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Alfa (α) and Gama (γ) Al_2O_3 Nanomaterial Effect on Mechanical and Microstructure Behavior of 7100 AL. Alloy Comparative Study

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Abstract: Aluminum Metal Matrix Composites (AMMCs) are preferred to other conventional materials in the field of automotive, marine applications and aerospace due to good corrosion resistance, light metal, high reflectivity, a good conductor of heat and electricity. AMMCs produced by stir casting method usually show porosity and fair distribution of nanomaterial in the base metal. A composite 7100 Al/Nano-Al_2O_3 of two types of alfa (α) and gama (γ) (20-30 nm) in size were injected by pure argon gas into the molten 7100 aluminum alloy separately. Mechanical properties and microstructure of the final product were investigated by tensile and microstructure tests, microhardness measurements and optical microscopy. The addition level of Al_2O_3 for both types is being varied from 2-6 wt.% in steps of 2 wt.%. The experimental test was done before and after addition of alumina and the results revealed that hardness and tensile properties are higher in case of a composites when compared to base metal 7100 Al. Alloy and α composites. Also, increasing the level of addition of both nanomaterials has resulted in further increase in both hardness and tensile properties. By this fabrication method Al 7100|6 wt.% α Al_2O_3 and Al 7100|4 wt.% γ Al_2O_3 have the best combination of hardness and strength. The Al_2O_3 Nanoparticles exhibited some good properties such as a fine grain and reasonably uniform distribution of Al_2O_3 in the matrix for both types.

Key words: Nanocomposites, alumina α, γ, mechanical properties, microstructure, stir casting technique, tensile properties

INTRODUCTION

Aluminum alloy is one of the wide world industrial alloy and due to toughness, strength and ductility. The aluminum alloys are lower density which can be used for many purposes by strengthened with nanoparticles like Al_2O_3. The aluminum -Zn-Mg alloys like (7100) is higher strength property e comparative with aluminum-Mg alloys. Based on a tensile test in selection material, material specifications and quality ensure, developing new material can be compared to others different materials.

The Metal Matrix Composite aluminum alloy 7075 (MMCs) (7075 Al Zn 5.5 Mg Cu) with different wt. of Al_2O_3 of particle size is 10 nm, manufactured using stirring molding technique. Effect of adding Al_2O_3 content on the mechanical properties of metal. He has been observed that improvement in the ultimate strength (σu) of maximum (BHN) Brinell Hardness Number, ductility and yield stress (σy). Improvements were due to regular distribution of Al_2O_3 and refined 7075 aluminum granules. The maximum improvement was observed in the hardness of BHN, σu and at 0.2% by weight. AL_2O_3. While was weight Al_2O_3 at 0.2% obtained the minimum value of ε%. (Al-Alkawi *et al*., 2017).

Al-MMCs with Al_2O_3 particles as reinforcement of power mineralogy techniques has gained a lot attention because of their unique properties which combines process roles, Al_2O_3 molecules and aluminum matrix contents and sizes The dispersion and locations of Al_2O_3 molecules on the matrix affect the mechanical behavior and end properties of the compounds which depend on the microscopic structure of the final compounds, porosity include usually. Deterioration of the mechanical properties of composite due to the aggregation and separation of particles (Xu *et al*., 2016).

Hybrid compounds based on 6061 aluminum alloy reinforced with different hybrid ratios of Sic and B4C were successfully synthesized using ultrasound-based condensation. The results indicate that, through ultrasonic cavitation effects such as transient cavity and acoustic flow. Compared with non-reinforced alloys, room temperature and tensile strength of hybrid vehicles increased significantly while the ductility and strength of shocks decreased slightly. The main reason for the increase in the mechanical properties of room temperature for hybrid vehicles should be attributed to the proportion of the largest hybrid of Sic and B4C nanoparticles (Poovazhagan *et al*., 2013).

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Al-MMCs in this investigation, micro-composites and nanoparticles (A356/Al_2O_3) have been manufactured with a different percentage of particles wt. by two melting techniques such as stir-molding and compo-molding. Tensile, stiffness and pressure tests were conducted to determine the mechanical properties of compounds. The results of the study revealed uniform micro-distribution, fine-grained and low porosity in micro-samples and nano-composites. Mechanical results showed that the addition of alumina (micro and nanoparticles) resulted in improved yield strength, maximum tensile strength, compressive strength and hardness (Sajjadi *et al*., 2012).

A different percentage of reinforcement is used. Tensile test, hardness test, pressure test on samples obtained by stirring casting process. The optical microscope was performed to determine the presence of the reinforced material phases. The rigidity test is used to evaluate the interstitial interface between the particles and the matrix by shifting the hardness with constant load and constant time. Optical microscopy was performed to determine the distribution of alumina particles in aluminum alloys (Karunesh and Manjunath, 2016).

