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COMPARATIVE STUDY ON MICRO AND NANO SIZED SiC PARTICULATES REINFORCED Al7075 COMPOSITES USING STIR CASTING PROCESS

This paper is designed to investigate the wear and mechanical characterization of metal matrix composites (MMCs) by using micro and nano SiC on Al to study the influence of micro/nano SiC on the properties of fabiricated composite. Micro and nano-composites with 1-4% of SiCp were developed using stircasting processes. From the outcomes, an improved grain refinement of micro and nano-composites when compared to monolithic was seen from the microstructural study. It found that an increase in SiC particulates content caused enhanced mechanical properties. Though, nano SiC reinforced MMCs resulted in improved mechanical properties compared to micro sized SiC particulates reinforced MMCs. The wear study was evaluated for comparison of micro/nano MMCs. The investigation indicates that, wear resistance of nano composites is better as compared to micro-SiCp reinforced MMCs. Fractured surfaces were inspected by the SEM analysis to study the nature of fracture in the micro and nano composite samples.

Keywords: Al-7075; SiC; Micro; Nano; Stir casting

1. Introduction

In the last few years, Al has been extensively used in various engineering applications like piston, fins and disc brakes due to low weight, better fatigue strength, good thermal conductivity and workability. Al metal matrix composites substitute pure Al matrix, where better creep and high wear resistance are essential under high temperature. Other investigators [1-3] studied the influence of ceramic particulates like SiC, TiC, TiB_2, Al_2O_3, B_4C and ZrB_2 into Al to enhance the wear and mechanical characteristics. Selection of reinforcements, particulate size and wt.% is very much necessary to achieve better combination of properties. The MMCs is an accepted technique applied to enhance the strength in alloys. In the race for fabrication of MMCs, Al composites have drawn specific attention from automobile and marine industries as potentially innovative structural materials in the last thirty years due to the higher strength, better wear resistance and the low cost production techniques [4,5]. The properties of Al composites significantly depend on the manufacturing technique; thus, the process of manufacturing method assumes an important contract to approve to the mechanical necessities and to give beneficial properties. The interference of delivering Al composites is because of high expense of support materials and heterogeneous fortification dispersal within the framework. The perception strategy for assembling MMCs is vital for the ever-increasing trend of applications. Presently, there is significant research ideas/interest on MMCs using micro and nano reinforcements. In several industrial applications, aluminium alloy is the most desirable material because of its low cost, better strength and other useful characteristics. Out of various processing technique [6,7], the stircasting technique can develop composites with a uniform dispersal of reinforcement and also complex shapes can be produced. This technique offers better bonding between matrix-particle and is very much easier to control the matrix structure. Stircasting technique is generally used to reinforce micro particulates in melt without any agglomeration or clustering of particulates [8]. Al MMCs reinforced with hard ceramic nano-particulates, especially SiC, have attracted much attention because of their extensive use in space, automobile and marine applications [9]. Dwivedi et al. [10] evaluated the effect of SiC particle and different stirring methods i.e., mechanical and electromagnetic methods. The results showed that the hardness, toughness and fatigue life enhanced with increasing content of SiC particulates and they also concluded that significant improvement in mechanical characteristics and homogeneity can be achieved by using electro-magnetic stirring technique.

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Sinan Kandemir [11] studied the effect of SiC nanoparticles reinforced with A357 alloy on the microstructural and mechanical characteristics. Mechanical strength of the nano-composites were remarkably improved compared to as-cast (A357 alloy), presenting the strengthening property of nano particulates and better bonding was achieved at the particulates interface. Pradeep et al. [12] concluded that, the Al matrix reinforced by nano-particles enhanced tensile, compressive and hardness of the MMCs. Amar Mahato & Subrata Mondal [7] concluded that the MMCs reinforced with nano particulates tended to exhibit better mechanical and wear behavior when compared to composites reinforced with micro sized particulates. From the literature survey, it is seen that many investigators have studied the influence of nano and micro sized particles on the wear characteristics and mechanical properties of Al MMCs at varying sizes and wt.% of hard particulates. The optimum results that show the best mechanical /wear behavior of the MMCs might be different when compared to each other due to the various parameters such as particulates size, wt.% of particulates and the MMCs were not manufactured at the similar fabrication conditions (melting / pouring temperature, etc.). Hence, it was very challenging to relate the Al composites reinforced with micro and nano particulates. To address this issue, the present study has been performed to investigate how the micro and nano size reinforcing particles influence the microstructural, mechanical, and wear behavior of Al based MMCs of varying weight. Stir casting produces a high percentage of micro- to nanosized SiC particles.

