Shot peening effect on surface characteristics and mechanical properties of aluminum matrix composite

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ABSTRACT

Keywords:
Al-Sic$_p$ Composite,
Shot Peening,
Grain Refinement,
Microhardness,
Tensile Strength,
Percentage of Elongation

In this work, the effect of shot peening (SP) and its duration on surface characteristics and mechanical properties of FG Al-SiC$_p$ composite reinforced with constant amount (10 wt.%) of SiC particles were studied. The composite surface characteristics after SP with 0, 70 and 140 s duration were investigated by XRD and surface topography by SEM. Moreover, Surface roughness, microhardness and tensile behavior of all the specimens were also studied. Results showed that the SP treatment favors to induce nanocrystalline (NC) structure with refined grains and improved other surface properties too which are enhanced along SP duration. It was also revealed that the grain refinement after SP provoked to rise the values of hardness, tensile and yield strengths. In contrast, longer SP duration causes reduction in percentage of elongation and increased surface roughness. However, SP is industrially popular method due to its superior benefits compared to other surface treatment methods.

1. Introduction

Aluminum matrix composites (AMCs) have received significant demand in aircraft, marine and automotive applications because of their high specific strength, hardness and modulus etc. [1]. Introducing a fine grain structure and high dislocation densities in the surface region due to microstructural changes were enabled the metallic components to improve the mechanical properties such as hardness, tensile strength and ductility of the AMCs. Therefore, extremely small grain size and high dislocations developed in the surface of Al_3Zr/AA6061 casted AMC via friction stir process (FSP) had shown an excellent improvement in tensile properties of the composite [2]. The tremendous improvement in composite tensile strength after FSP can be attributed to enormous reduction in the grain size and which was strengthened the AMC according to Hall-Petch relation pronounced by the authors after their investigation.

The Hall-Petch relation have such an ability to define how the materials receive the strength by virtue of its reduced grain size and which is having an inverse relationship with grains size. Because smaller grains can possess higher ratios of surface area to its volume of the bulk material which in other words higher grain boundaries to respective dislocations. This concept is perfectly proved in the case of material subjected to the severe plastic deformation (SPD). Hence, the mechanical properties such as microhardness and tensile strength of the AMC improved well owing to the reduction in grain size after surface modification via FSP as one of the SPD method [3]. In addition to the improvement in strength as defined by Hall-Petch relation, the defects such as pores, coarse grains and segregation appeared on the surface of AMC after casting had vanished when it was subjected to SPD [4].

Therefore, the surface modification by SPD enabled the composite to have small size grains accompanied by high dislocations which in turn improves the mechanical properties of the AMCs. Besides, the industry has an everlasting requirements such as low cost, high productivity, simplicity, flexibility and time saving methods for better efficiency. In order to satisfy the above requirements one of the SPD method shot peening (SP) is a chosen process for surface modification and practical method to increase

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component performance under different service conditions [5]. And due to its flexibility in treating components of any shape, it is most widely used by the industry. Moreover, SP has proved its ability in modification of surface into small size grain structure (also known as NC) with low cost, flexibility, simplicity [6] compared to the other surface modification methods [7] as sought by the industry.

But AMCs subjected to the SP is very scanty and concentrated majorly on hardness, grain size and dislocation density in the case of CNT/AA6061 AMC [8], TiB_2/AA6351 AMC [9] and Graphene/Al AMC [10]. Till now no study is available on effect of SP on the surface characteristics and mechanical properties of SiC_p/AA6061 AMC. Bearing the fact in mind this study aimed to investigate the tensile behavior of the selected composite along with its surface characteristics by the influence of SP and its duration. In this regard, the surface characteristics such as grain size, dislocation density, and micro-strain have been analyzed by XRD. Besides, the surface roughness, microhardness and tensile properties have been studied in association with surface characteristics.

