

CHARACTERIZATION AND PROPERTIES OF ALUMINIUM- SILICA SAND NANOPARTICLE COMPOSITES

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ABSTRACT

Aluminium base alloys have mostly been used as structural components and aerospace application due to light weight and environmental resistance. However aluminium pure powder product's applications were limited despite many potential merits. The present study aims to develop an aluminium matrix composite with nanoparticle silica sand. The nanoparticle silica sand with average particle size of less than 100nm was produced by several stages of ball mill and heating combinations. Aluminium matrix composites with 2, 4, 6 and 8 wt.% of nanoparticles silica sand were developed through powder metallurgy technique. It was observed that addition of 8 wt.% nanoparticles silica sand was able to increase the hardness and tensile strength of the composites up to 50 HRB and 323.77 MPa, respectively. Despite of decreasing in its density the composite showed improvement in mechanical properties.

Keywords: Aluminium silica; sand; mechanical properties;

INTRODUCTION

The extensive utilization of aluminium reinforced with silicon carbide in different structural applications has motivated the need to find a cost effective technological production method for these composites. Homogeneity, machinability and interfacial reaction of the constituents represent the significant problems pertaining to these composites. Production of a homogenous, high strength and net-shape structural component made from aluminium-silicon carbide can be achieved using powder metallurgy (PM) technology [1].

M. Rahimian et al. [2] investigated the effect of reinforcement of Al_2O_3 on the properties of Al composites. Alumina particles were mixed with Aluminium in the range of 0-20%. The average particle sizes for the matrix and reinforcement were $30\mu\text{m}$ and $12\mu\text{m}$, respectively. The samples were prepared at two levels of sintering temperature for a constant sintering time of 45 min. it was illustrated that at high weight fraction of reinforcement, the relative density decreases while hardness and wear resistance increases. Results showed that by increasing the amount of alumina from 0% to 10%, the hardness increased from 33 to 62 BHN, while the compressive strength was raised from 133MPa to 273MPa. L. Geng et al. [3, 4] had used ZrO_2 as reinforcement

with an average diameter of 30nm with pure aluminium of average diameter of 40 μ m as matrix. The volume fraction of ZrO₂ was 5 and 10 wt. % respectively. The ZrO₂ were firstly mixed with ethanol and then separated by ultrasonic for 30 min, then they were mixed with pure aluminium particles for 24 h in a mixer. The ethanol in the mixer was evaporated by a hot water bath, and then mixed powders were put into a die for hot pressing. The microstructure of the composites in hot extrusion state was studied that showed that the size and shape of reinforcement in composites greatly differ from that of original ZrO₂ particle, indicating that a new phase had been formed during the fabrication.

Acchar, et al. [5, 6] prepared a Li₂O-ZrO₂-SiO₂-Al₂O₃ (LZSA) glass powder mixed with 30 wt. % of ZrO₂ or Al₂O₃ (submicron size), uniaxially pressed under 40 MPa and sintered at 650 °C/30 min. in some samples a second sintering step at 1000 °C during 30 minutes was also performed in order to improve the mechanical properties by increasing the crystallized fraction. The sintered samples were characterised by bending strength measurement, X-ray diffraction and scanning electron microscopy analyses. Apparent densities values were determined by the Archimedes's method. The results obtained in the work indicated that the addition of ZrO₂ and Al₂O₃ (reinforcing particles) decreases the density of glass-ceramic materials. X-ray diffraction analysis indicated an increase of the crystallized fraction in samples sintered at 1000 °C. Fracture strength values have showed to be dependent on the sintering temperature and also on the reinforcing crystalline particles.

H. Zuhailawati et al. [7] reported that the preparation of aluminium-silica particulate composites and showed that the silica sand aluminium composites had better results than that of pure Al-SiO₂ composites. In the present work the silica sand nanoparticles were produced by series of ball milling and heating combinations. This study will investigate the characterization and property of the aluminium matrix composites with nanoparticles silica sand.

EXPERIMENTAL DETAILS

Materials and Processing

The silica sand originated from Tronoh, Perak, Malaysia was grounded to nanoparticle size by using low speed ball mill with zirconium ball as grinding media and the production of silica sand nanoparticles (with average size less than 100nm) was confirmed by using the ZetaSizer, Nano ZS (ZEN 3600) (Malvern)) nanoparticle analyser. Photon correlation spectroscopy (PCS) or dynamic light scattering (DLS), is a technique used to determine particle size by examining the diffusion rates (i.e. Brownian motion) of suspended particles. The technique utilizes a light source to illuminate the samples and scattered light is collected at a detector typically positioned at a fixed scattering angle. The latest generation of PCS/DLS instruments, such as the Zetasizer Nano, utilize a backscatter angle of 173 degrees. This optical configuration accommodates both high and low sample concentration, low sample volumes, and reduces the probability of intensity biasing, a phenomenon that occurs in 90 degree

systems where the magnitude of light scattered by a large particle overshadows the light collected from the smaller particles. These results are then verified microscopically through FESEM. The chemical composition of silica sand was analyzed by using XRF technique.

The commercial aluminium powder of 99 % purity with 30 μ m particle size was used. The Aluminium matrix composite reinforced with Silica Sand Nanoparticles (ASSN) was prepared in stages by using the ball mill and furnace. The amount of silica sand nanopartilces used in this study were 2, 4, 6 and 8 wt. %. The silica sand nanoparticles were firstly heated up to 400°C and furnace cooled prior mixed with aluminium powder by using ball mill for 1 hour. The autopalletiser (capacity of 80KN) at 27MPa force by using a metallic mould of diameter of 13mm was used to make the compacted pellets. The green compacts were then sintered at 600°C for 90 minute in an argon atmosphere. Both green and sintered densities of relevant samples were measured by using Mettler Toledo AX205 density measurement instrument following the Archimedes's method. All samples were mounted, polished, and finally analysed by using FESEM and EDX analysis. The Rockwell (Scale B) hardness tester was used to measure the hardness (by using 100 kg-force and steel ball of 1/16 inches diameter).

RESULTS AND DISCUSSION

Analysis of Silica Sand Nanoparticles

The Tronoh's silica sand was grounded in ball mill for 6 hour and then analysed for nanopartilces size. The result was graphically produced by "size distribution by intensity" generated from Zetasizer Nano Analyser as shown in Figure 1. The average silica sand particle size produced was 78.82nm.

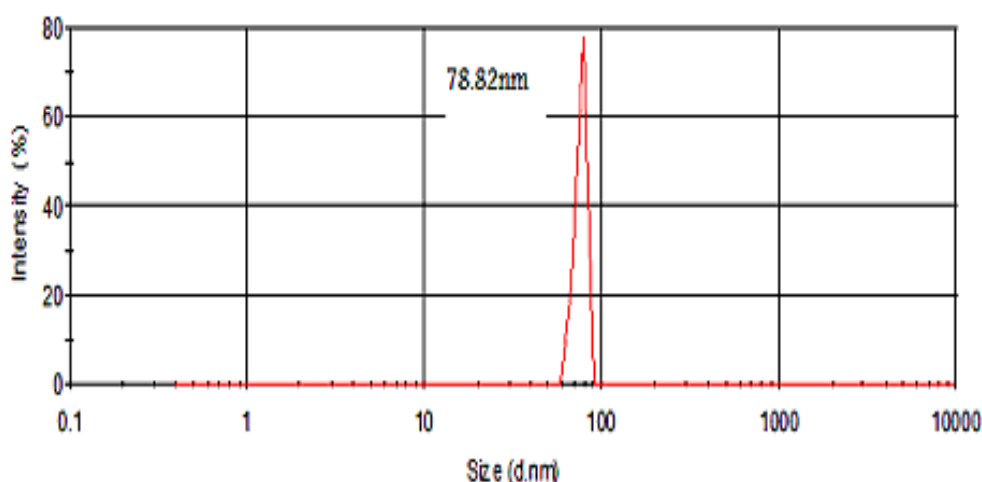


Figure 1: Particle size distribution by intensity produced by Zetasizer Nano Analyser. The average size is 78.82 nm

Size and distribution of the Tronoh's silica sand nanoparticles are shown in Figure 2. Agglomerations of the nanoparticles were clearly observed. Several attempts were taken in order to reduce this structure which then promoted to further investigations. EDX analysis on the silica sand, shown in Figure 3, reveals the presence of high SiO_2 content with little amount of Al_2O_3 .

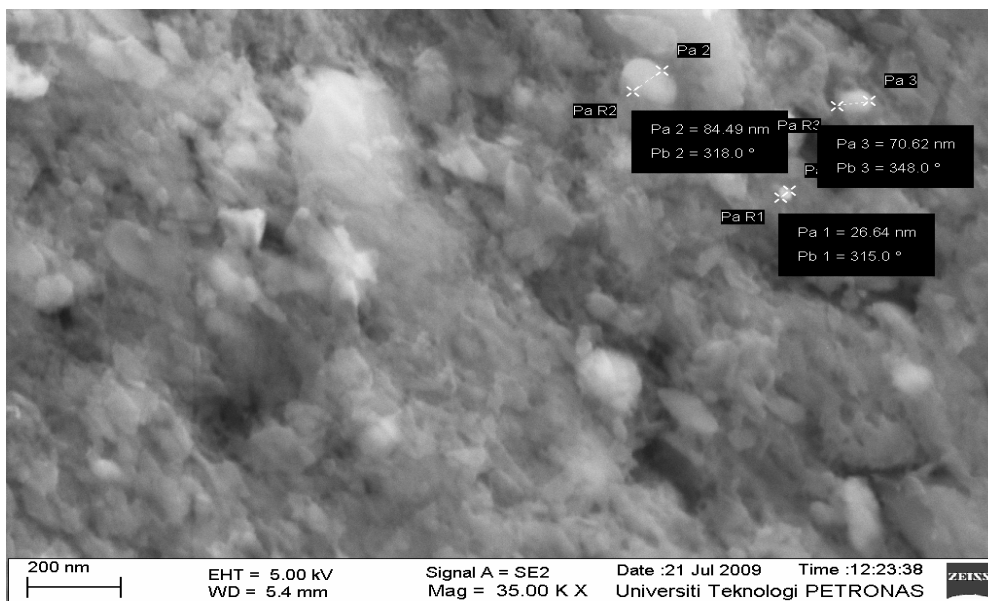


Figure 2: FESEM image of the silica sand nanoparticles (35000X)

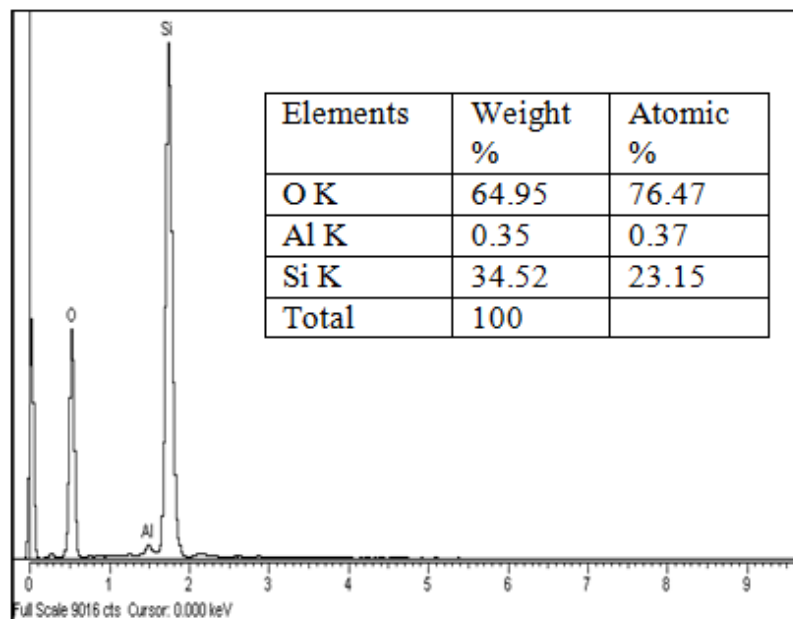


Figure 3: EDX analysis of the nanoparticles silica sand

Chemical composition of silica sand nanoparticles

The chemical composition of silica sand was analyzed by using XRF analysis by following the STG2-S4-Check measurement method.

Table 1: chemical composition of silica sand

Al ₂ O ₃ (%)	SiO ₂ (%)	P ₂ O ₅ (%)	K ₂ O (%)	CaO (%)	TiO ₂ (%)	Fe ₂ O ₃ (%)
2.99	95.22	0.77	0.095	0.139	0.16	0.121

Characterization of the Aluminium Silica Sand Nanoparticles Composites

Aluminium based composite with 2 wt. % Silica Sand Nanoparticles

Figure 4 shows the ASSN with 2 wt. % of silica sand nanoparticles. Island of silica nanoparticles, resulted from its powder agglomeration, and residues of porosity can be seen clearly. The 2 wt.% silica sand nanoparticles occupy and fills the porous places of the ASSN. Little amount of silica was detected in this ASSN as shown in Figure 5.

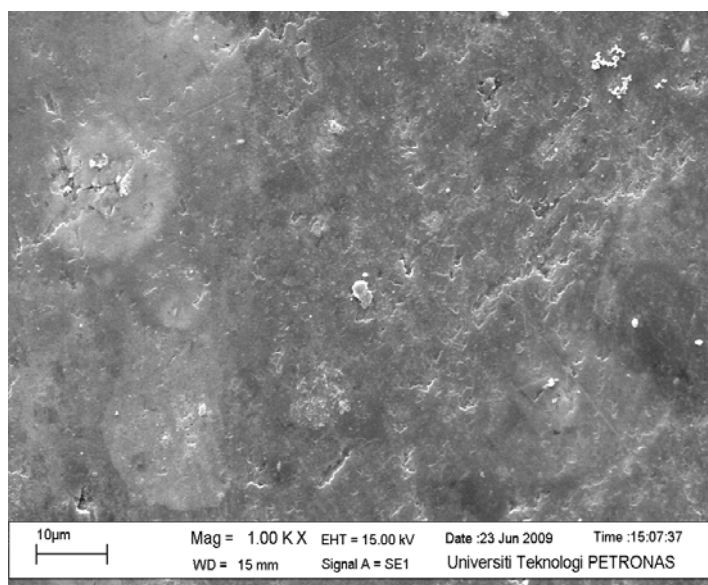


Figure 4: FESEM image of the ASSN with 2 wt. % silica sand nanoparticles

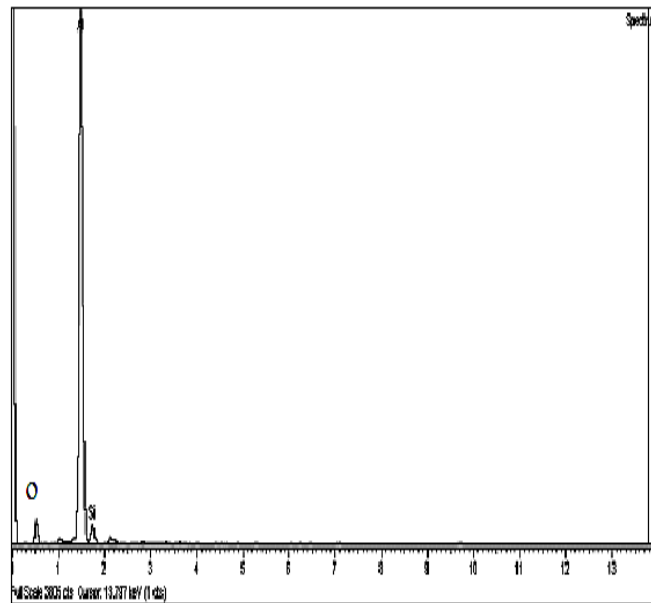


Figure 5: EDX analysis of the ASSN with 2 wt.% silica sand nanoparticles

Aluminium based composite with 4 wt. % Silica Sand Nanoparticles

Figure 6 shows more porous places are filled due to addition of 4 wt.% silica sand nanoparticles. More presence of silica in ASSN composites were detected (Figure 7) as compared with Figure 5.

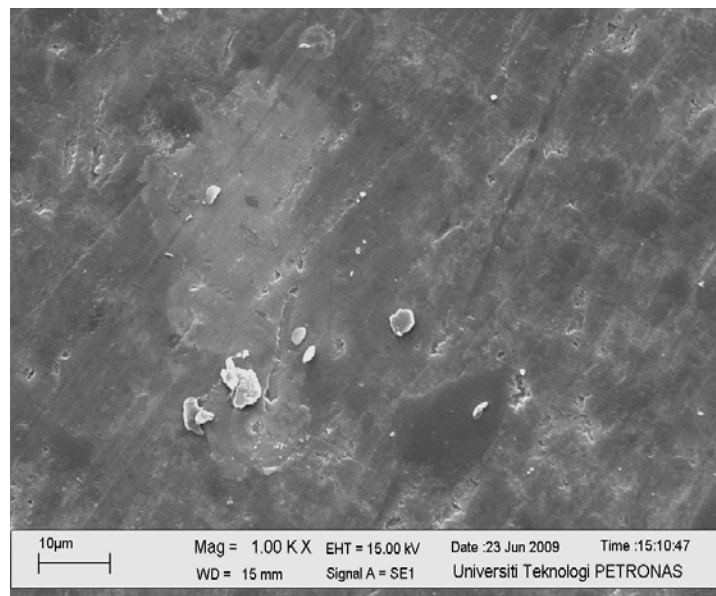


Figure 6: FESEM image of the ASSN with 4 wt. % silica sand nanoparticles (1000X)

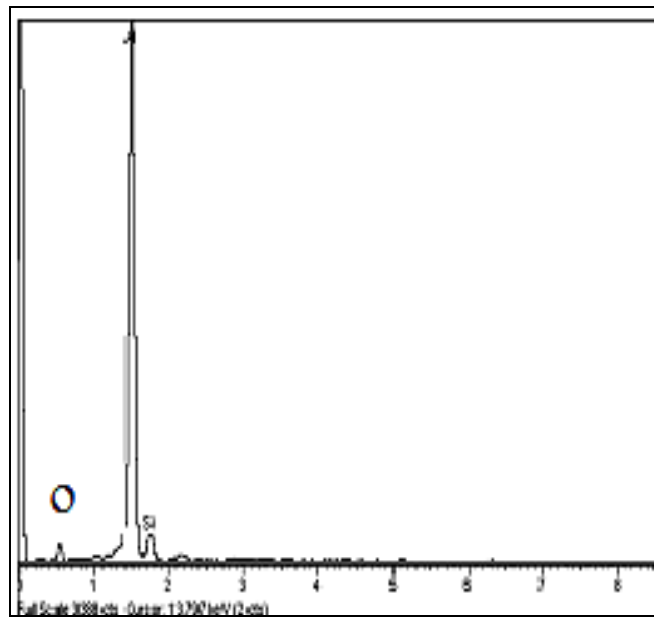


Figure 7: EDX of the ASSN with 4 wt.% silica sand nanoparticles

Aluminium Matrix composite with 6 wt. % Silica Sand Nanoparticles

Obviously from Figure 8 it is clear that more pores are filled than of previous 2 and 4 wt.% addition of silica sand nanoparticles. At the same time more amount of silica were found as highlighted in Figure 9 as compared with Figure 5 and 7.

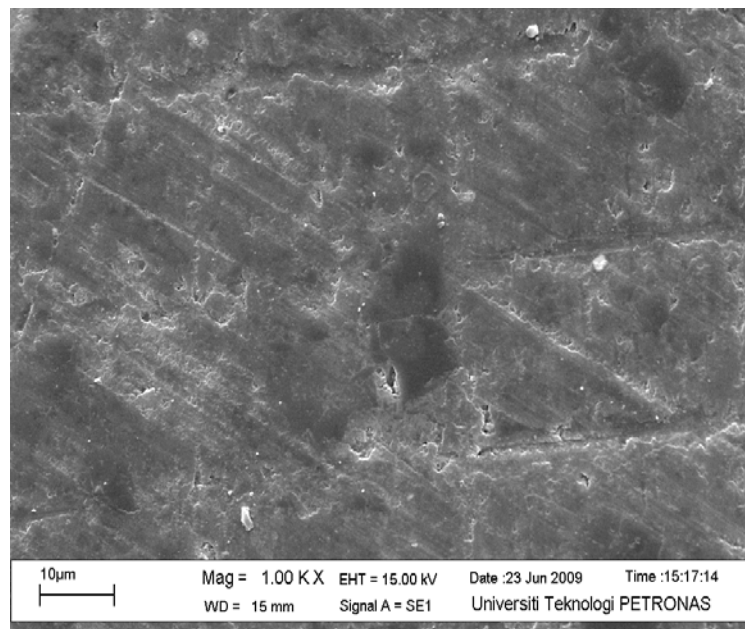


Figure 8: FESEM image of the ASSN with 6 wt. % silica sand nanoparticles (1000X)

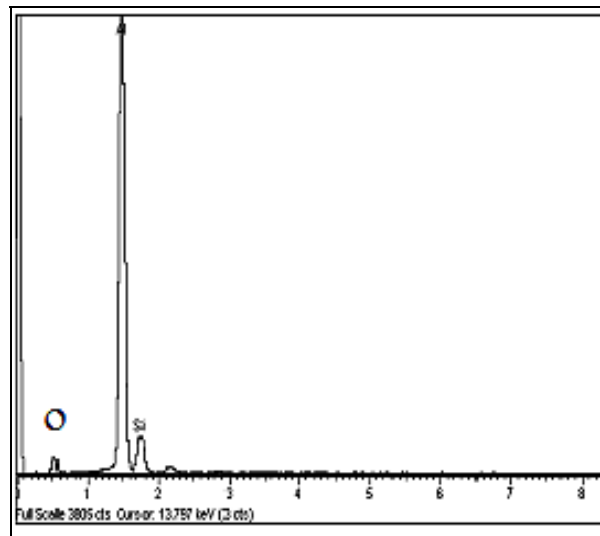


Figure 9: EDX analysis of the ASSN with 6 wt.% silica sand nanoparticles

Aluminium Matrix composite with 8 wt. % Silica Sand Nanoparticles

Most pronounce filling of porous places are observed in Figure 10 as compared with earlier ASSN composites. Increased of the silica amount in the composite was inevitably seen as shown in Figure 11.

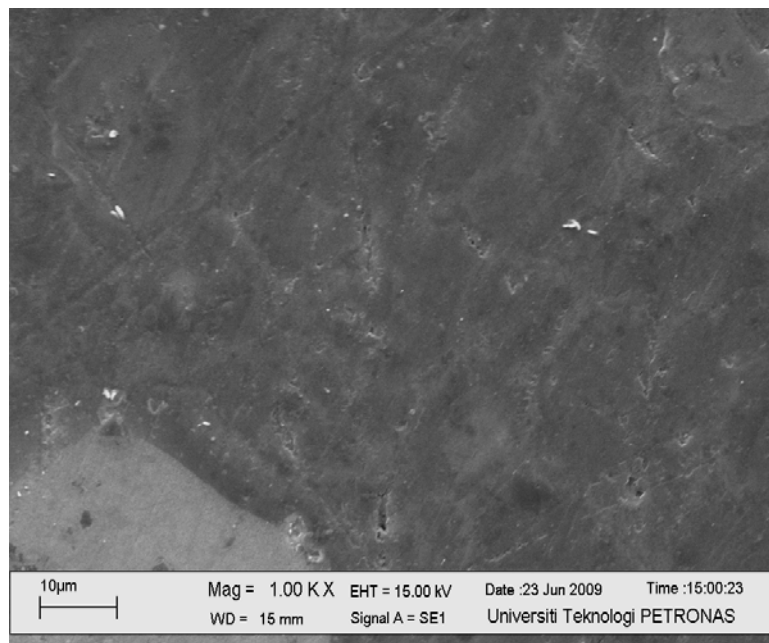


Figure 10: FESEM image of the ASSN with 8 wt. % silica sand nanoparticles

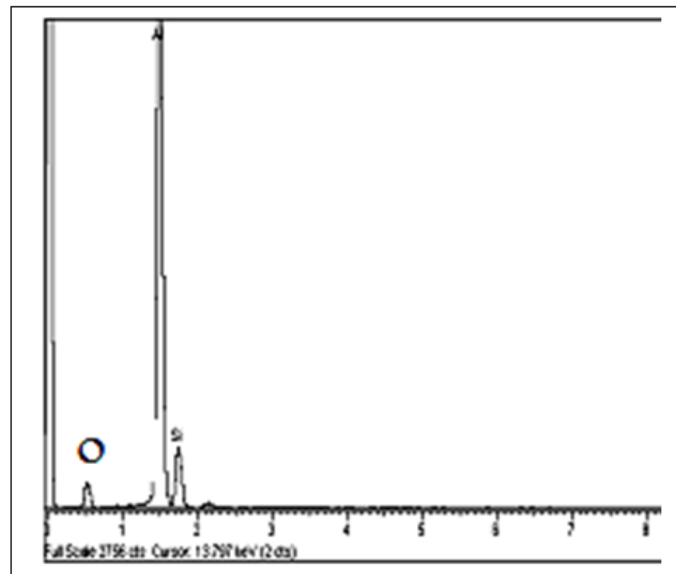


Figure 11: EDX analysis of the ASSN with 8 wt. % silica sand nanoparticles

Aluminium Matrix Composites with Silica Sand Nanoparticles Property: Density

Figure 12 shows a decrease in green density as increasing amount of silica sand nanoparticles which indicates the presence of porosity in the green samples. Contrary to that, the reinforcing of silica sand nanoparticles shows an improvement in densities after sintering. Also after sintering the porosity of the samples decrease and the presence of silica sand nanoparticles in aluminium probably reduce the mobility of aluminium grain boundaries during sintering and shows full densification. It also shows a better adhesion between aluminium matrix and silica sand nanoparticles which improve the sintered densities.

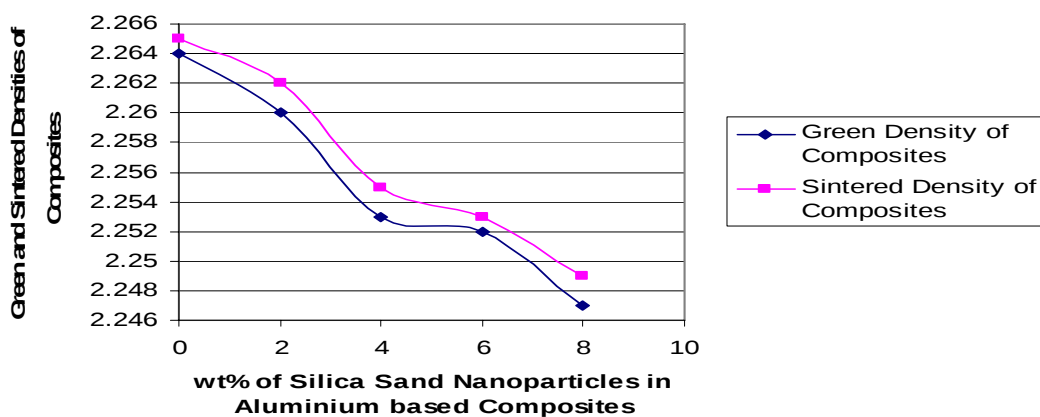


Figure 12: Green and sintered densities of ASSN with 2, 4, 6 and 8 wt.% of silica sand nanoparticles

The sintered density of 2.25g/cm^3 was achieved by using only 8 wt.% nanoparticle silica sand at 27 MPa compaction pressure. This pressure was much less as compared with 200 MPa pressure used to produce the sintered density of 2.4407g/cm^3 by addition of 40 vol.% of silica sand, as reported by Zuhailawati et al.[7]. Both works are using the same sintering temperature, i.e. 600°C .

Aluminium Silica Sand Nanoparticles Composites Property: Hardness and Tensile Strength

The hardness and tensile strength results (Figure 13) show that the a little addition of silica sand nanoparticles enhance these properties in regular interval. Such behaviour is due to replacement of soft aluminium matrix by harder silica sand nanoparticles and forming a layer of aluminium silica sand nanoparticles which occupies the porosities places and also increases the adhesion force between matrix and particulates. The approximate tensile strength is calculated from HRB values [9].

