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Comparison Between Mechanical Properties, Microstructures and Electrical Conductivity of AA2024 Doped with Various Amount of Alumina and Zirconium Oxide

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Abstract: Preparing two aluminium matrix nanocomposites using stir casting method results in many desirable benefits. The currents research is focused on fabricating AA2024-Al_2O_3 and AA2024-ZrO at (2, 3 and 4 wt.%) Al_2O_3 and ZrO. The casting temperature and stirring speed were 850°C and 1000 rpm for 1.5 min stirring time. A microstructural study was carried out using optical microscopy and scan electric microscopy SEM, the effect of two types of reinforcements on microstructural feature was discussed. It has been observed that the reinforcement particles of the two nanomaterials Al_2O_3 and ZrO uniformly distributed in AA2024 matrix composites. But the Al_2O_3 composites had better distribution than the ZrO composites. The experimental results showed that the mechanical properties such as Brinell hardness, UTS and yield stress increases with the addition of the nanomaterial content. But the ductility for both composites reduced when the nanomaterial content increased taking almost linear trend. Also, the electrical conductivity for both composites was slightly improved with increase of nano content.

Key words: Aluminium alloy 2024, microstructure, two types nano reinforcement, mechanical properties, conductivity, composites

INTRODUCTION

Nanocomposite material can be durable and strong which can use it in engineering applications, structures of aircrafts, cars, industrial equipment, etc., nano composite are designed in order to support significant loads with low fraction which can use in many applications (Raju *et al*., 2015a, b; Han *et al*., 2016; Hossein-Zadeh *et al*., 2013).

These types of composites gain strength, thermal stability wear and corrosion resistant because of using processes make nano particles uniformly distributed in the matrix during staring and formation. Controlling the process of milting and staring nano particles is so, important in order to tailor their mechanical properties to optimal and good performances were reviewed (Kala *et al*., 2014; Prajapati *et al*., 2016; Kant and Verma, 2017).

Raturi *et al*. (2017) used Al 7077 as a metal matrix reinforced with Al_2O_3. The mechanical tests were conducting after manufacturing the nanocomposite, it was notice improving in the mechanical properties when the nano particles increase until it was reached 7 wt.%, decreasing stated in the mechanical properties which was examined because of clusters of nano particles and porosity were shown in SEM and optical microscopy for different wt.%.

Murthy *et al*. (2016), this study had used Al 2219 as a metal matrix reinforced by (0.5, 1.5 and 2 wt.%) with SiC nano particles (50 and 15 nm) in size, the uniform distribution of nanoparticles in matrix of composite had been examined through advanced SEM microscopy, during the investigation the wear rate was high and there was increasing in the mechanical properties (ultimate and tensile stress) and hardness were noticed (Kannan and Ramanujam, 2017) made a comparative study on the mechanical and topological for Al matrix when it reinforced by single and hybrid nano composite the single was used 2 wt.% nano with size (30-50 nm) in Al 7075 while the hybrid was of 4 wt.% nano Al_2O_3, the nano composite was manufactured by stir casting preheated with different temperatures, It was noticed improving in the hardness and ultimate tensile test when squeeze casting with a pressure of 101 MPa had been used for manufacturing the composite.

Raju *et al*. (2015a, b), it was investigated in this study on MMNCs using X-ray and SEM techniques, two types

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of processes were used in order to form the composite, it was noticed that mechanically alloyed powder metallurgy gives better distribution for the nano particles than using pellets of the powders because of contamination due to pullets in the same area.

Suresh *et al*. (2011) the effect of micro and nano particles of Al_2O_3 on an aluminium matrix up to 10 wt.% was studied. It was found the mechanical and hardness for the matrix which reinforced by nano particles were higher than the composite with micro particles and it was noticed the stir casting are more economical than other process more examination were conducted by SEM to evaluate the distribution of particles in two sizes, it was found that the distribution of the micro particles is better than the nano particles in a matrix because the latest produced agglomeration and porosity.