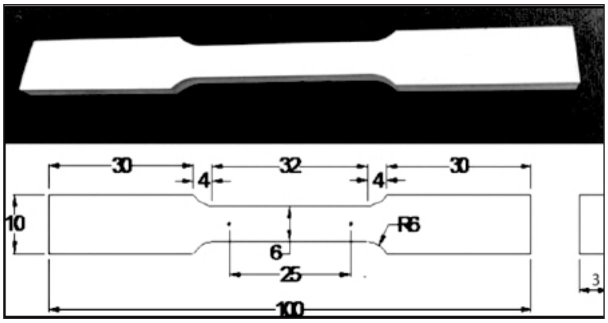

Fig. 1. Tensile specimen as per ASTM E-8 standard.

2. Experimentation

2.1 Material and specimen preparation

The material utilized in this study was a stir casted SiC_p/AA6061 composite having a constant reinforcement percentage 10 wt.% of SiC_p with size range 40–55 µm. The composite having AA6061 alloy matrix and SiC_p reinforcement sometimes referred to as functionally graded (FG) Al-SiC_p composite [11]. The elemental composition details of matrix alloy is listed in Table 1 and the tensile specimens prepared as per ASTM E-8 specifications shown in Fig. 1.

2.2 Shot Peening (SP) treatment

SP treatment was performed according to the MIL-S-13165 standard [12]. During SP a large number of pressurized steel shots (S-230) bombarded on the material surface as shown in Fig. 2.

And the SP was continued for 70 s as first step and 140 s as second step and then stopped after identifying that there is no considerable improvement in hardness with reference to the 70 s SP duration. Then specimen without SP is referred to as un-SP, whereas SP with 70 and 140 s duration as SP70 and SP140 respectively.

Table 1
Elemental composition of AA6061 aluminum alloy.

Element	Cu	Mg	Zn	Mn	Si	Fe	Cr	Ti	Al
Wt. %	0.33	1.24	0.41	0.39	0.78	0.31	0.3	0.24	Bal.

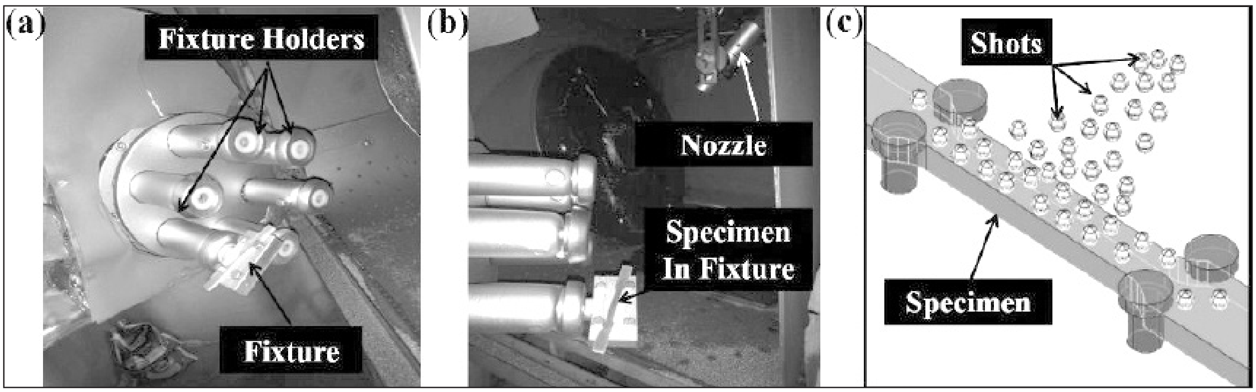

Fig. 2. Experimental setup
(a) Specimen fixed in Fixture (b) SP Chamber (c) SP schematic.

2.3 Surface characterization

The surface characteristics such as grain size, dislocation density, micro-strain and full width at half maximum (FWHM) of the specimens were examined by XRD (Bruker, Model: D-8 Advance) with Cu-Kα radiation. Then surface topography by using scanning electron microscope (SEM) (TESCAN VEGA-3).

2.4 Mechanical characterization

The surface roughness on the surface of all the specimens in the present work was measured by using stylus-contact roughness tester (Mitutoyo SJ-210). The microhardness measurements were performed on the surfaces and cross-sections of the un-SP, SP70 and SP140 specimens using Digital microhardness tester (Wilson Wolpert 401-MVD) as per the ASTM: E-92, with 100gf load and 10s dwelltime. Finally the tensile tests were carried out by using a computer controlled Shimadzu Universal testing machine (Japan Made), the specimen position before and after the test as shown in Fig. 3.