2. Materials and fabrication

In this study, Al7075 alloy has been used as a matrix. SiC particles i.e., nano and micro-sized reinforcement were utilized for the fabrication of composite and nanocomposite. Al composites were produced by reinforcing SiC particles (1, 2, 3 and 4 wt.%) of nano-size (30-50 nm) and micro-size (220 mesh size). Stir-casting was used to fabricate the MMCs. A 750°C electric furnace was utilized to melt the base material. As the Al molten melt was being added to the pre-heated reinforcements, they were pre-heated in a small oven. Continuous stirring action of 100 rpm, for 2 minutes, was applied to the composite melt as reinforcement was added, and the melt was poured into a pre-heated die. In general, the wetting in MMCs among the micro / nano reinforcements and the base metal matrix mostly relies such as Chemical reactions and Wettability of ceramic particulates. No reaction between the Al-7075 alloy and liquid phases is generally recommended; minimum or no reaction/inter diffusion in the interfacial region, no degradation of reinforcing micro / nano particles is usually desirable in almost all metal matrix composites or nanocomposites. Similarly, wettability of the ceramic particulates that appear on the reinforcement surface usually reduce the wetting of reinforcing micro / nano particles by molten metals as the reinforcement engulfment by melt metals would be difficult, especially when the reinforcing phasis added from the top of the melt. Therefore it is recommended that any hindering of ceramics be removed first if their existence might weaken the contact in solid-liquid interfacial regions. In the final stage of the process, the solidified samples were extracted from the die. CNC machining process was used to prepare the composite samples (Fig. 1).

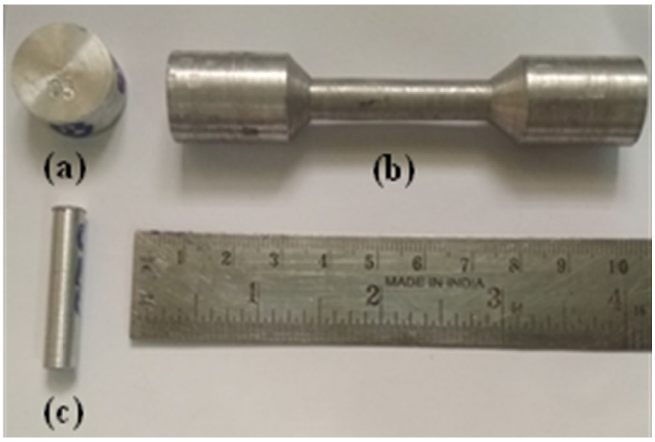


Fig. 1. Test samples Images of (a) Hardness, (b) Tensile and (c) Wear

3. Results and discussions

3.1. Microstructural analysis

The distribution of hard particulates in the matrix was observed through Nikon optical microscope. A visual comparison of the Al7075, composite and nanocomposite is shown in Fig. 2.