Kumar *et al*. (2014) used hybrid casting process to improve the distribution of nano particles in a matrix. Al 2024 matrix reinforced with 1 wt.% Al_2O_3 by injection with argon gas. SEM, EDAX tensile was proving that the nano particles are well distributed on the matrix. Tensile strength was improved by 43% compared with the Al 2024 alloy (Pazhouhanfor and Eghbali, 2018). Aluminium 6061/TiB_2 composites were fabricated by using stir casting route with different amounts of reinforcement (3, 6 and 9 wt.%). Microstructure and mechanical properties of fabricated composites were tested and it was concluded that a uniform distribution of nanoparticles in metal matrix was observed, also, mechanical properties were enhanced by increasing the amount of TiB.

Selvam *et al*. (2018) focused on preparing AA6061/(TiB_2+Al_2O_3) nanocomposites using *in-situ* reaction between (Ti), boric oxide (H_3BO_3). It was found that the microhardness and tensile strength were enhanced from 60-122 HV and 160 -287 MPa at 15 wt.%, respectively.

Tekeli *et al*. (2007) investigated the effect of TiO_2 addition on the microstructure and electrical conductivity of cubic zirconia. The experimental results revealed that when the TiO_2 doped cubic zirconia and undoped specimens grain size decreased with increasing TiO_2 content while the electrical conductivity of TiO_2 doped decreased with increasing TiO_2.

Tie *et al*. (2015) studied the effect of different heat treatment on microstructure, mechanical and conductive properties of Al-0.9 Si-0.6 Mg wt.%. They concluded that the tensile strength, elongation and resistivity of T_8 heat treated alloy reached 336 MPa, 13.7% and 29.3 nμm, respectively. After T_9 heat treatment, the above properties were raised to 338 MPa, 6.0% and 30.2 nμm, respectively.

The present study is focused on fabricating two types of nanocomposites and examining microstructures, AA2024/Al_2O_3 and AA2024/ZrO using stir casting technique. A detailed and comparison characterization (mechanical and electrical conductivity) of the prepared composites were recorded and discussed.

MATERIALS AND METHODS

It has been presented in this study, the materials which are used, its chemical composition and mechanical properties.

Materials used: There are two stages performed to fabricate the two types of composite, the first stage was the metallurgical process, heating the Al2024 with the chemical composition tabled in Table 1 to get liquid matrix and then in second stage adding nano particles after heating at 200°C with different weight present (2, 3 and 4 wt.%). Both of moult and the nanoparticles were been staring to 1000 rpm for 1.5 min in order to get better distribution to the nano particles in matrix, to provide high level of mechanical properties, casting followed these processes in a special mould to prevent contamination. A rod with 15 mm diameter and length 150 mm has been produced. The mechanical properties of 2024 Al alloy are compared with Tie *et al*. (2015) are summarized in Table 2.

Tensile samples and test rig: Samples for a tensile test were machined by CNC lath, the shape of the samples were made, according to E8/E8M-09 standard Fig. 1

Table 1: Chemical composition of 2024 Al alloy examined at state company for standard and measured in wt.%

Elements (wt.%)	Cu	Mn	Mg	Fe	Others	Al
Standard	3.8-4.9	0.3-0.9	1.2-1.8	Max. 0.5	Traces	Balance
Experimental	4.2	0.52	1.48	0.46	Traces	Balance

Table 2: Mechanical properties of 2024 Al alloy tested compared with the standard

2024 Al	Hardness (BH)	Strength σu (MPa)	Yield stress σy (MPa)	Ductility (%)
Standard (Tie *et al*., 2015)	72.3	100.46	87	10.5
Experimental	55.0	181.00	85	11.0

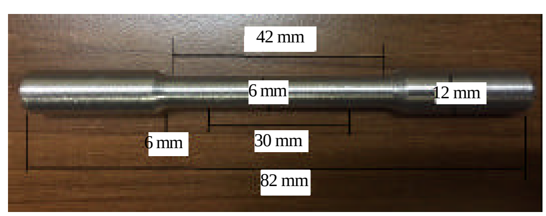

Fig. 1: The dimensions of the sample are given from Han *et al*. (2016) standerd values

and good surface finished were performed, two groups of samples were produced, first group was used to establish mechanical properties while the second group was used to determine the electrical conductivity and microstructural analysis for the base metal and nanocomposites. The mechanical testing have been conducting using (Tinius Olsen k 1000) machine with the maximum capacity 1000 kN as shown in Fig. 2.