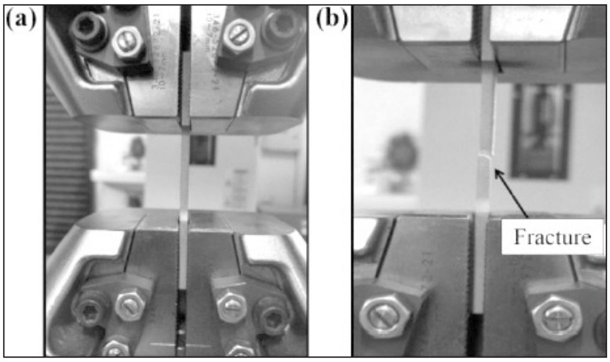

Fig. 3. Specimen in grippers
(a) Before (b) After (Fractured) the test.

3. Results and Discussion

3.1 Microstructural study after SP by XRD

The SP and SPD methods are tend to rearrange the surface characteristics by applying plastic deformation as a part of cold working process. The surface characteristics of peaks by means of FWHM has been given crucial approaches for calculating grain size on material surface which is being treated by SPD processes to observe the microstructural changes. The earlier researchers Pandey et al. [13] have generally using Scherrer-Wilson, Williamson-Hall and Williamson equations by the help of FWHM in order to calculate grain size, micro-strain and dislocation densities of severely deformed materials. Fig. 4 (a) presents the magnified view Al (311) of XRD of FG Al-SiC_p composite with and without SP [12].

As seen from the XRD Peak of un-SP, SP70 and SP140, the FWHM broadening increased by raising the severity of plastic deformation by SP process. This is an indication to the grain refinement [14]. This Al (311) peak clearly discernible that the diffraction angle has shifted towards lower side angle which is an evident for enhancing atomic level lattice strain caused by SP as a surface modification technique [12].

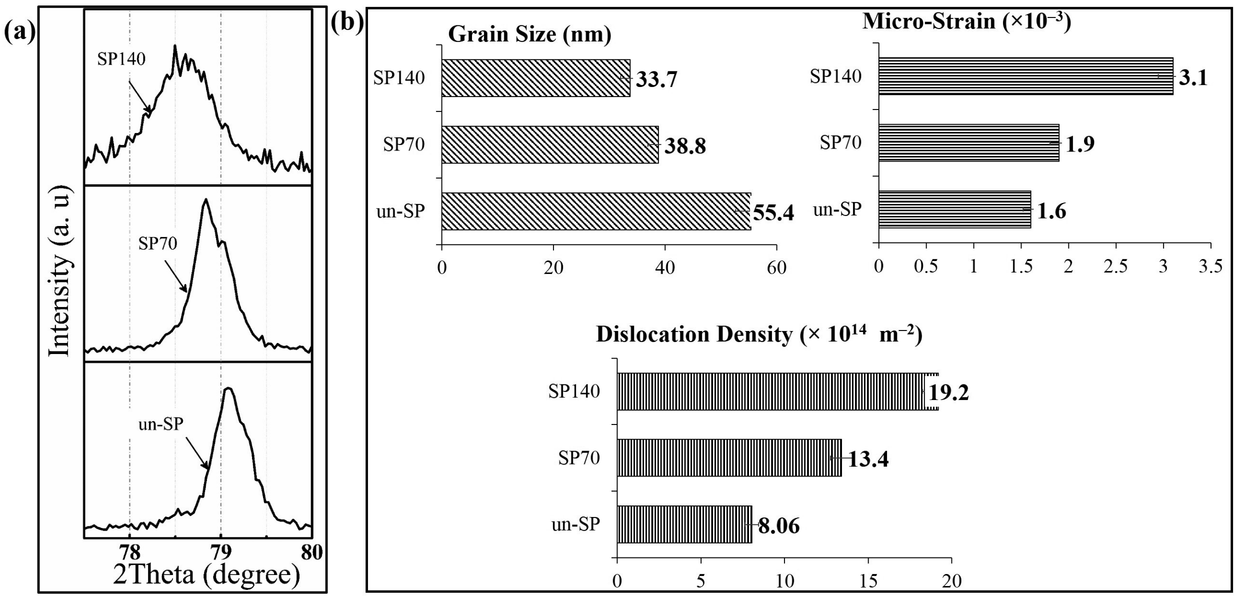

Fig. 4. Surface characteristics by XRD.

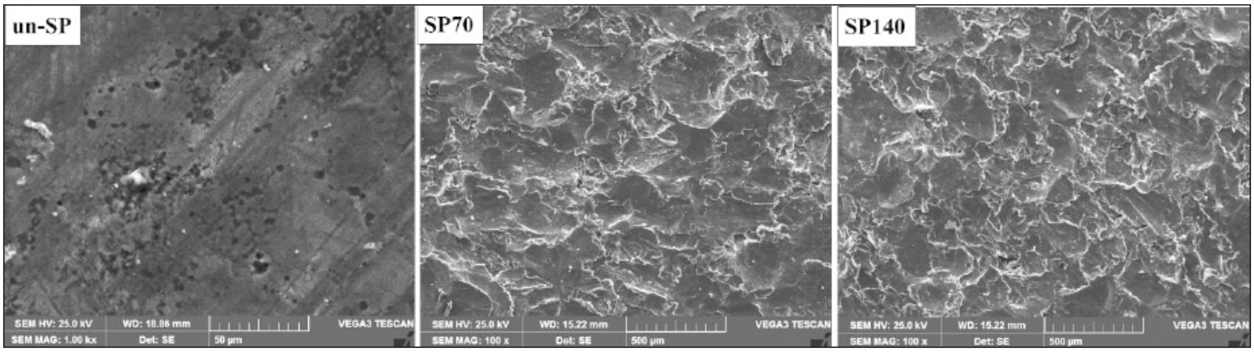

Fig. 5. SEM Observations of un-SP, SP70 and SP140 surfaces.

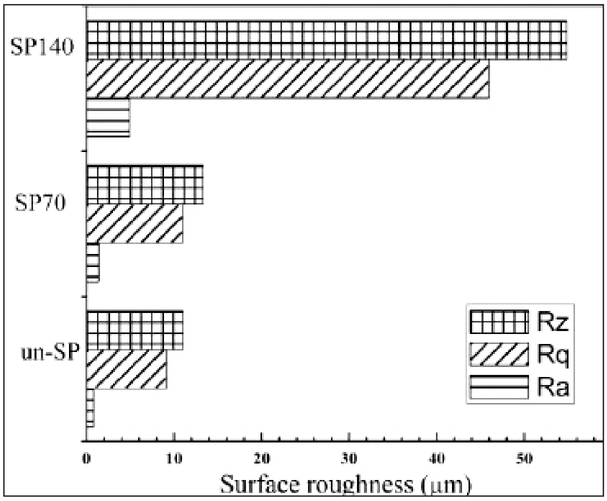

Fig. 6. Surface roughness parameters.

Since peak shifting after peening was attributed to the atomic level lattice strain improvement [13].

Therefore, as increasing the FWHM broadening the average grain size decreased from 55.4nm to 33.7nm with SP duration from 0 to 140 s respectively as noticed form Fig. 4 (b). During SP, when the shots are coming with high velocity and small size generally gives the specimen surface a large vertical force and resulting Hertizan effect can generate shear stress in substrate which will refine grain size [15]. Similarly, the micro-strain have reached to top values after shot peening as shown in Fig. 4 (b). Its value initially 1.6×10^{-3} (un-SP), after SP for 70 s duration it raised to 1.9×10^{-3} and further extension in 140 s reached to 3.1×10^{-3} on the specimen surface. Moreover, the dislocation density generated from continuous impact of shots which is increased with increasing SP duration. Its value on the composite surface reached 13.4×10^{14} m^{-2} in SP70, 19.2×10^{14} m^{-2} in SP140 from 8.1×10^{14} m^{-2} of un-SP.