The newly synthesized Metal Matrix Nano-Composite (MMNC) of 7075 with (1.5% Sic) weight to reinforce was prepared using the new ultrasonic cavity method. The high resolution Electron Microscope (SEM) and the Field Emission Scanning Electron Micrograph (FESEM) scan show a uniform distribution and good dispersion of Silicon carbide nanoparticles within the aluminum metal matrix (Gopalakannan and Senthilvelan, 2013).

The 7075 aluminum alloy was used as a base material for metal matrix composites with different wt.% of Al_2O_3, manufactured using stirring molding technique. It has been observed that the enhancement of nanomaterials led to a significant improvement in final strength, yield stress, BHN hardness and ductility improvements were due to good distribution of Al_2O_3 and refined basic aluminum granules for base matrix. Maximum improvement in maximum strength, yield stress and BHN hardness was observed at 0.2 wt.% of Al_2O_3. While the minimum elongation value was obtained at 0.2 wt.% Al_2O_3. The maximum strength of tensile strength and rigidity is shown in the results of tensile tests and hardness measurements (Zhang and Chen, 2008).

In this research, A7100 Al alloy has been taken as the base metal of composites with average size of (20-30) nm of alumina. The fabrication of two nanocomposites alfa (α) and gama (γ) was carried out using stir casting route and comparison of mechanical and microstructure properties were made for various weight percentage of nano Al_2O_3 contents.

Experimental work: The casting method was adopted to manufacture a sample of 7100 Al/Al_2O_3 composites (MMCS). Before the introduction of Al_2O_3 in the solute was pre-heated 200°C. The 3 wt.% of Al_2O_3 was used in the sense (2, 4 and 6) of Alpha (α) and Gama (γ). The casting temperature was 850°C using the metal die casting. Perform the manufacturing procedure described in the following steps:

- Aluminum alloys are cut into cubes 3 cm^3, the resulting parts are washed away process with alcohol and distilled water several times (3-5)
- Dry the hot air steam wash parts the temperature is 100°C. Dry parts are heated by 200°C by an electrical device heater
- Lift the oven covers and load the resulting parts of the heating process from the top and close cover tightly
- Addition of nanoparticles to the molten aluminum alloy with gas pump
- After several minutes rotation (4 min) is poured, the metal molten in the mold to get the final product in a shape of cylindrical shaft of 14 mm in diameter and 150 mm in length

Hardness measurements of the composite samples have been measured using macro Vickers hardness testing. Tests were conducted using a steel ball of 2.5 mm diameter and load of 0.2 kg force. Three measurements of hardness were performed on each sample. The tensile tests were carried out using tensile testing machine. Tensile specimens with height 100 mm and diameter 10 mm and diameter at the center 6 mm.

MATERIALS AND METHODS

Metal matrix compounds materials containing the proportions of 2, 4 and 6 of the wt.% of Al_2O_3 particles were produced by a stirring casting process. For MMCs production Al7100 alloys were used as matrix material while Al_2O_3 particles were used with an average size of 20-30 nm as reinforcements.

Nanoparticles: Metal Matrix Nanocomposite (MMNCs) are being investigated worldwide in recent years because of its promising properties suitable for a large number of functional and structural applications. The reduced size of the booster stage down to the nanometer is that particle interaction with disturbances becomes very important and when added to other enhancement effects typically found in conventional MMCs, it results in a marked improvement in mechanical properties (Zhang and Chen, 2008; Sanaty-Zadeh, 2012; Luo *et al*., 2012).

Table 1: Chemical composition of aluminum alloy 7100 AL

Chemical composition	Element wt.% of Al 7100
Zn-Zinc	2.0000
Mg-Magnesium	1.5000
Si-Silicon	0.7640
Cu-Copper	0.4410
Fe-Iron	1.0000
Ti-Titanium	0.0404
Mn-Manganese	0.3910
Cr-Chromium	0.0402
Pb-Lead	0.1550
Sn-Tin	0.1140
Ca-Calcium	0.0200
V-Vanadium	0.0121
Others	0.1350
Remaining Al-Aluminum	93.4194

The matrix metal used in the current research is 7100 aluminum alloy. The chemical composition of the matrix is presented in Table 1 (where the samples were analyzed in the company for examination and CIER. The nanoparticles used in this study are Al_2O_3 which have good thermal stability, high hardness and corrosion resistance. This enhancement has been selected because, to date, Al_2O_3 particles are most commonly used with Al matrix to generate matrix metal matrix combinations. The sample surface was grinded by 200, 300, 500, 800, 1000 and 2000 grit sheets and then refined by a 2 nm diamond paste in order to measure the surface roughness.