Electrical conductivity and microstructure specimen: The specimen of electrical conductivity and microstructure is the same in dimensions and can be illustrated in Fig. 3 with their dimensions and schematic diagram for measuring the electrical conductivity using the LCR-8110G/8105G device, working with wide test frequency 20 Hz-10 MHz with 0.1% basic accuracy and test speed of AC(>2 hH). This device can measure the impedance, phase angle, inductance, capacitance, AC resistance, quality factor and conductance.

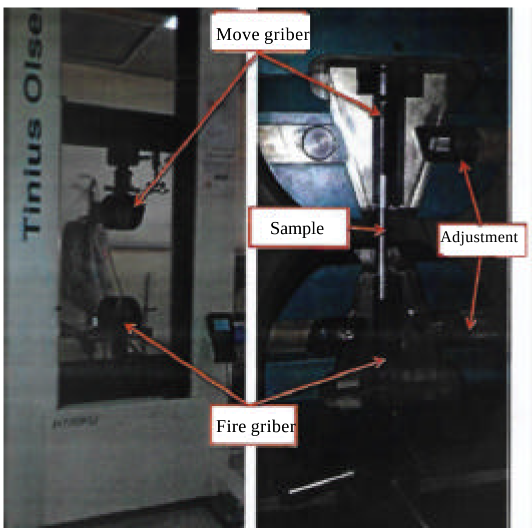

Fig. 2: Tensile test rig (Tinius Olsen k 1000) machine with the maximum capacity 1000 kN

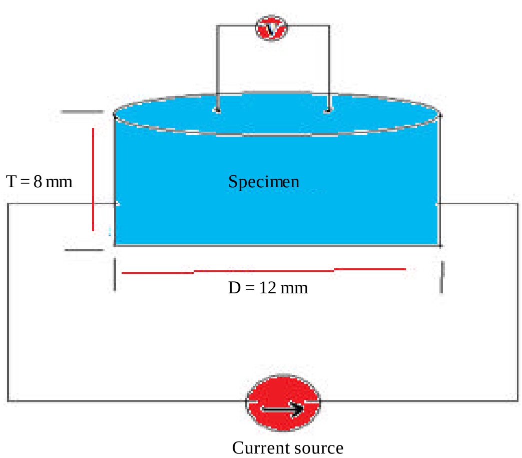

Fig. 3: Specimen dimensions for electrical conductivity and microstructure

RESULTS AND DISCUSSION

Mechanical properties: Table 3 gives the results of Brinell hardness for both composite with Al_2O_3 and ZrO. The variation in hardness with wt.% for 2024/Al_2O_3 and 2024/ZrO composites are presented in Fig. 4. The hardness tests were done on a Brinell hardness device. It is clear that Brinell hardness of the composites in both cases is greater than that of the metal matrix alloy. In both cases the hardness of composites increases with increasing the wt.% of Al_2O_3 and ZrO. But the composite of Al_2O_3 have higher hardness compared to ZrO composites.

It was observed from Fig. 4, the hardness of the specimens seems increases significantly with variation of reinforcements of nanoparticles Al_2O_3 and ZrO. Brinell hardness values reaching a maximum value in case of AA2024/4 wt.%Al_2O_3 and AA2024/4 wt.% ZrO composites and these composites show the highest hardness value due to the good compatibility between the base metal and reinforcement phase.

Muralidharan *et al*. (2018) tested the Hardness (HV) and mechanical properties for AA 2024 (0, 2.5, 5,7.5 and 10 wt.%) ZrB_2 composites. They concluded that the HV increased from 66 at 0 wt.% to 140 at 10 wt.%. The UTS enhanced from 155 MPa at 0 wt.% to 275 MPa at 10 wt.%.

Figure 5 shows increasing in the yield stress with increasing in different weight percent for both types of

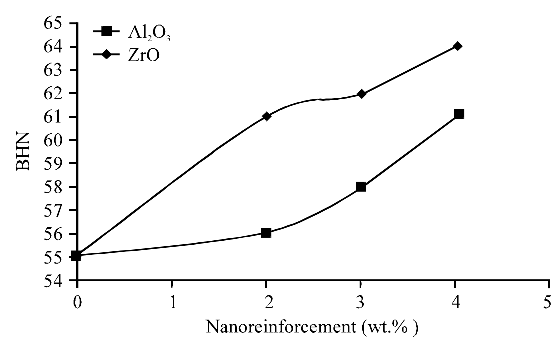

Fig. 4: The BHN (AA 2024 with neno) against the wt.% for two nanocomposites

Table 3: Brinell hardness number of two composites

	wt.%			
Composite	0	2	3	4
2024 Al-Al_2O_3	55	57	62	68
2024 Al -ZrO	55	57	59	61

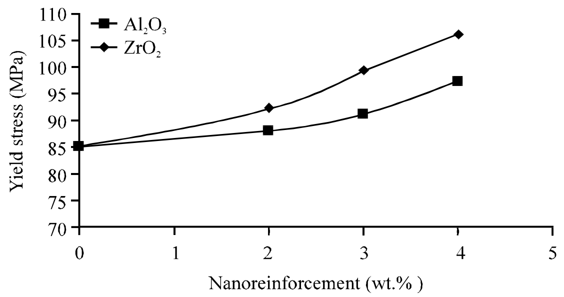

Fig. 5: Yield stresses (AA 2024 with neno particals) against the wt.% for two types of nano composite

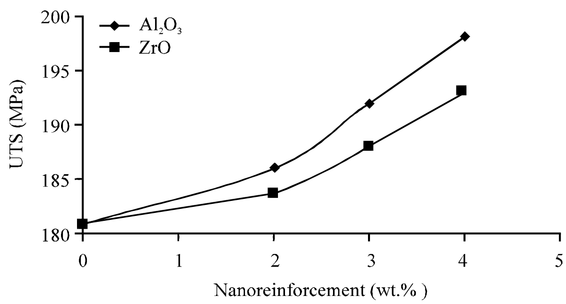

Fig. 6: Ultimate tensile stress (AA 2024 with neno) against the wt.% for two nanocomposites

nanoparticles this is due to the strength of the nanoparticles which is uniformly distributed in the matrix.

Figure 6 shows increasing in the ultimate tensile stress with increasing in different weight percent of nano particles for both Al_2O_3 and ZrO and it is clear that little difference in the increasing between these two types of nano reinforcement particles.

Tensile engineering stress-strain curve of 2024 Al metal matrix and composites for both nano reinforcements Al_2O_3 and ZrO are illustrated in Fig. 7 and 8. As it is seen 2024 Al has a lower strength and higher ductility than the nanocomposites and the ductility almost varies in a linear manner.

A significant hardness and mechanical properties enhancements in both composites has been obtained from adding Al_2O_3 and ZrO. The main reasons for the above improvement could be forming the followings: the Al_2O_3 and ZrO particles act as obstacles to the motion of dislocation and they work as barrier to initiation of slip band and damage (Su *et al*., 2012). The uniform dispersion of Al_2O_3 and ZrO in AA2024 resulted to increase the hardness of the composite and also these nano particles are harder than AA2024 alloy leading to raise the hardness of composites (Ezatpour *et al*., 2014). Significant amount of dislocation generated due to the thermal mismatch stress resulting in improvement of hardness.

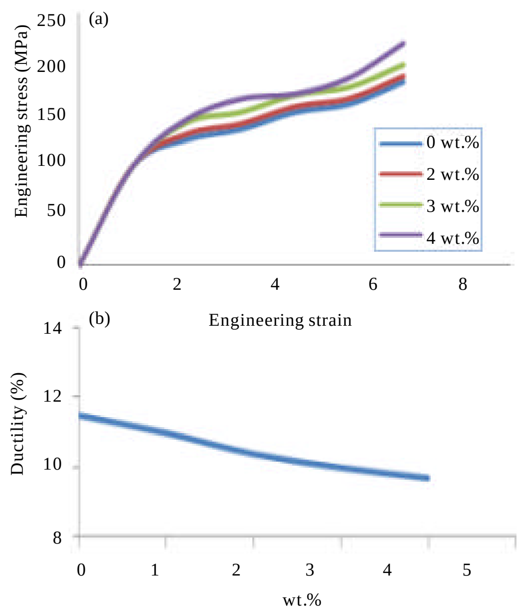

Fig. 7: a) Average stress strain curve of base metal 2024 Al and 2024-Al_2O_3 composites and b) Ductility containing different amount of Al_2O_3

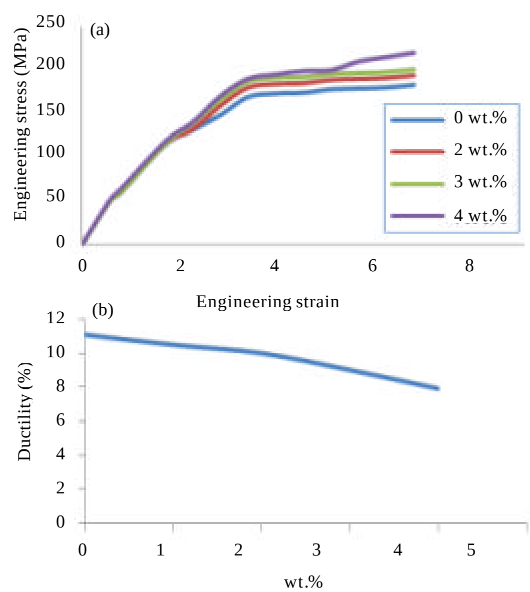

Fig. 8: a) Stress-strain curves of base metal 2024 and 2024-ZrO composites and b) Ductility variation with the ZrO content

Hardness and strength measurements illustrated enhancement due to addition of Al_2O_3 and ZrO nanoparticles to aluminium alloy. It was comprehended that Al_2O_3 composites have higher values of hardness and mechanical properties compared to ZrO composites. The reasons are directly due to less porosity, less crack formation and more homogenous of nanomaterials in the metal matrix (Abdizadeh *et al*., 2014).

Optical microstructure: Figure 9 shows the microstructure of the base metal without adding any nano particles using optical micrograph examination at 40x magnification the diameter of the grain size is 114 μm. Figure 10a-c show the composites with different weight percent when nano particle of Al_2O_3 (2, 3 and 4 wt.%) optical microscopically examination at 40x magnification. The grain size of the composites have been decreasing when the weight percent of nano composites increasing the grain size are (98, 88 and 64 μm), respectively. When the grain size decrease the distribution of nano particles The grain size of the composites have been decreasing when the weight percent of nano composites increasing the grain size are (98, 88 and 64 μm), respectively. When the grain size decrease the distribution of nano particles uniformly distributed in the microstructure, the mechanical properties have been increasing with the increasing of the nano particles in the base metal. Optical microscopic at high magnification showed uniform distributed in the base material and adding nano particles with different weight percent. Figure 11a-c show different composites

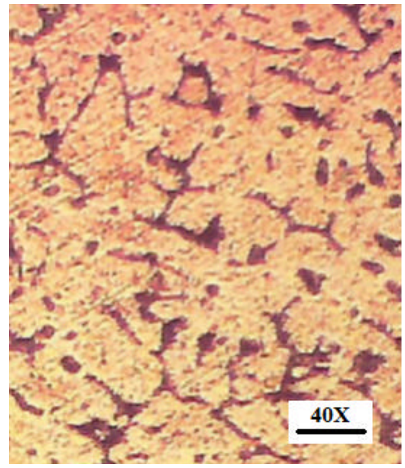

Fig. 9: The optical microstructure to the base metal

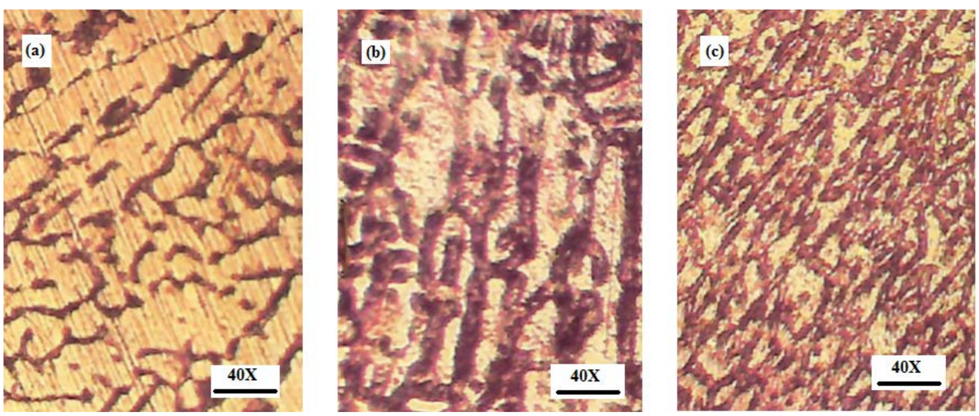

Fig. 10: Optical microstructure of the Al reinforcement with: a) 2 wt.% Al_2O_3; b) 3 wt.% Al_2O_3 and c) 4 wt.% Al_2O_3

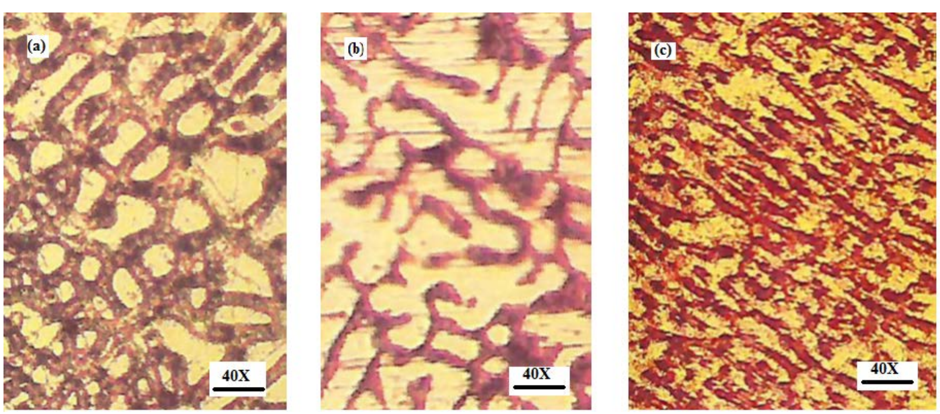

Fig. 11: Optical microstructure of the nanocomposite reinf microstructure of the Al reinforcement with: a) 2 wt.% ZrO ;b) 3 wt.% ZrO and c) 4 wt.% ZrO

microstructure of Al adding different weight percent of nano ZrO (2-4 wt.%) microsocial examination have been conducted. It was noticed that the grain size of composites decreasing as the nano particles increase.

Fig. 12: SEM of 2024 Al alloy

The grain sizes are (105, 96 and 80 μm), respectively, the photographs contains primary α-Al dendrites and Al_2O_3 are dispread at the inter-dendritic area. It is also noted that the grain size of the composites is smaller than the alloy with zero nano. Referring to Fig. 11 there is a continuous distribution of ZrO in the base metal. This type of distribution is desirable which play a major reason for improving the mechanical and electrical properties.

Scan Electrical Microscopy (SEM): SEM has been used to examine the distribution of the nano particles in the Al matrix at high magnification; the microstructure of the Al matrix without any addition is show in Fig. 12. While Fig. 13a-c shows the Al with Al_2O_3 nano particles at 2-4 wt.%, respectively. Figure 14a-c show the composite with nano ZrO at 2-4 wt.%, respectively. From the experimental results obtained for the measuring the grain size. Table 4 gives the variation of grain size measured by liner average intercept method with the content of nano added to the base metal.

Comparison between the two composites 2024 Al-Al_2O_3 and 2024 Al ZrO can be seen in Fig. 15 in terms of grain size of nanocontent with grain size takes the trend but the Al_2O_3 composite slightly lower than the ZrO. The less grain size gives best dispersion of the nanomaterial in the matrix.

(a) (b) (c)

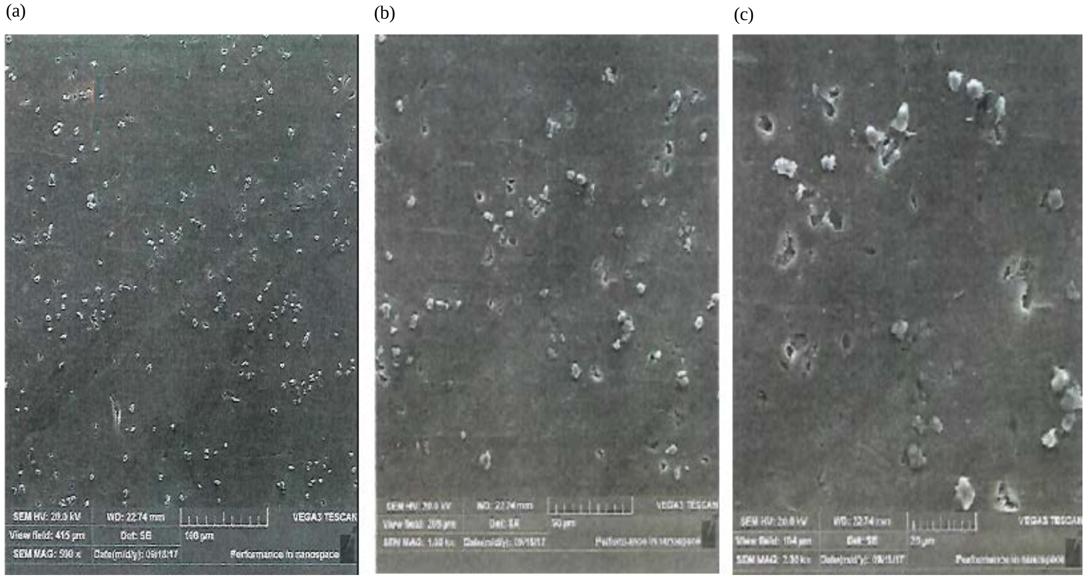

Fig. 13: SEM of composite with: a) at 2 wt.% nano Al_2O_3; b) 3 wt.% nano Al_2O_3 and c) 4 wt.% nano Al_2O_3

Table 4: Electrical conductivity for two nano composite at 0-2000 Hz

Types of composite	Al 2024/Al_2O_3				Al 2024/ZrO			
(wt.%)	0	2	3	4	0	2	3	4
Electrical conductivity $(\Omega m)^{-1}$	410	422	417	432	410	408	432	436
Grain size (μm)	114	98	88	64	114	105	96	80

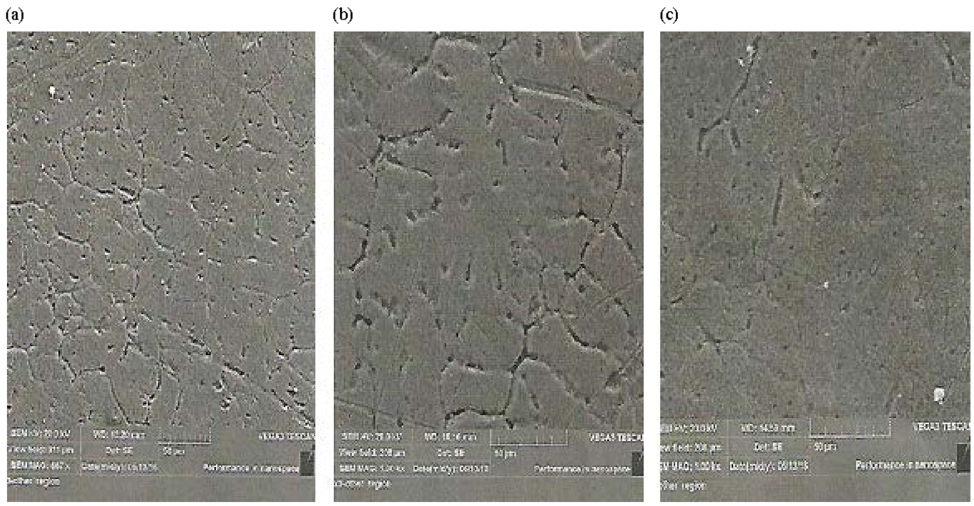

Fig. 14: SEM of composite with: a) at 2 wt.% nano ZrO; b) 3 wt.% nano ZrO and c) 4 wt.% nano ZrO

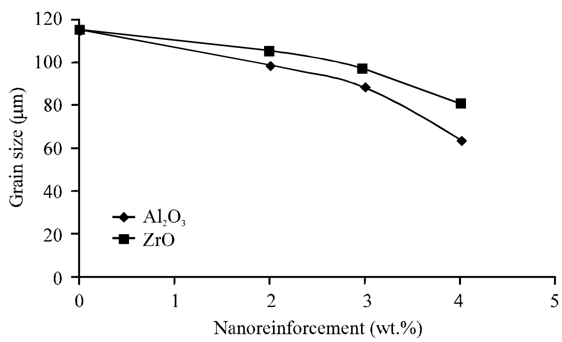

Fig. 15: Variation of wt.% of nanoreinforced materials (AA 2024 with nano particals)

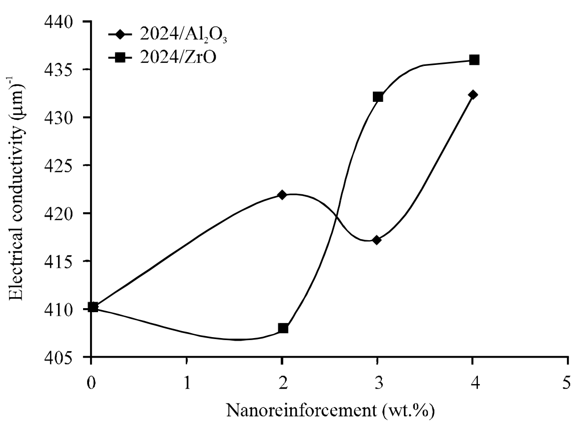

Fig. 16: The electrical conductivity against the weight percent of nano composite for both Al_2O_3 and ZrO

Electrical properties of materials: The enhancement in the electrical conductivity is shown in Table 4 after adding nano particles, the grainsize were decrease when the wt.% of nano particle increase. Figure 16 shows improving in the electrical conductivity when the weight percent of nano composite increase.

The electrical properties of materials are important when materials selection and pressing decisions are being made during the design of a component or structure. For example, materials that are used in the several components of one types integrated circuit components package. Some need to be highly electrically conductive e.g., connecting wires) whereas electrical in respectively is required of others.

CONCLUSION

The major remarks drawn from the current research can be summarized. AA 2024-Al_2O_3 and AA2024-ZrO nano composites were successfully prepared using liquid metallurgy method. The addition of Al_2O_3 and ZrO particles as reinforcement is advantages for getting high feature homogeneity in the metal matrix composites. Based on the microstructure evident, it was found that the addition of Al_2O_3 and ZrO caused dendrite refinement which could be attributed to enhance the mechanical and electric properties. Also, increasing the nanoconteant resulting in a more refined microstructure.

The hardness and mechanical properties of composites have improved and they increase with increase the wt.% of the nanomaterials for both composites. But the composite 2024-Al_2O_3 has higher improvement compared to AA2024-ZrO composite. Increasing the weight percentage of reinforcement causes a decrease in ductility and the reduction in ductility almost takes a linear trend for both nano composite. Addition of nano particles Al_2O_3 and ZrO slightly improved the electrical conductivity for both composites.

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