3.2 SEM analysis

Surface topography of the specimens before and after shot peening are shown in Fig. 5. The SEM photograph of un-SP specimen with 1000 X magnification has smooth surface compared with that of shot peened specimens. The composite surface after 70 and 140 s SP generated with distinct dimples and extruded ridges around the edge of the dimple are observed with 100 X magnification. These changes are attributed to the highest energy exerted by the shot media during shot peening. Moreover, the number of dimples moved and approached very close, results in increasing number of dimples per unit area as extending duration of SP from 70 to 140 s. The similar type of behavior has been noted form investigation related to 316L stainless steel when subjected to SP with different durations done by Azar et al. [16].

3.3 Surface roughness

As the result of distinct dimples and extruded ridges formed on the composite surface led to increase the surface roughness after SP. Developing rough surface is common by SP process and it is considered to be side effect of SP [17]. Here, the roughness parameters Ra, Rq and Rz of un-SP, SP70 and SP140 specimens have been shown in Fig. 6.

The values of roughness parameters were increased as increasing SP duration. In general the surface roughness values decreases as increasing SP duration it is proved in the case of alloys [17, 18]. Whereas in the case of AMC particularly SiC_p/AA6061 composite it is not worked. It may be due to the presence of hard phase SiC in the matrix alloy.

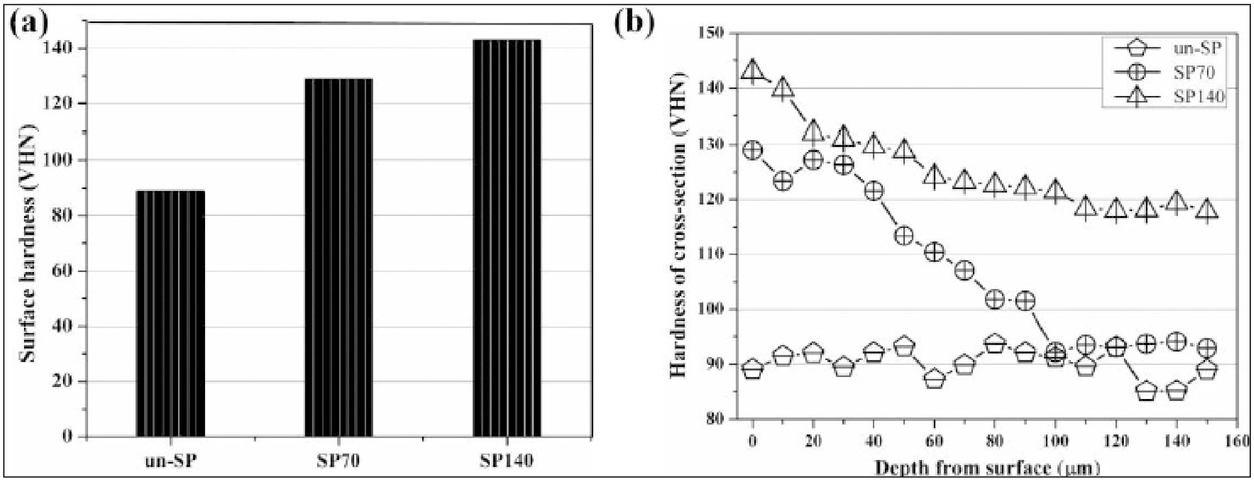

Fig. 7. Microhardness on the (a) Surface (b) Cross-section.

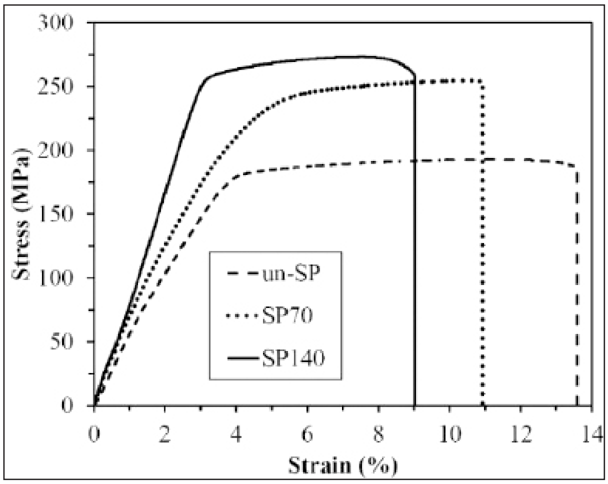

Fig. 8. Stress-Strain curves of specimens with different SP duration.