Tension tests: The tests were carried out on specification of the test specimen's geometry is provided to achieve regular results, various profile and dimensions of specimens were used in this testing machine. It is model name Laryee, country of origin China, the model is WDW-50, the capacity is 50 kN with defferint testing speed.

RESULTS AND DISCUSSION

The 7100/Al_2O_3 composites in both cases, α and γ types of Al_2O_3 of (20-30 nm) particle size diameter were successfully produced using stir casting method with 850°C casting temperature and sintering time 4 min (Table 1-3).

Microstructural studies: In the present research AA7100 matrix composites with Nano size α and γ alumina particles were produced. The level of addition of alumina powder used in the composites were 2, 4 and 6 wt.%. The optical micrographics of 7100 Al alloy with 0, 2, 4, 6 wt.% alumina particles were presented in Fig. 2-7. This figures presents three different structures draw the attention sharp-edged grains represent Al_2O_3, dark gray areas represents porosities and the third areas light gray represent the AA7100 base \metal. The details of the

Table 2: Mechanical properties of aluminum alloy 7100 AL and α/AL_2O_3
Nano-particle AL_2O_3 type α (alfa) particles size 20-30 nm

Wt.%	σu (MPa)	σy (MPa)	E (GPa)	G (GPa)	μ	HV(kgf/mm²)	ϵ (%)
0	115	82	67.0	26.20	0.28	74	16.72
2	156	116	70.0	26.92	0.30	85	16.72
4	140	112	69.0	26.94	0.29	83	15.00
6	165	126	72.3	27.59	0.31	90	14.20

Table 3: Mechanical properties of aluminum alloy 7100 AL and □/AL_2O_3
Nano-particle AL_2O_3 type γ (Gama) particles size 20-30 nm

Wt.%	σu (MPa)	σy (MPa)	E (GPa)	G (GPa)	μ	HV(kgf/mm²)	ϵ (%)
0	115	82	67.0	26.20	0.28	74	16.72
2	117	92	68.0	26.35	0.29	80	16.20
4	203	155	74.0	28.00	0.32	82	19.42
6	110	78	67.5	26.36	0.28	78	15.60

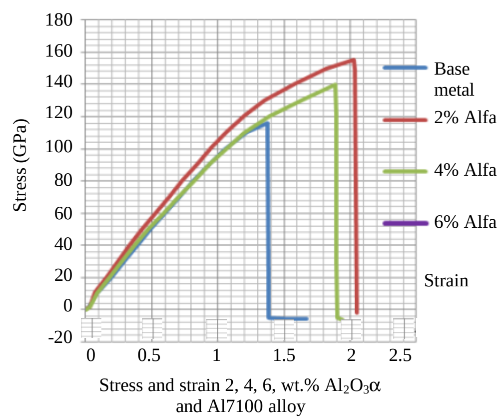

Fig. 1: Stress and strain 2,4,6, wt.% Al_2O_3 α and Al 7100 alloy

microstructure behavior can be shown in Fig 1-7 which shown the optic micrographs of AA7100/Al_2O_3 composites.

It can be seen from the microstructure feature that when the Al_2O_3 particles distributed uniformly in the metal matrix, this situation lead to improve the mechanical, electrical and fatigue properties while the particles do not distribute homogeneously this situation would affect the above properties of the composite negatively (Lee *et al*., 2001) (Fig. 1-8).

Microstructure features: Al 7100 base metal, Al 7100 and 2% Alfa Al_2O_3, Al 7100 and 2% Gama Al_2O_3, Al 7100 and 4% Alfa Al_2O_3, Al 7100 and 4% Gama Al_2O_3, Al 7100 and 6% Alfa Al_2O_3, Al 7100 and 6%Gama Al_2O_3

Mechanical properties

Vickers Hardness (HV): Figure 9 shows the results of Vicker hardness (HV) conducted on the metal matrix 7100 Al alloy and the composites containing different wt.% of

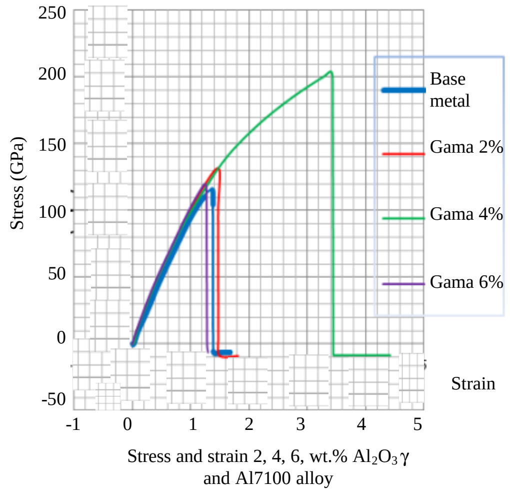

Fig. 2: Stress and strain 2, 4, 6, wt.% