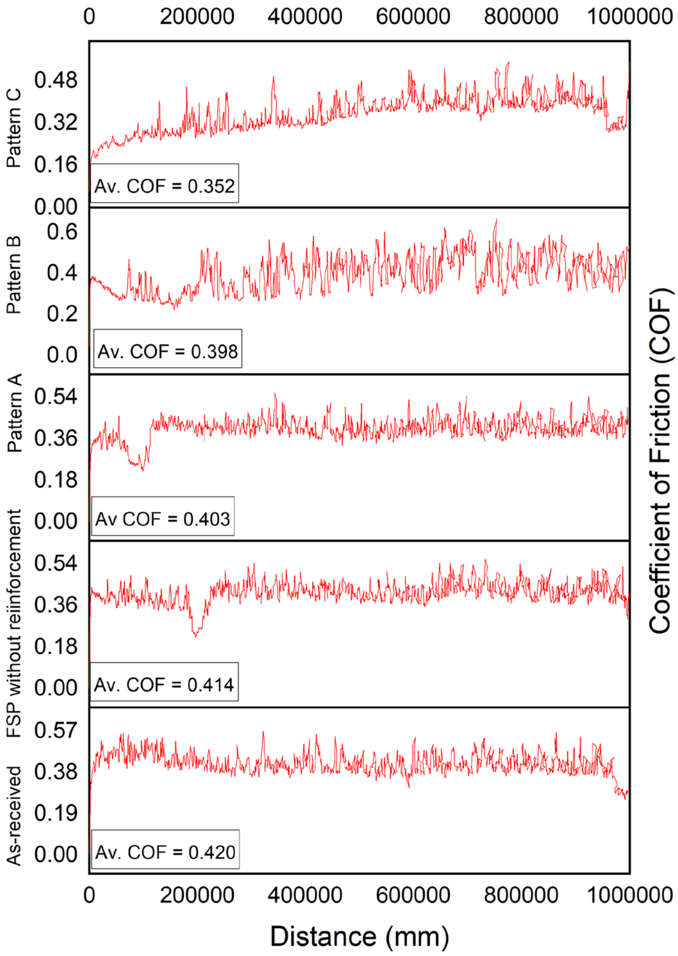

Fig. 7. Variation in the COF to sliding distance

4. Conclusions

The influence of volume fraction of SiC/Gr hybrid reinforcement was studied on AA5083 surface composite produced by three passes FSP. The conclusions can be summarized as:

1. The optical microscopy and SEM analysis showed that the three passes of FSP helped in the homogeneous dispersion of the reinforcement material in samples with 301.6 mm^3 and 452.42 mm^3 reinforcement volume without any major clustering or agglomeration.
2. Because of the uniform distribution of reinforcement material, the microhardness of the prepared surface composite was enhanced in comparison with the base matrix. FSPed specimen “A” showed 28.6% enhanced microhardness followed by specimen “B” by 22.9% and “C” by 20.07% in comparison with the base material.
3. The prepared AA5083/(SiC-Gr) surface composites showed the least wear loss of 91.8 μ/mm in specimen “A” as compared to specimen “B” of 113.7 8 μ/mm and specimen “C”

with 129.8 μ/mm. This is because of the presence of SiC/Gr hybrid reinforcement material which behaved like a solid lubricant and hence behaved as a barrier in the steel disc and the specimen and thus reducing the wear loss.

4. Among all the FSPed specimens, specimen "A" showed the least COF of 0.352, followed by specimen "B" of 0.398 and specimen "C" with a COF of 0.403. This is because of the presence of more volume of Gr. particles in the specimen, which provided lubricant property and thus reduced the friction between the surface composite and the counterpart.

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