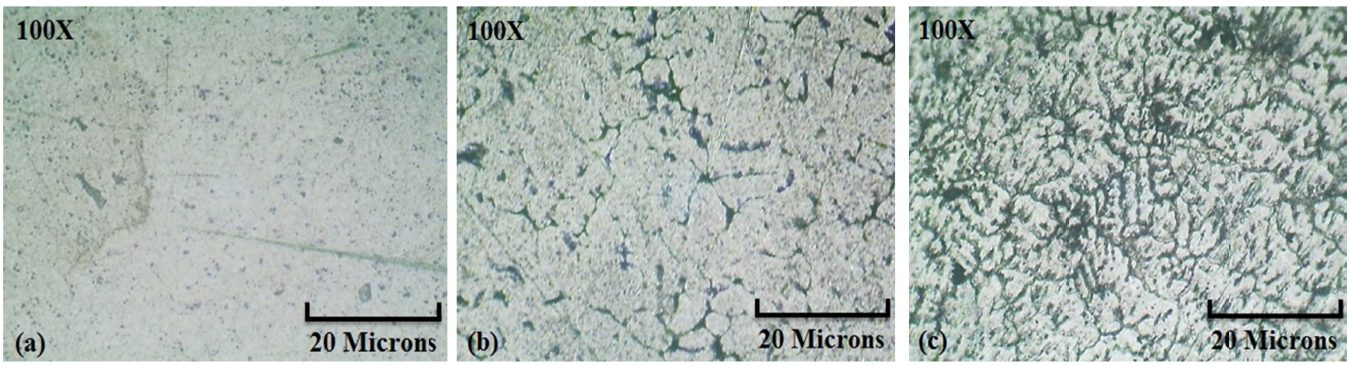


Fig. 2. Micrographic photographs of: (a) Monolithic alloy, (b) Micro and (c) Nano composite

The Fig. 2(a) (monolithic alloy / base alloy) shows the clear grain boundaries without presence of any reinforced particulates.

The micrograph of base material is free from casting defects. In micro-composite (Fig. 2(b)), particulate SiC is observed as part of the microstructure (SiCp = 4%). The matrix phase indicates proper dispersion of the reinforcement phase. Here, the particulates are free from clustering and agglomeration due to the stircasting technique [6]. In Fig. 2(c) showing a 4% nano-sized SiC reinforced nano-composite (shown in light colour) indicates the presence of aluminum and the dark locations indicate the agglomeration of particles. For enhanced wear and mechanical behavior of composites, it is essential to disperse silica nanoparticles in an aluminium matrix [1]. Compared to grain structures surrounding a SiCp-free matrix alloy, the microstructure images reveal finer grain size around SiCp. Thus, SiC particles may increase the nucleation between particulate and matrix materials, resulting in the recrystallization of aluminium alloys. When flaky bits of SiC (micro or nano) are mixed with the composite material, the grains are generally deferred from crystallizing. Compared to micro SiC reinforced MMCs, nano SiCp reinforced MMCs exhibit improved grain refinement [7].

3.2. Hardness

Hardness of composite and a nanocomposite were evaluated according to E92 standards. The hardness test sample was indented continuously for 20 seconds with an indenter of diamond shape under a continuous load of 1,000 grams. A total of 3 regions were tested for hardness. The average values of the hardness were recorded. Hardness of the composite and nanocomposites is depicted in the Fig. 3. The outcomes show that the hardness of composite and nano composites exhibit higher values compared to the Al alloy due to the presence of hard SiC particulates which form the ionic bond in the hard particulates. Hard particulates hold the soft material generally which creates MMCs strong in its nature. Enhancement in composite / nanocomposite hardness is generally due to the particulates strengthening within the Al matrix. Increase in SiC concentration in the Al matrix intensely hinders the plastic flow due to the effect of high hardness. As a result of the high compact structure development and the improved interfacial bonding strength between the particulates, nano-particulates reinforced MMCs display a higher hardness than those reinforced with microparticles. In addition, nano-sized SiC can produce highly Orowan-strengthened films due to its smaller particulate size as well as more uniform spacing between its particles [13-17].