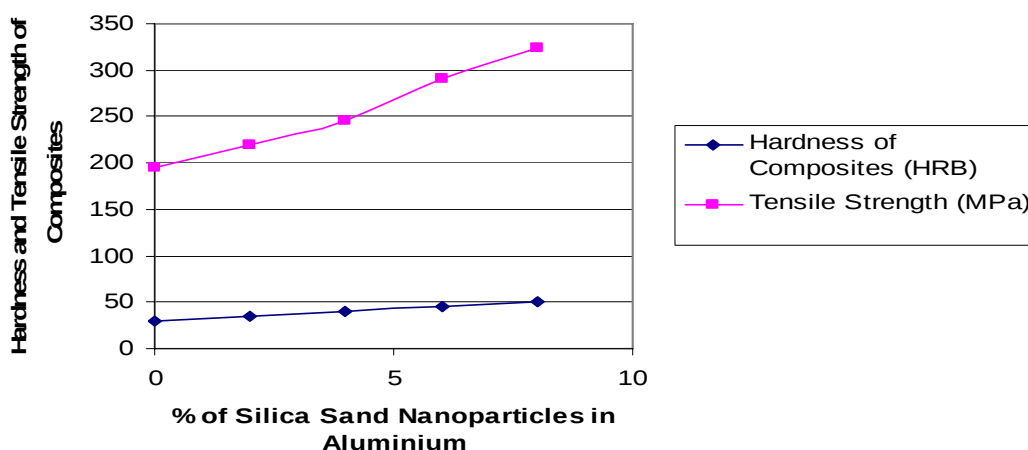


Figure 13: Hardness and tensile strength (approximate) of ASSN with 2,4,6 and 8 wt.% of silica sand nanoparticles

XRD Analysis Aluminium based Silica Sand nanoparticles composites

It has been observed from XRD results that an increasing wt% of silica sand nanoparticles increased the intensity peaks of silica sand as shown in Figure 14. The results also shows that there is no structural changes occur during fabrication process and silica sand nanoparticles have the same crystalline structure because similar peaks are observed in all composition of composites, which shows that silica sand particles are homogeneously distributed in Aluminium matrix.

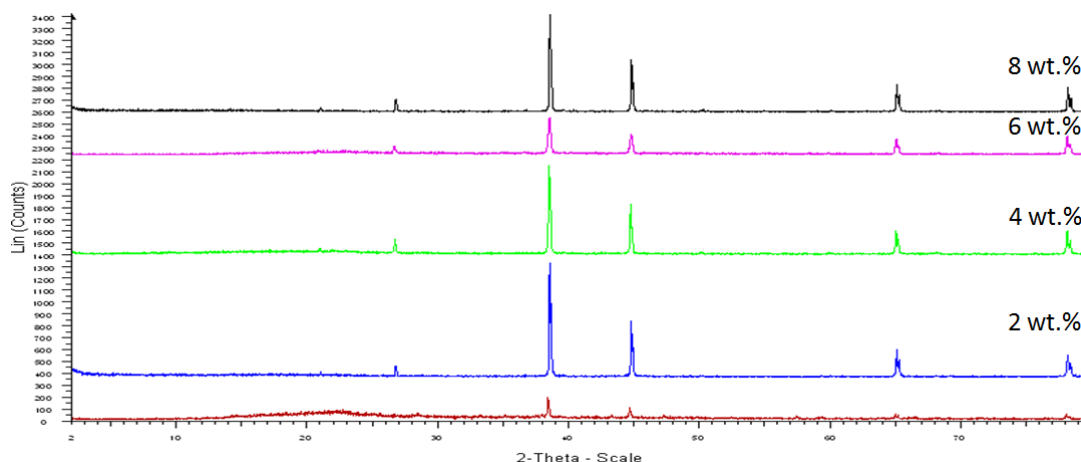


Figure 14: XRD analysis of pure 99.0% aluminium, 2 wt.%, 4 wt.%, 6 wt.% and 8 wt.% of silica sand nanoparticles aluminium based composites

CONCLUSION

The addition of silica sand nanoparticles upto 8 wt.% was capable of filling the porosity places of the ANSS. These are achieved through silica sand nanoparticles diffusion into the porosity sites. Crystalline structure of the silica sand nanoparticles in the ASSN composites was remained same as observed by XRD analysis. In all ASSN composites, both hardness and tensile strength were found to increase with the content of silica sand nanoparticles. The results showed that the addition of silica sand nanoparticles to aluminium enhanced the hardness from 30 HRB to 50 HRB and from 194.26 MPa to 323.77 MPa which indicates that these ASSN composites have equivalent hardness and tensile strength to commercial aluminium alloys. The addition of silica sand nanoparticles in aluminium open new horizon in this direction of research to develop new composites of low cost and easy fabricated.

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