3.4 Surface hardness

Vickers microhardness measurements indicated that the significant increase in hardness in the surface layer after SP. From Fig. 7 (a) it is understood that the hardness reached 129 VHN (SP70) and 143 VHN (SP140) which are 45% and 61% higher than un-SP specimen. As a result of refined grains, more severe micro-strains and dislocation densities which are maximum at the upper surface after 140 s SP duration contributed to induce maximum hardness over the top surface layer. The increment of hardness is mainly attributed to the fine grains and high value dislocation densities [9].

The trend of hardness profile on cross-section (Fig. 7(b)) helps to assess the thickness of the plastically deformed layer. Here, the SP140 and SP70 forms hard layer up to 40-50 µm with compared to un-SP. This could be attributed to refinement in grain size, high dislocation density and FWHM broadening induced after SP. The effect of SP induced in the surface which is the effective depth identified by the SP70 sample is only 40-50 µm, beyond the 100 µm it is as same as the un-SP. Whereas, SP140 shows a substantial improvement in the hardness even after 50 µm as compared with un-SP and SP70 specimens.

3.5 Tensile properties

Fig. 8 shows the stress-strain curves of FG Al-SiC_p composite by different SP conditions. It is observed that the ultimate tensile strength (UTS) of SP70 and SP140 specimens is reached to 254 MPa and 273 MPa respectively from the value 192MPa of un-SP specimen. The tensile strength has been increased as result of SP duration and which is primarily due to the developed surface characteristics by SP process.

Because of the refinement in grain size after SP many metals have obeyed and yielded an expected results in tensile properties [19]. Moreover the yield strength of the many metals have an intimacy with grain size which is popularly proved with intervention of Hall-Petch relation [20].

Therefore, in this study the improvement in yield strength of the composite after SP process is mainly attributed to the grain refinement, FWHM broadening and high dislocation density induced on the surface after SP. Hence yield strength reached 149MPa (SP70) and 158MPa (SP140) which are 60% and 69% higher than un-SP specimen. In contrast, the percentage of elongation exhibited higher value 13.6% in the case of specimen without SP. Whereas the specimens after 70 and 140 s peening exhibited only 10.9% and 9.02% which are lower when compared that of un-SP specimen. This is due to the loss of softening (ductility) by the development of surface properties such as refined grains, dislocation density and surface hardness after SP.

This SP process which is mostly known to be a strengthening mechanism develops surface hardness and work hardening layer over the treated surface. In general, by increasing reinforcement fraction in the composite also results in lowering this value even they have possessed high tensile and yield strengths along the hardness which is generally discernible. Therefore the percentage of elongation is having inverse relation with hardness seen after tensile test of the composite treated by SP process.

4. Conclusions

From this study the following conclusions can be drawn.

1. The grain refinement, dislocation density, micro-strain and FWHM broadening increases by SP process as compared to untreated composite. Surface roughness increases after SP as result of dimples and extruded edges formed on the composite surface by the impact of shots.
2. The improvement in hardness and its work-hardened layer up to certain depth from the treated surface are attributed to the surface characteristics developed after SP process. And they are enhanced by SP duration which in turn increased the both tensile and yield strengths of the composite.
3. But, hardness development causes to the loss of percentage of elongation after SP as compared to untreated composite.
4. Effect of SP is more pronounced while glancing into grain size and dislocation density. As they are higher after 140 s duration provokes to increase hardness, tensile and yield strengths of the composite even with constant reinforcement fraction.
5. In order to improve various surface characteristics and mechanical properties of metallic components including alloys and composites. SP can be notified as most economical, time saving and flexible with superior benefits as compared to other SPD surface modification techniques.

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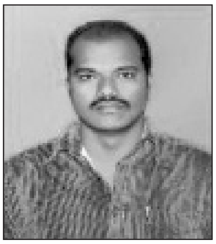

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