3.3. Ultimate Tensile Strength

The tensile test was performed based on ASTM-E8 standards. Test trials were carried out under the load capacity of 450 KN. As shown in Fig. 4, the tensile strength (UTS) of composites and nanocomposites was determined. When compared to base alloy, the micro and nanocomposites were found to possess enhanced tensile strength. The result showed that the tensile strength was improved by increasing in SiCp content. Improvement in the tensile strength is generally due to resistance to the dislocations [18]. As a result of the stronger bond between the particulates and the matrix, the highest tensile strength values were recorded for nanocomposites when compared to micro-composites. In the early days of composites research, scientists suggested many methods for strengthening the materials, including grain refinement, load sharing, and nano-particle strengthening. Among all of these different mechanisms, the effect of load-sharing and fine grain refinement resulting from the Hall-Petch theory concept seemed to be the main cause for improvement in UTS. When solidified at room temperature, a change in coefficient of thermal expansion (CTE) of base material and nano-particles causes UTS of nano sized particles reinforced MMCs to increase. Based on this, the composites treated with SiC reinforced nanoparticles may have improved in tensile strength.

Stress-strain graph of the composite and nano composite are shown in Fig. 5(a & b). In these curves, the major characteristics are the decreases in fracture strain that result from the increase of particles content and the increase in ultimate tensile strength.

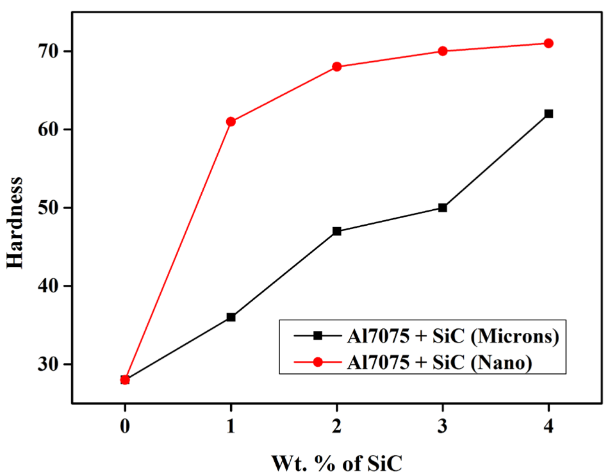


Fig. 3. Hardness of micro Vs nano composite samples

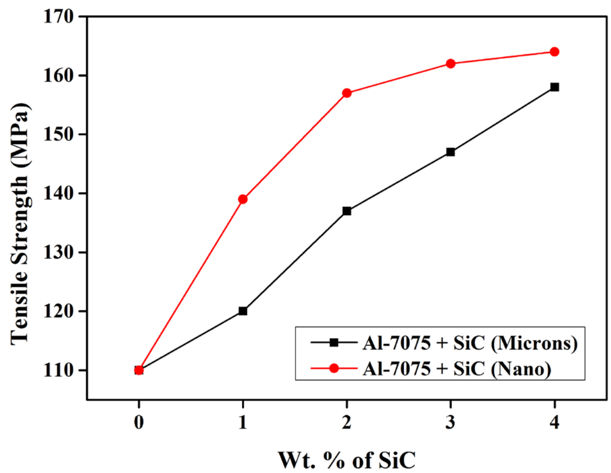
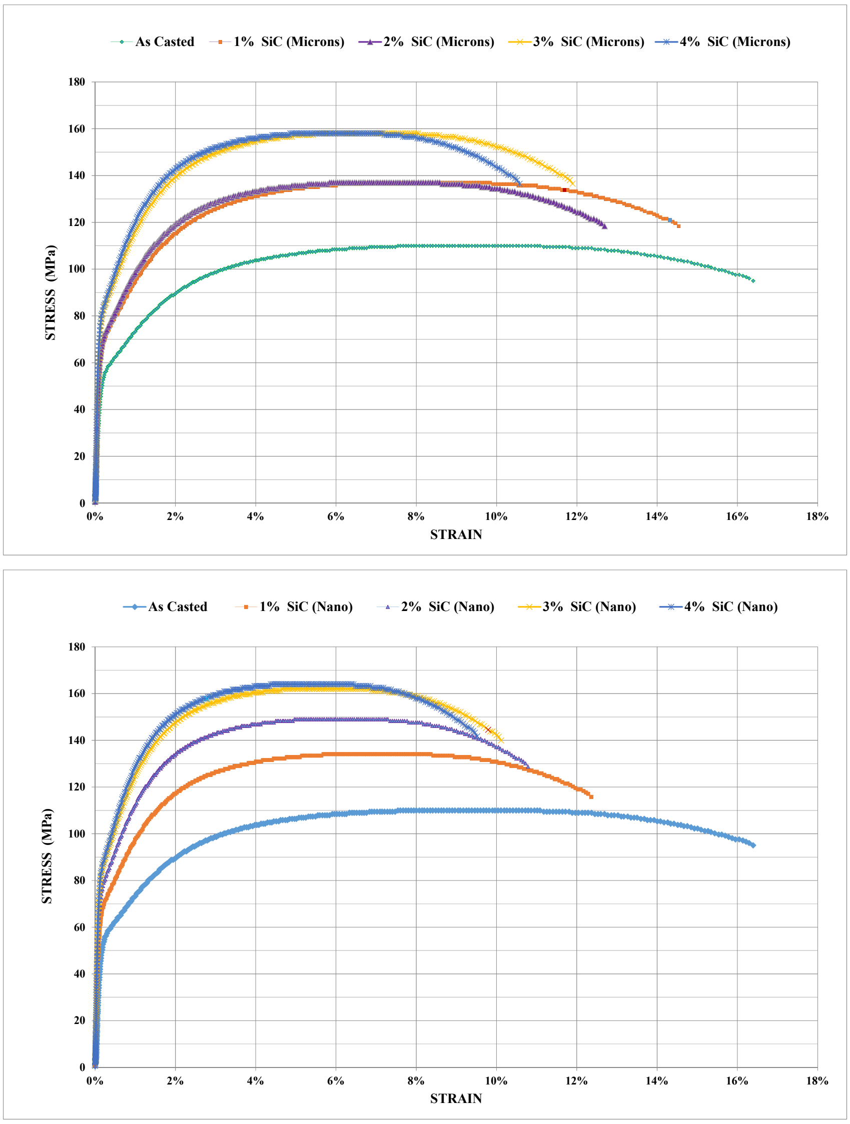


Fig. 4. Tensile strength of micro Vs nano composite samples



(a)

(b)

Fig. 5. Stress strain curve for (a) micro (b) nano-composite samples

When compared with micro and nanocomposites, monolithic alloys (base materials) exhibit the highest plastic strain and the lowest resistance to deformation due to their lower flow stresses. Comparing the micro and nano composites with their monolithic alloy counterparts, both provide superior tensile strength. There are many reasons for this, including fine particle refinement and particle strengthening. A mismatch strengthening produces a pretentious increase in tensile strength while the nano sized SiC particles produce a high load bearing capacity. CTE of the matrix and reinforcements vary, which is predicted to account for this. Nanoparticles reinforced MMCs are enhanced by the dislocations trapped by hard SiC nanoparticles [19].

As shown in Fig. 6, we have analyzed the fractured surfaces of composites and nano composites by Scanning Electron Microscopy (SEM). Tensile fractured surfaces confirm the high ductility of the MMCs and also indicate more dimples. In this case, there is a higher amount of clustering particulate with the fine grain boundaries because there are more dimples with large sizes joined together at the boundaries. MMCs developed using SiC particles exhibit significantly improved tensile fractured surfaces. It can be seen from the fractured surfaces that when the size of the particles is decreased, there are more cavities and also fewer grains. Cracks and cavities generally form at the interface between matrix and particulates when the distance between particulates decreases thereby lowering the distance between particulates. The interface bonding of developed MMCs deprive their ductility, so the present research attributed this to the lack of ductility [19-21].

3.4. Wear rate

The wear resistance of the MMCs specimens was tested by using pin-&-disc testing equipment. Wear results of composite and nanocomposites specimens tested at constant parameter of 3 kg load and 1.66 m/sec sliding speed is shown in Fig. 7. Experimental result shows that high wear resistance was observed in nano particulates reinforced composites than micro particulates reinforced composites. Nano SiC particulate plays a noticeable role for the enhancement of wear property of nano-composites.

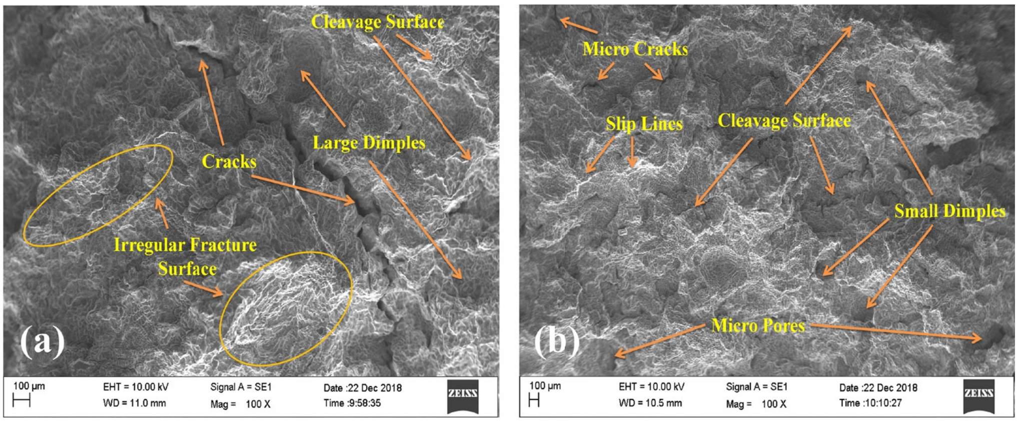


Fig. 6. Post tensile test fractured images of (a) micro composite and (b) nano composite

As-cast shows the high wear loss due to their identical nature of the molecules generally which leads to increase in the plastic flow of material [13-15,22,23]. From the outcomes, it is noticed that the wear rate has enhanced up to a specific content wt.% of reinforcements and later remains uninfluenced because of various factors like wettability and agglomeration of nano particulates [1,24].

To study the wear mechanisms of the developed composites, the worn-out surfaces of the micro and nanocomposite samples were studied by SEM images. SEM photographs of worn-out surfaces of the composites and nanocomposite samples of 4% SiCp are shown in Fig. 8(a & b). Micropits, narrow grooves, and high flow of materials were observed on the worn-out surface, indicating ploughing and delamination as the mechanisms of wear. In addition to protecting sliding surfaces, these ceramic particles improve wear resistance. There are some dust particles that have broken into pieces, and there are a few that are pulled from the worn out surface. On worn-out surfaces, hard particulates can be seen as the cause of rough wear. On the wornout surfaces of micro and nano composites, a significant number of large and deep grooves are visible. Wearing of Nano-composites produces deep grooves on their worn surface that are visible in dark layers by SEM analysis. Comparing nanocomposite and micro-composite, it is evident that nanocomposite exhibits higher wear resistance.

Fig. 9 shows nano particle reinforced MMCs studied with EDS. It has been found that the interface layer contains Al, Zn, Mg, Si, and Fe. In the developed MMCs, silica particles (SiCp) can be seen as a Si peak in the EDS study.

The analysis shows the existence of iron (Fe). The presence of Fe content on the surface suggests the transfer of iron content from the hard steel disc to surface of the test samples. Mechanically mixing layer of materials (MML) has formed among the sliding surfaces, as shown by these results. In general, MML acts like a thin solid layer of lubricant on steel disc and test sample surfaces such that wear loss is reduced [1,25-28].

