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Evaluation of the effect of strontium and tungsten carbide on the microstructure evolution, tribological and mechanical behaviour of Al-Zn-Mg-Cu-5Sr-WC metal matrix composite

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Abstract

The present study focused on the experimental investigation of the metallurgical, tribological, and mechanical behavior of the developed Al-Zn-Mg-Cu-Sr-WC (Al7075-Sr-WC) metal matrix composite. The effect of the reinforcements such as strontium and tungsten carbide (WC) along with a 2 wt% magnesium as the wetting agent during the stir casting of the synthesized aluminum metal matrix composite (MMC) was investigated by varying the weight percentages. The microstructure examination was characterized using field emission scanning electron microscopy (FE-SEM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy dispersive spectroscopy (EDS) techniques. Wear analysis and mechanical testing were conducted to study the effect of WC particles in the matrix phase by examining their wear rate, tensile strength, proof strength, and hardness values. From the mechanical and tribological tests, it was observed that there was an increase of 55% in hardness and 43% in tensile strength, along with a 31% reduction in wear rate. The secondary phases revealed from XRD analysis lead to more hardness along the refined grain boundaries. The tensile strength of the composite initially increased with a 3 wt% of WC and 5 wt% strontium due to hindrance to the dislocation movement but decreased with more reinforcement particles caused by brittleness. The hard WC particles presence has reduced the wear rate significantly due to its resistance towards abrasive wear and lubricating effect. The unique combination of a grain refiner and a binder helped develop a novel composite with superior characteristics that could replace many aerospace components made up of Al7075 alloy.

1. Introduction

Composites are considered in large scale industries as substitutes for the alloys which are applicable in the automobile, aeronautical and marine industries. Enhanced characteristics along with light weight has attracted industrialists to use aluminum matrix composites in the fields of aerospace, marine and automotive. These industries with the increased demand for fuel economy have forced them to make use of these materials with high strength and stiffness for long term applications. Stir casting is used for the preparation of such composites due to its flexibility and cost effectiveness. Metal matrix composites and hybrid composites are widely produced by the stir casting process and significant improvement in the characteristics was noticed [1], [2]. Ramezenali *et al*. [1] studied the effect on the microstructural and mechanical characteristics of the addition of Nickel in Aluminium 2024 melt which formed nickel aluminides as intermetallics. Idrisi *et al.* [3] found the presence of SiC micro particles which were added in aluminum alloy during an ultrasonic-assisted stir casting technique reveals the reasons for better physical and mechanical characteristics which were a result of proper stirring and mixing, thereby reducing the possibility of voids. Prabhu *et al*. [4] used the stir casting process to mix rutile particles in Al6061 melt and studied the effect of the addition of rutile particles on the mechanical behavior of the composite.

The primary processes for the manufacturing of composites are classified as the solid state process, liquid state and liquid-solid processes. Stir casting, squeeze casting, spray casting, powder metallurgy, compo-casting are the methods which come under these categories. Metal hybrid composites are those which contain more than one reinforcement which will make the material better or comparable with composites that are obtained when added with only a single reinforcement. Bijay kumar *et al*. [5] developed a new Al6351 hybrid composite by the stir casting route and compared it for two sets of hybrid reinforcements, such as Al_2O_3 and SiC and also TiC and SiC. Among these, the latter showed better performance due to less segregation of particles. SiC, Al_2O_3, B4C, WC, Gr, CNT and SiO_2 are the reinforcements primarily used for the production of aluminum composites [6-9]. Shalaby *et al*. [10] used SiC and Si_3N_4 particles to develop A359 hybrid composites and examined the compressive strength which was later processed by squeeze casting after fabricating it by stir casting. The squeezing process after stir casting has reduced gas porosity and improved density.

One of the reinforcements used for the Al7075 composite for the study is strontium (Sr) and it is considered to be an effective modifier. The investigations were conducted on the effect of strontium in the matrix phase of the base alloy and the intermetallic phases Al4Sr and SrMgSn were formed due to the addition of strontium which hindered the dislocation motion. The studies were conducted [11-14] on strontium based alloys and observed that a high percentage of strontium (>15 wt%) was used formerly for Al-Sr alloys but the slow dissolution of Al_2Si_2Sr, $SrSi_2$ or AlxSr intermetallics at elevated melting point (~750°C) has decreased the use of these alloys [11-14]. Al-Sr alloys containing lower than 10% strontium is used for modifications recently [15,16]. Here, for the current investigation, 5 wt% of strontium is added. The other reinforcement used is tungsten carbide because of its excellent rigidity, much better than steel, which can be incorporated with aluminum alloy for various automotive and aerospace applications. Tungsten carbide possesses good wear and abrasion resistance, impact resistance, high rigidity, and thermal conductivity. The investigations were done on different other alloys with tungsten carbide as reinforcement has revealed that it improved the hardness and tensile strength of the material with increased weight percent of tungsten carbide. Results were obtained from the study on Al6061 added with SiC and WC and inferred that the reinforcement of WC in the base alloy especially at the periphery has increased the hardness due to the rise in strain energy that constrained the deformation [17-20]. The corrosion rate and wear rate of the composite were also found to be less than the base alloy because of the presence of tungsten carbide. Govindarajan *et al.* [21] explored the possibilities of WC in titanium alloy and has come up with promising results. A decline in microcracks and delamination was also observed by the existence of WC particles [22].

The attributes of the stir casting process like furnace designs, properties, production methods and research possibilities were reviewed and the advancements like squeeze attachment along with electromagnetic and ultrasonic stirrers are recommended for further research quality in the area of development of composites [23-25]. Many researchers found that the desirable properties as per the requirement for industrial applications can be easily tailored to get MMCs from aluminum alloys [26,27]. Ravikumar *et al.* [28] stated that while adding reinforcements, it is very much needed to ensure the property has to be enhanced, since some of the properties will diminish while compensating for the improvement of certain characteristics. Al7075 alloy was modified with different reinforcements such as molybdenum disulfide, hexagonal boron nitride, graphite, boron carbide, coconut shell fly ash, and silicon carbide in order to make hybrid composites with enhanced characteristics. Among these, graphite has emerged as superior to other solid lubricants. Since the addition of graphite tends to increase the bonding between the matrix and particles, whereas SiC enhances ductility and hardness because of the good bonding between the matrix and the reinforcement along with uniform distribution of particles within the base alloy [29-32].

It has been observed from a literature review that the combination of strontium and tungsten carbide hasn't been reported even if those elements have a significant role in refining and binding a metal matrix composite. Therefore, an investigation has been carried out to study the tribological, mechanical and metallurgical characteristics of a novel AMMC developed by reinforcing it with strontium and tungsten carbide.

2. Experimental details

2.1 Materials

Al7075 alloy was used for the investigation, which includes zinc as its primary alloying element. The composition of the alloy used for the study is furnished in Table 1. 5 wt% strontium was added as a reinforcement along with varying weight percentage of tungsten carbide (0, 3, 6, 9, and 12 wt%). In order to increase the wettability of the reinforcements in the aluminum melt, 2 wt% of magnesium was also added. The presence of magnesium will reduce the surface tension of liquid aluminum due to affinity with oxygen [33]. Thus ensuring efficient dispersion of reinforcement particles in the matrix.

2.2 Experimental procedure

With a fixed 5 wt% of strontium obtained from strontium ingot as one of the reinforcements, the Al7075 alloy was reinforced together with tungsten carbide particles of size 12 µm at four different weight percentages, such as 3, 6, 9, and 12 wt%. 1 kg of Al7075 was melted by heating up to 850°C in a steel crucible of a resistance furnace (Model: INDFURR) under protective atmosphere. Stir casting process, which is a highly productive and economical manufacturing method, was adopted for the process. The stirrer was placed in the crucible after the alloy temperature reached the pouring temperature. Then for getting various compositions of the composite, different wt% of tungsten carbide powder, 5 wt% of strontium and 2 wt% magnesium for wettability were added into the crucible and continually agitated for the complete mixing of the elements in the composite. At 700°C, the mixture was agitated at 400 rpm and after a thorough diffusion of the melt and the reinforcements, it was put into a warm rectangular die with a diameter of 100 mm and a length of 300 mm and allowed to cool in the open air.

The porosity of the composites was found after measuring the experimental and theoretical densities of the samples. The Archimedes' principle also known as the water displacement method given in Equation (1) was adopted for finding the experimental density (ρ_{ex}).

$$\rho_{ex} = \frac{\text{Mass of the specimen}}{\text{Volume of the water displaced}} \quad (1)$$

Table 1. Chemical composition of Al7075.

Element	Al	Zn	Mg	Cu	Fe	Cr	Mn	Si
Nominal composition (wt%)	87.52	6.1	2.9	2	0.5	0.28	0.3	0.4
Actual composition (wt%)	88.31	5.59	2.83	2.1	0.4	0.21	0.26	0.3

The rule of mixture was used to determine the theoretical densities of the composite samples and it is given in Equation (2).

$$\rho_{th} = \rho_m V_m + \rho_{r1} V_{r1} + \rho_{r2} V_{r2} \quad (2)$$

The theoretical densities of the matrix (ρ_m) and reinforcements (ρ_{r1}, ρ_{r2}), and also the values of volume fraction of matrix (V_m) and reinforcements (V_{r1}, V_{r2}), were used to calculate the theoretical density of the composite (ρ_{th}). Then the of porosity of the casted composites was found by using the Equation (3).

$$\text{Porosity} = \frac{\rho_{th}-\rho_{ex}}{\rho_{th}} \times 100\% \quad (3)$$

Hardness tests were carried out on the samples using a Vickers hardness tester (model: VM 50) with a maximum load capacity of 50 Kgf. The samples with varying weight percentage of tungsten carbide were tested by applying a load (P) of 30 Kgf and a dwell time of 15 s was given for indentation. The experiments were repeated for three times and the mean value was taken as the hardness value obtained by using the Equation (4).

$$\text{Vickers hardness number, HV} = 1.854 \times \left(\frac{P}{d^2}\right) \quad (4)$$

The diagonal values of the indentation produced by the diamond indenter on the surface of the sample were measured (d) and the hardness values were obtained. Three samples for tensile testing were machined as per ASTM B557M standard dimensions with a diameter of 6 mm and the gauge length of 25 mm. Tensile tests were carried out on the Instron 33R universal testing machine. The strain rate of the composites of various compositions under tensile loading was in the range of 10^{-2} to 10^{-4} s^{-1}.

2.3 Microstructure characterization

Samples were prepared from casted specimens for microstructural examination using standard metallographic methods and Keller's reagent was used with the recommended composition of HNO_3, HCl and HF for 30 s. The etched samples were evaluated using scanning electron microscope (SEM) and the microstructure was examined. ZEISS GeminiSEM was used for the SEM analysis and optical microscopic images were taken from Olympus U-PO3. In order to examine the evolution of any secondary phases, X-ray diffraction (XRD) profiles were captured from Bruker D2 Phaser with a Cu (Kα) X-ray source.

2.4 Wear testing

For the wear test, cylindrical pins having 25 mm length and 10 mm diameter as per the ASTM G99-04a standard were machined from each of the composite of varying weight percentages of WC. The dry sliding wear test was done using DUCOM Pin on disc tester TR-20 model for different loads (25, 50, 75, and 100 N) applied on different pins. The tests were repeated for three times for the same material and load condition. The counter disc material was hardened chromium steel of thickness 8 mm and diameter 160 mm. The contact surfaces were made free from burr and debris by frequently cleaning them with acetone. A stationary pin holder was used to hold the pin vertically against the rotating counter surface. The speed of the disc was set to 191 rpm and the sliding distance was 948 m. The height loss of the pin and the frictional force were monitored in the tests carried out at ambient temperature and dry conditions.

3. Results and discussion

3.1 Microstructural evolution

The microstructural characterization of Al 5 wt% Sr-WC composite by varying its wt% of WC (0, 3, 6, 9, 12) was done using optical microscopy and scanning electron microscopy. The optical microscopic images and FE-SEM images of the synthesized composite are provided in Figure 1 to Figure 3. A fair distribution of the reinforced particles throughout the base matrix has been observed from the micro-structural analysis and it is revealed from the SEM-EDS analysis. In the as-cast structure, which appears to be an eutectic structure which presents AI_4Sr lamellae alignment, as displayed in Figure 1(b), whereas large faceted plates of AI_4Sr will be exhibited for hyper-eutectic alloys. The structure is primarily composed of α-Sr or α-Al and Al_xSr intermetallics in Al–Sr binary alloys in different compositions [34]. It is obtained from studies that strontium has solubility under 54 ppm. Along with the α phase, different intermetallics such as Al_2Sr, Al_7Sr_8, and Al_4Sr are seen in both strontium-rich and aluminum-rich alloys. Up to 20 wt% of strontium is used for industry purposes, so only the Al_4Sr intermetallic is observed in alloys. Here also the presence of Al_4Sr intermetallic is confirmed from optical microscopy and XRD [34]. A fine inter-dendritic pattern of grains is displayed by the aluminum matrix which on casted along with the reinforced particles which were deposited and precipitated at the intersection of grain boundaries. The eutectics like Mg_2Al_2, Zn-Al_2, Mg_2Si, and Cu-Al_2 are precipitated at the grain boundaries. From the optical microscopic images of stir casted Al7075 shown in Figure 1(a). It can be examined that the effect of stirring has caused a spherical or rosette shape for the primary aluminum phase [35]. At the grain boundaries, they get resolved as inter-metallic compounds. It is evident from the optical microscopic images that the presence of more WC particles collapsed the lamellar structure of Al-5Sr in the microstructure and dispersed the WC reinforcement particles to modify the microstructure with finer grains as displayed in the optical micrographs [38]. The elemental composition study revealed the presence of added elements within the base matrix along with the presence of alloying elements of the base alloy.

The reinforcement particles cannot be dissolved to its capacity limit even at an increase of molten metal's temperature and may appear as fine globular entities, whereas the distribution of reinforcement particles is found to be homogeneous in the matrix phase. The reason is that the WC particles have higher melting points and possess more hardness than the base alloy. The strength of the composites is also influenced by the cushioning effect of the undissolved reinforcement particles. The 7075 alloy contains magnesium and copper and also additives such as manganese and chromium and the ever-present iron and silicon. One or more variants of $(Fe,Cr)_3SiAI_{12}$, Mg_2Si, and a pseudobinary eutectic made up of aluminum and $MgZn_2$ form in the casted 7075 alloy. Subsequent heating may lead to a phase which includes aluminum and copper as substitutes for zinc and can be written as $Mg(Zn,Cu,Al)_2$. Then the iron-rich phases will get transformed to Al_7Cu_2Fe on further heating. $Mg(Zn,Cu,Al)_2$ quickly starts to dissolve even if Mg-Si is relatively insoluble and favours spheroidization and some Al_2CuMg precipitates which needs elevated temperatures and lengthy soaking for those to get completely dissolved. In the primary dendritic regions, chromium gets precipitated from super-saturated solution as $Cr_2Mg_3Al_{18}$ dispersoid [36].

The FESEM image of the composite revealed the presence of Al_2Cu intermetallic exactly at spectrums 22 and 23 which has an α-Al matrix in between the regions. Spectrum 24 indicates the α-Al matrix. The large precipitates of Al_2Cu compounds can be seen at the α matrix grain boundaries. Figure 2(a) shows the FESEM image of the composite. Spectrums and the EDS analysis of the spectrums are provided in Figure 2(b-c).

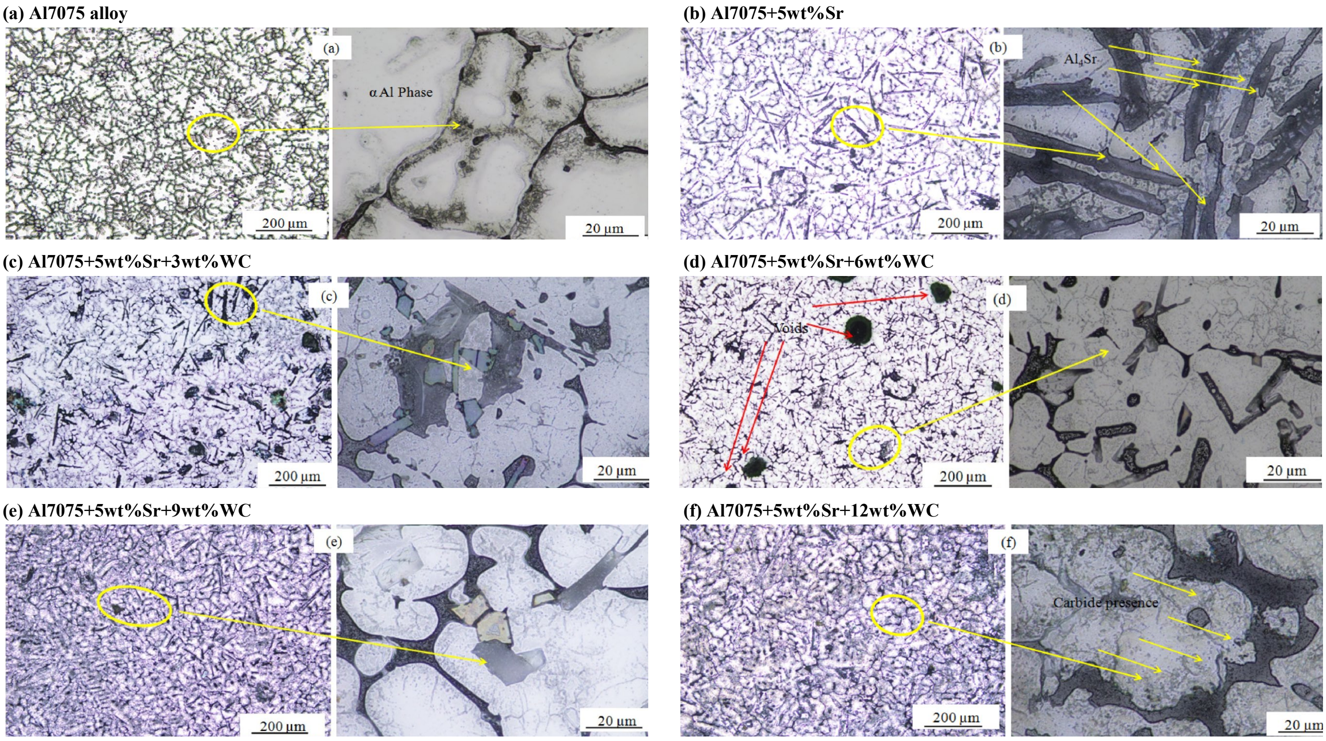

Figure 1. Optical microscopic images of the base alloy and the developed composites (10x and 100x magnifications).

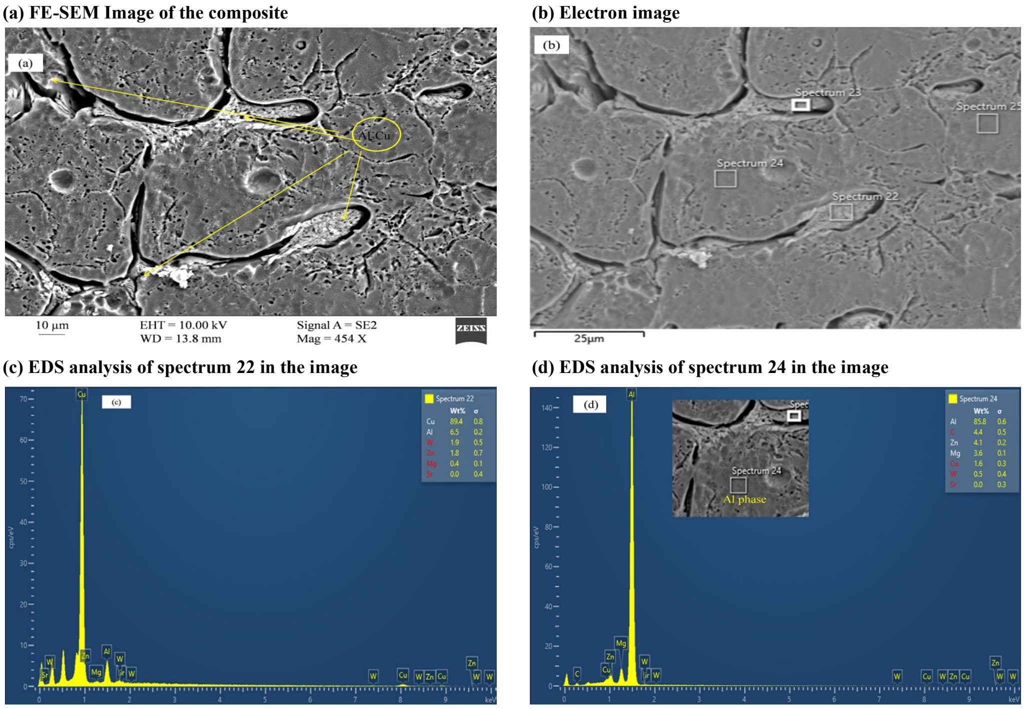

Figure 2. FE-SEM analysis of the developed composite.

The FESEM image given in Figure 3(a) and Figure 4(a) reveals the presence of tungsten carbide and strontium in the matrix, which indicates the proper dispersion of added reinforcements within the base alloy. Figure 3(b), and Figure 4(b) display the spectra taken for the EDS analysis. Figure 5 indicates the proper dispersion of the strontium and tungsten carbide particles.

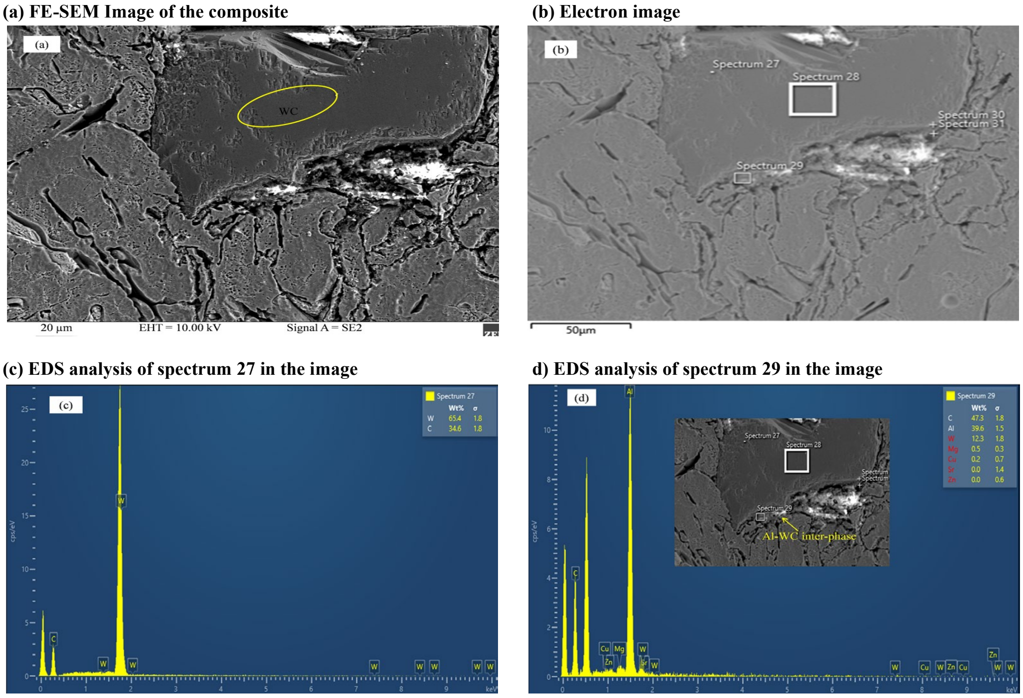

Figure 3. FE-SEM analysis of the developed composite.

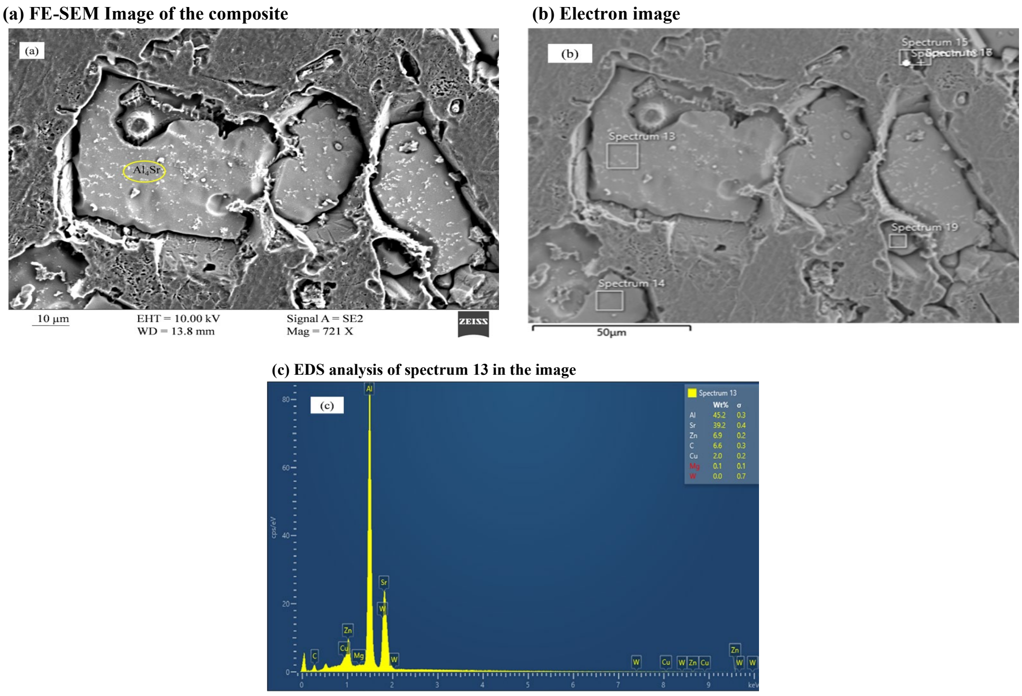

Figure 4. FE-SEM analysis of developed composite.

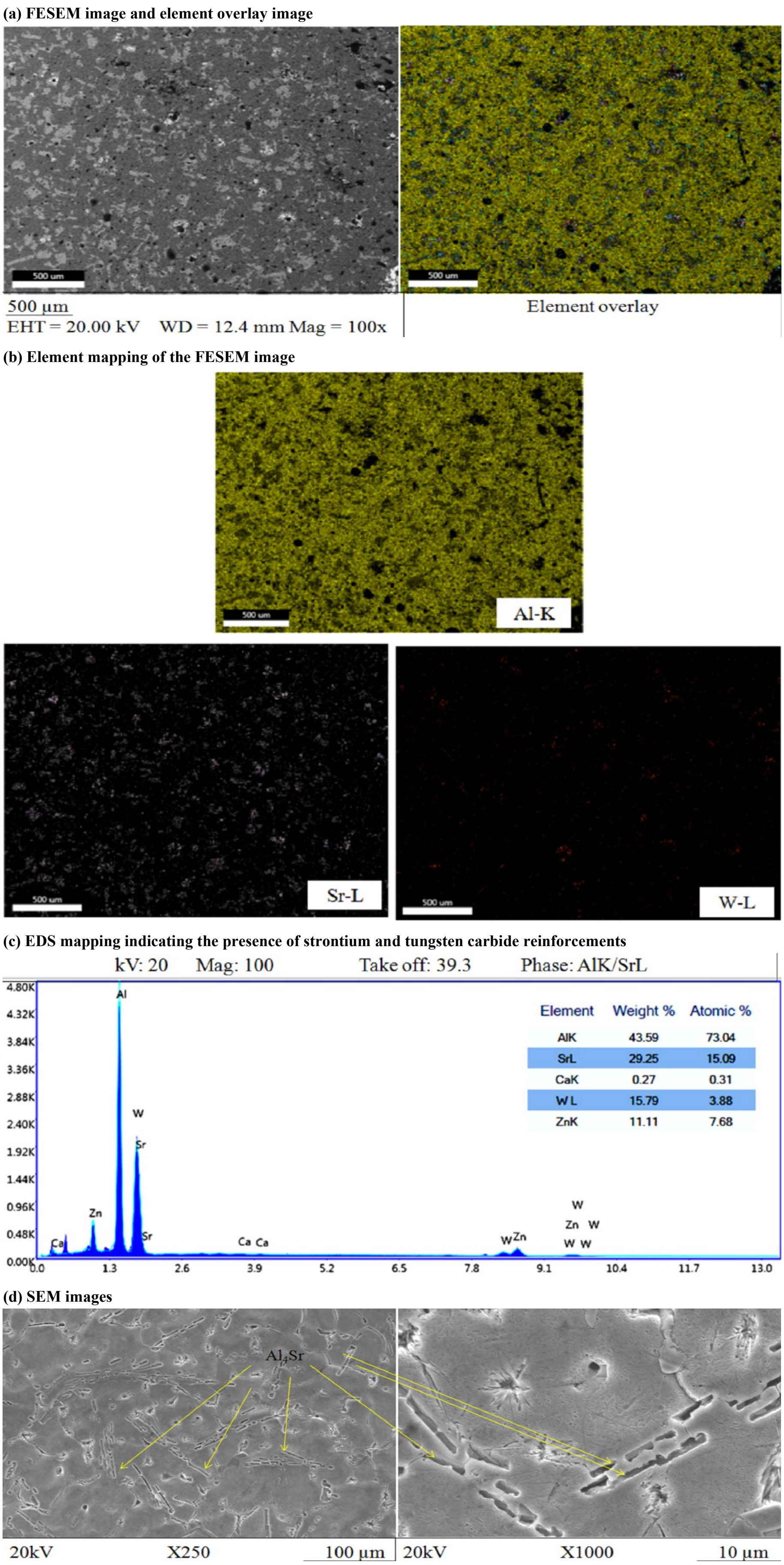

Figure 5. FE-SEM-EDS mapping and SEM images of the developed composite

3.2 XRD analysis

The XRD patterns of the alloy and different composites are presented in Figure 6. The composites displayed strong diffraction peaks in correlation with α-Al and more peaks in tune with the additions made for the production of composites. Multiple peaks were observed for the XRD patterns of composites with strontium and tungsten carbide powder reinforcements other than the base alloy pattern which indicate the presence and solubility of the added particulates in the matrix alloy. The formation of Al_4Sr, the intermetallic which formed during the addition of strontium, is confirmed from the XRD pattern by the existence of smaller peaks displayed in the pattern than the base Al7075 alloy. The longest and intermediate peaks correspond to the base alloy which is common in all the XRD patterns, whereas multiple smaller peaks lead to the formation of $MgZn_2$ when the reinforcements were added, since Al7075 alloy contains more zinc than other aluminum alloys. The XRD patterns of casted Al7075 alloy, Al7075 alloy with 5 wt% strontium, and Al7075 with 5 wt% strontium and 12 wt% tungsten carbide are given in the Figure 6(b-d).

3.3 Density and porosity measurement

Table 2 gives the values of the experimental and theoretical densities along with the percentage of porosity present in the fabricated composite. The presence of voids in the material after casting is due to the addition of high reinforcement content which may agglomerate within the base matrix. This led to the increase in porosity for the composites with more tungsten carbide presence. Even if the particles used for addition were preheated, air may entrap while adding the reinforcement which also brings void in the final casting. The proper agitation and processing methods adopted during the process of stir casting has ensured the proper mixing of added reinforcements which kept the porosity values of all the composites less than 3%.

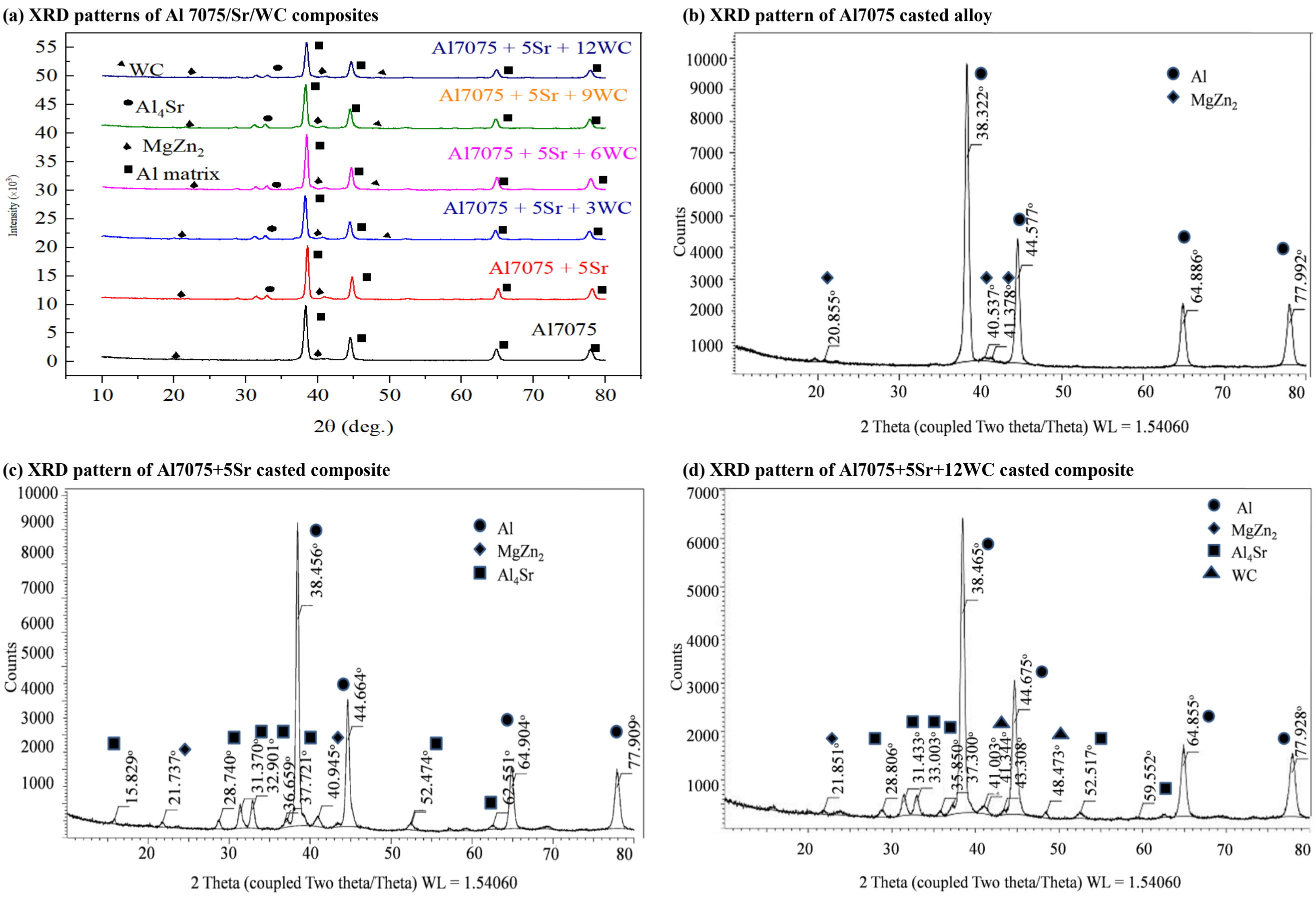

Figure 6. XRD patterns of Al 7075/Sr/WC composites.

Table 2. Porosity measurement.

Composite	Theoretical density ($g\cdot cm^{-3}$)	Experimental density ($g\cdot cm^{-3}$)	Porosity (%)
Al+5Sr	2.76	2.71	1.81
Al+5Sr+3WC	2.83	2.79	1.41
Al+5Sr+6WC	2.9	2.82	2.76
Al+5Sr+9WC	2.98	2.92	2.01
Al+5Sr+12WC	3.1	3.01	2.9

3.4 Hardness and tensile characteristics

The hardness values of the developed composites for different wt% of WC along with 5 wt% of strontium is demonstrated in Figure 7. It is evident from the graph that the hardness value increases with the WC content but decreases drastically after 9 wt% addition. The addition of the WC brings a stronger and stiffer reinforcement into the matrix, hence enhancing the hardness. The presence of grain refining agent strontium along with the WC particles caused the dislocation punching phenomena at the matrix-reinforcement interface [37]. A significant 55% increase in hardness was observed in the developed composite when 9 wt% of WC along with 5 wt% of Sr was added. The presence of hard WC particles improved the hardness of the composites because of its ability to obstruct the dislocation movement and reduces plastic deformation. The uniform distribution of WC particles up to 9 wt% has also enriched the base matrix with better hardness. And thereafter, a 29% decrease in hardness was examined when the WC content was 12 wt%. More WC reinforcements cause agglomeration and mask the presence of strontium, which leads to the decrease of hardness of the composite at 12 wt%. From the optical microscopic images it was found that the rod like structure as that of the Al4Sr gradually became disrupted when WC particles were added and thereby causes differences in crystal structure and composition. When the wt% of WC became 12 wt%, more particles aggregated at the grain boundaries which surrounded the strontium particles. The chemical reactions may have occurred between the reinforcements and aluminum matrix which caused the formation of new phases and interfaces. The increased hardness is also an effect of precipitate formation which causes obstruction to dislocation motion [33].

From the tensile tests, it was found that as the wt% of WC was increased along with the fixed 5 wt% strontium, from 0% to 12%, the tensile strength value improved up to 3 wt% and then decreased for the remaining samples. Improper bonding between the aluminum matrix and the added reinforcements led to a decrease in the tensile strength of the specimen with more than 3 wt% of WC and 43% increase, has been observed from 0 wt% to 3 wt% of WC. The proof strength of the 3 wt% WC specimen also showed a steady increase in its value than other samples and then decreased. From the graphs, it was found that at 0.2% of plastic deformation of the 3 wt% WC composite exhibits better endurance against the tensile load and observed a 22% improvement from 0 wt% to 3 wt% WC. Tensile strength, 0.2% proof strength, and % elongation of the developed composites are presented in the Figure 8 to Figure 10. The existence of hard tungsten carbide particles within the matrix phase has contributed to the enhancement in the resistance to tensile stresses. Improvement in tensile strength is also due to the decrease in the interspatial distance between particulates, which leads to dislocation pile-up as the particulate content is increased. Therefore, a restriction in the plastic flow was there due to the random distribution of the particulates in the matrix. Table 3 shows the values obtained from tensile testing of the prepared composites.

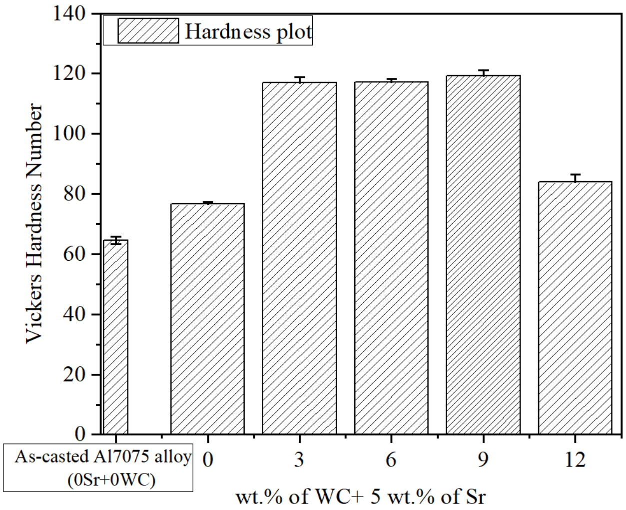

Figure 7. Hardness of the composites.

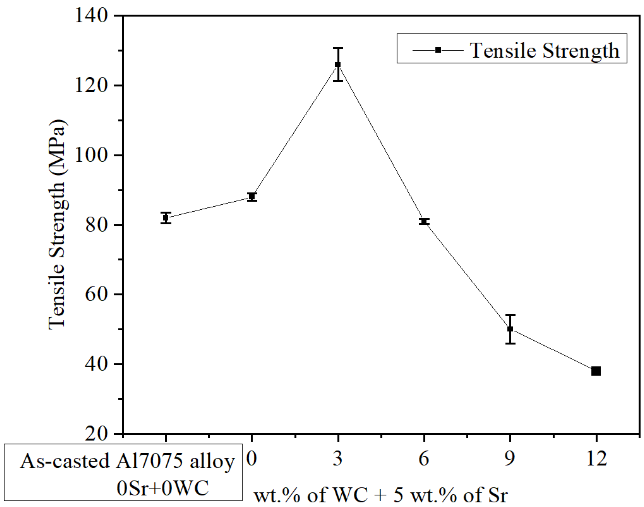

Figure 8. Tensile strength of the composites.

Table 3. Tensile characteristics of the composites.

Composites	Tensile strength	0.2% Proof strength	% Elongation
Al+0Sr+0WC	82	76	29
Al+5Sr	88	82	33
Al+5Sr+3WC	126	100	15
Al+5Sr+6WC	81	65.5	10
Al+5Sr+9WC	50	43	7
Al+5Sr+12WC	38	32	6

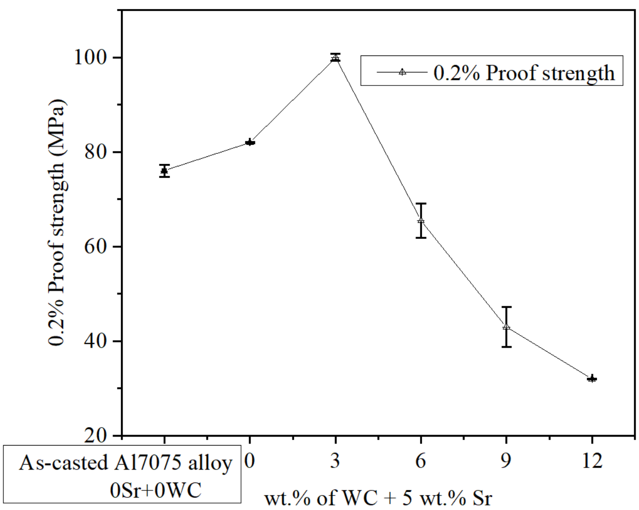

Figure 9. 0.2% proof strength of the composites.

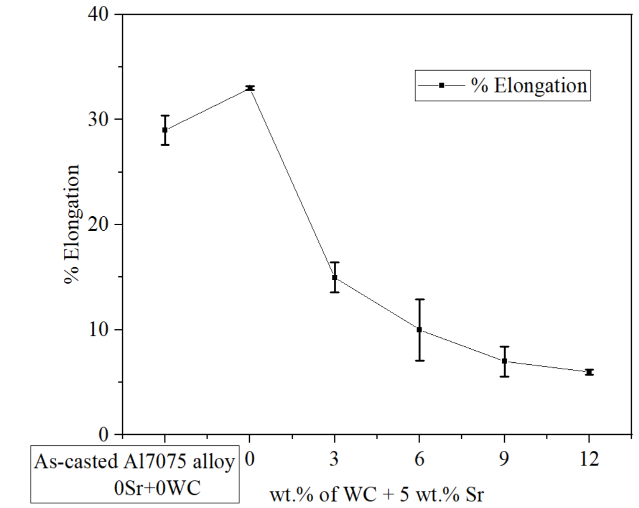

Figure 10. % Elongation of the composites.

One of the reasons for the enhancement in tensile strength for AL7075 5 wt% to 3 wt% WC composite is that the interfacial bonding among hard WC particles and soft Al matrix [38,39]. Ductility of the composites keep on decreasing with the inclusion of WC particles which attributes to the fact that % elongation decreases with increase in ultimate tensile strength and also the yield strength [28]. The stress fields created around the added particles restricted the dislocation motion and also the crack growth propagation, which enhanced the tensile strength [37]. It is observed that the composite with strontium addition alone shows more % elongation than other composite samples, it is due to the fact that the addition of strontium along with magnesium which was added for wettability have promoted the fine grain growth during the solidification, thereby increased the ductility and the strength of the material.

3.5 Wear analysis

For high wear resistance based applications, tungsten carbide based metal matrix composites have been the materials of choice. If the combination along with strontium, which act as grain modifier will develop a composite of superior characteristics. In order to analyze the tribological characteristics, dry sliding tests were conducted on a pin-on-disc tribometer under various loads. The wear rate, frictional force, and coefficient of friction were obtained for different samples under examination. Archard's Equation (5) was used for finding the wear coefficient, 'k'.

$$k = \frac{3H}{P} \times \frac{V}{L} \quad (5)$$

where 'H' is the hardness of the specimen, 'P' is the applied load, 'V' is volume loss by wear and 'L' is the sliding distance. This equation indicates that there will be a decrease in wear volume because of increase in hardness, whereas it will increase with increase in load and sliding distance. Figure 13 shows the wear coefficient of composites developed with different weight percentages of WC. The wear rate increases with applied load. The pressure concentration during the wear testing on the reinforcement was found to be less at low load and at intermediate loads fragmentation was observed and the particles tended to shatter outside of the zone. More plastic deformation along with thermal softening was examined for higher load and shows more wear rate than other load conditions. The addition of strontium as a modifier could decrease the stress concentration of the particles at the subsurface region which restricted the cracking of the particles, thereby increasing the wear resistance [40].

The volume loss due to wear can be easily found from the amount of height loss of the pin provided by the tribometer, since there is no change in the cross sectional area. The wear rate was found to be decreased with the addition of WC particles. Figure 11 and Figure 12 demonstrate the wear rate and specific wear rate of the developed composites and base alloy and it is examined that the increase in wear resistance is due to the formation of secondary phases within the composite which leads to more hardness than the base alloy. And at the same time, more WC content leads to a decrease in the wear resistance due to agglomeration of particles near the grain boundaries. A least wear rate of 19.60×10^{-3} $mm^3 \cdot m^{-1}$ was recorded for 3 wt% of WC addition along with 5 wt% of strontium as reinforcements to the Al7075 base matrix when the applied load was 25 N. That means a 31% decrease in wear rate for the new composite. Similarly, an 11%, 25% and 16% reduction in wear rate was examined for 50 N, 75 N and 100 N applied loads respectively.

Wear resistance of Al7075-Sr-WC composites with respect to WC content is shown in Figure 14. The amount of reinforcement added has a significant contribution to the wear resistance. More reinforcement particles will get exposed to the counterpart than those with lesser percentage content. This will lead to higher wear resistance. The contact area of the added particles is large for high volume fraction of the reinforcement in the matrix and this decreases the exposed area of the lighter matrix phase, thereby decreasing the frictional force which also leads to low coefficient of friction (COF). Figure 15 shows the variation of COF with different wt% of WC. The wear in microns for the composites obtained at different loads from the experiments is presented in Figure 16 and Figure 17. Figure 18 and Figure 19 provide the amount of frictional force generated during the wear test.

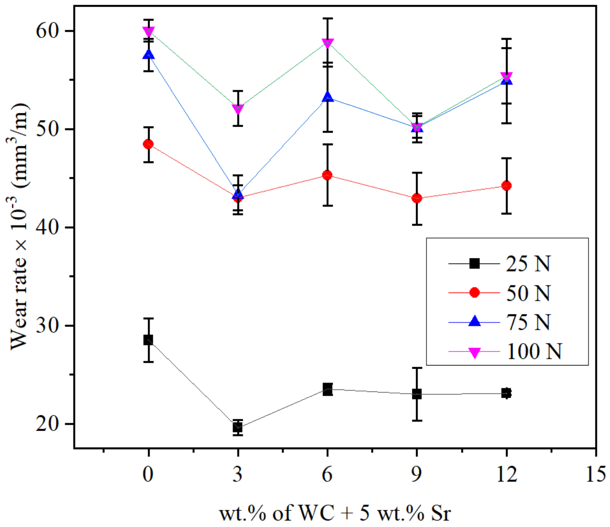

Figure 11. Wear rate of Al7075-Sr-WC composites as a function of WC.

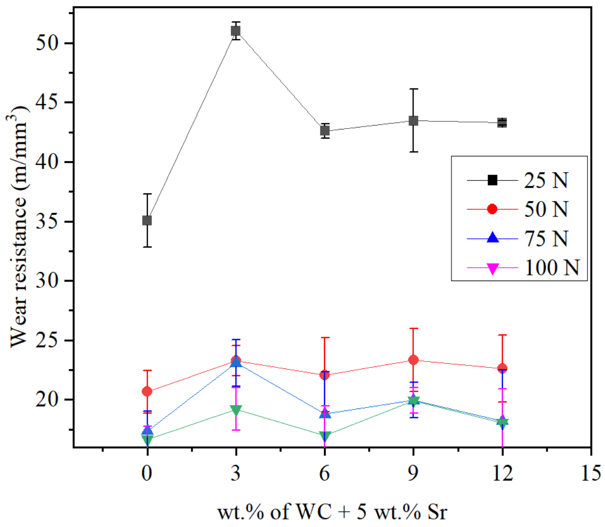

Figure 14. Wear resistance of Al7075-Sr-WC composites as a function of WC.

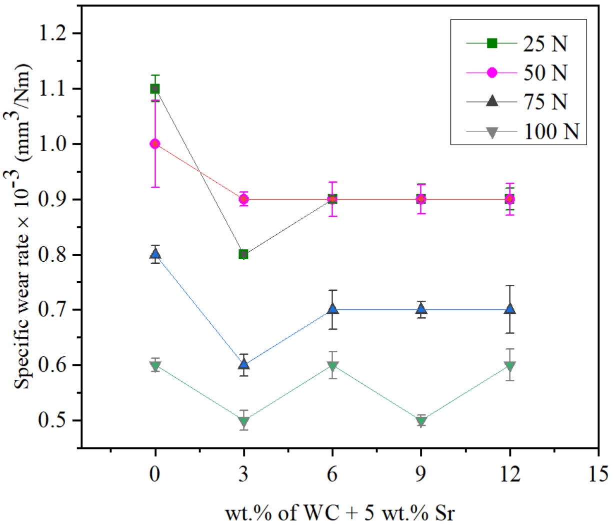

Figure 12. Specific wear rate of Al7075-Sr-WC composites as a function of WC.

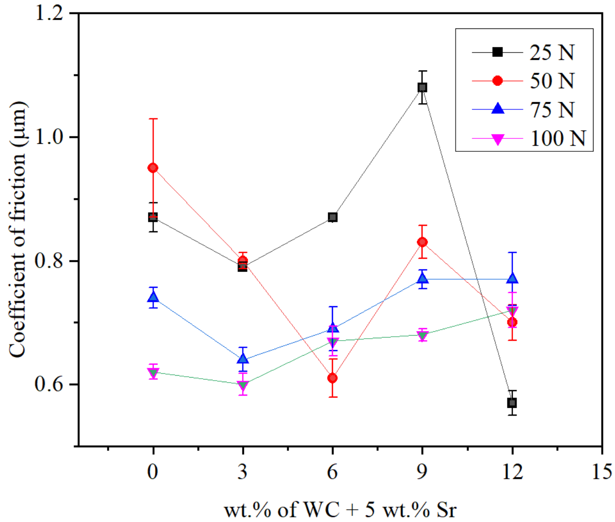

Figure 15. Coefficient of friction of Al7075-Sr-WC composites as a function of WC.

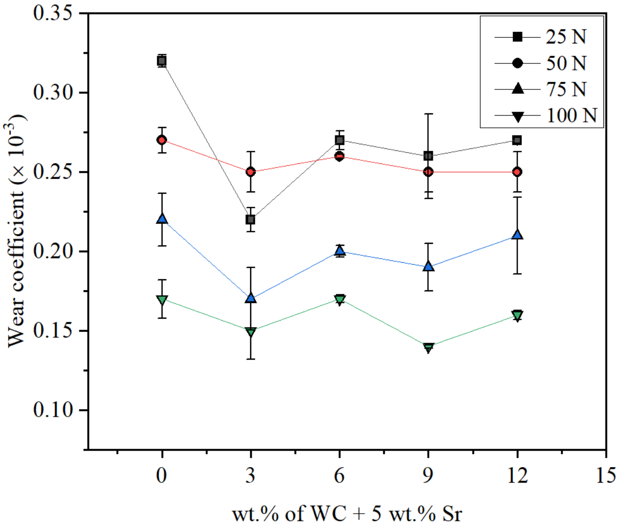

Figure 13. Wear coefficient of Al7075-Sr-WC composites as a function of WC.

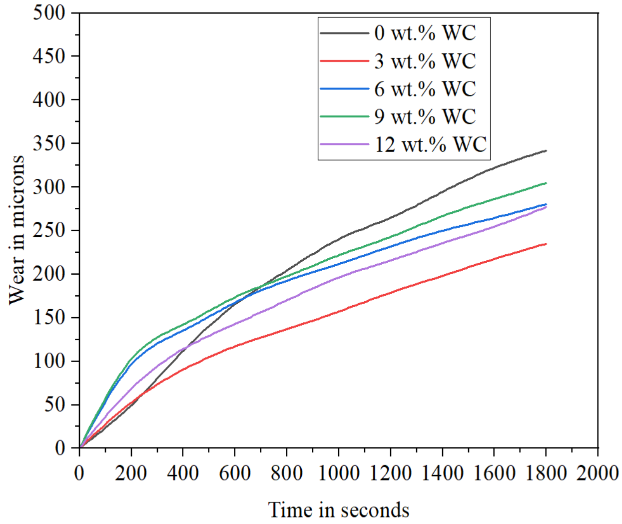

Figure 16. Wear of the composites (Al7075+5Sr+3WC-Plot3, Al7075+ 5Sr+ 6WC-Plot1, Al7075+5Sr+9WC-Plot2, Al7075+5Sr+12WC-Plot0) as a function of time for the normal load of 25N.

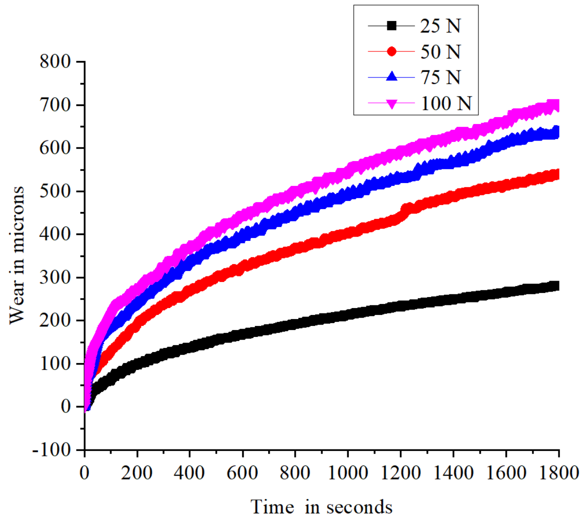

Figure 17. Wear of Al7075+3Sr+6WC as a function of time for the normal loads of 25 N-Plot0, 50 N-Plot1, 75 N-Plot2, 100N-Plot3.

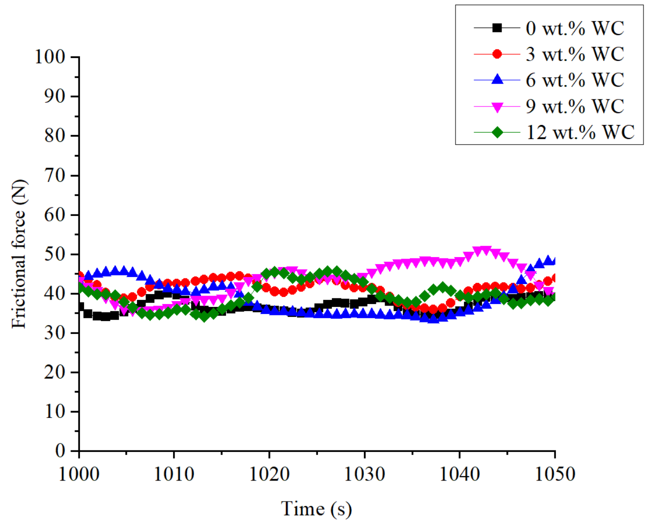

Figure 18. Frictional force generated of the composites (Al7075+5Sr+3WC, Al7075+5Sr+6WC, Al7075+5Sr+9WC, Al7075+5Sr+12WC) as a function of time for the normal load of 100N.

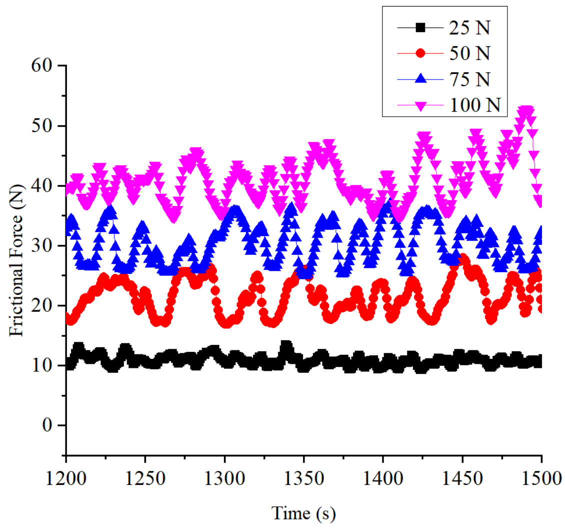

Figure 19. Frictional force generated of Al7075+3Sr+3WC as a function of time for the normal loads of 25 N, 50 N, 75 N, 100N.

4. Conclusions

- A novel composite was able to synthesize with Al 7075 as the matrix with strontium and tungsten carbide as reinforcement particles which could replace many aerospace components made up of Al7075 alloy such as wings and fuselages and also military and automobile parts as well due to the fact that the new composite shows superior wear resistance, strength, and hardness than the pure Al7075 alloy.
- The optical microscopic images of the microstructure of the developed composite which has strontium as the only reinforcement reveals the presence of Al_4Sr intermetallics. The XRD results also confirmed the presence of the intermetallics along with the diffraction peaks of α-Al, $MgZn_2$, and Al_2Cu.
- The existence of tungsten carbide along with strontium was examined from the FESEM EDS analysis and XRD results of the composites with varying wt% up to 12%. The EDS results confirmed a fairly uniform distribution of the reinforcements within the parent alloy phase.
- A 43% improvement in tensile strength is obtained for the 3 wt% WC composite compared to other composites along with 5 wt% of strontium and then its value has decreased. The enhancement of the strength is due to dispersion strengthening of the material by the addition of tungsten carbide particles, thereby restricts the dislocation movements. Similarly, the presence of strontium refined the grains thereby hindered the dislocation movement as well. The structural integrity of the material has also increased because of the improvement in hardness and wear resistance and it benefited the material's tensile strength. From the porosity measurement, it was found that more tungsten carbide particles increased the porosity of the composite which adversely affected the tensile strength. At certain regions of the composite, agglomeration of tungsten carbide particles were seen which reduced the tensile strength. So, the composite with 3 wt% of tungsten carbide and 5 wt% strontium was showed better performance during tensile test.
- The hardness of the composites were increased by 55% when 9 wt% of WC along with a fixed 5 wt% of strontium were incorporated within the base alloy. More reinforcement particles tend to decrease the properties, especially for the composite with 12 wt% of WC due to the agglomeration of particles at certain locations of the grain structure. The improvement in the hardness was increased because the WC particles constrained the plastic deformation due to the rise in strain energy. The enhancement is due to the consequence of better bonding of reinforcement particles within the matrix at the interface.
- The wear rate was reduced for the composite with 3 wt% of WC and a 31% decline in the value was obtained and then showed an increase and wear loss of 12 wt% WC, somewhat more, perhaps due to de-bonding of WC particles at the interface and the presence of agglomerated particles. Moreover, there will be a rise in wear of the material due to more friction at the surfaces in contact with larger loads.
- Among all the composites taken for the study, Al7075 with 5 wt% strontium and 3 wt% tungsten carbide has shown better characteristic values. And also this composite exhibits the least wear rate among all the other composites and the values are well above

the values of as-casted Al7075 alloy. Further investigations on the effect of secondary processing methods on the developed material might enhance the composite by refining its grain structure and removal of defects caused by the conventional methods.

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