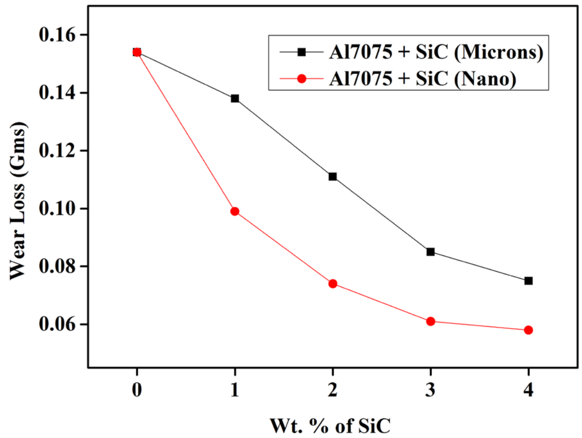


Fig. 7. Wear loss of micro Vs nano composite

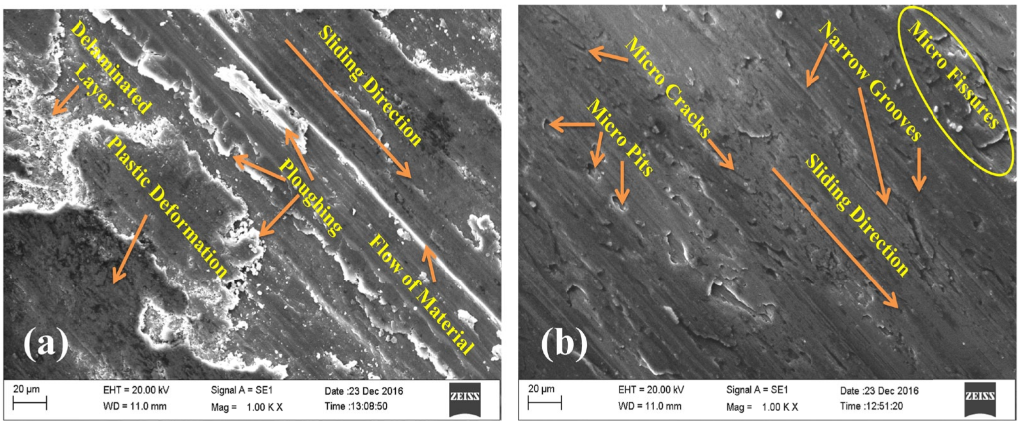


Fig. 8. SEM fractography of worn-out surface of (a) micro and (b) nano composite

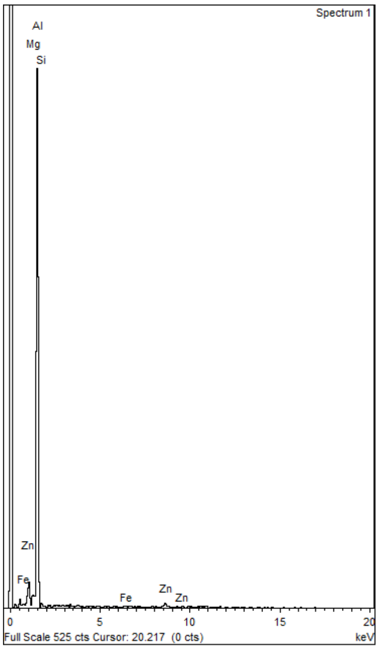


Fig. 9. EDS spectrum of nano composite sample

4. Conclusions

The significant conclusions arrived from the present study outcomes are as follows.

The present research work involves the fabrication of micro and nano crystalline Al7075 reinforced with SiC by stircasting. The influence / effect of micro & nano sized SiC particles on wear and mechanical ehaviour were studied. By comparing the microstructural images of the developed micro and nano-composite materials to those of the base material, the micro- and nano-composite materials demonstrated superior grain refinement. By incorporating hard reinforcements (SiC) into the matrix material, the mechanical ehaviour of the material such as micro hardness was improved. It was found that nano-composites showed higher strength compared to micro composites. In comparison with the base material, the developed micro and nano composite presented improved wear resistance and reduced wear loss. As a result of agglomeration and wettability of nano particles, the percentage of SiC content remained unaffected. In the developed composites, Al, Mg, Zn, Si, and Fe were identified. In general, the silicon peak in the EDS study indicates that there are SiC particles present in the developed MMCs.

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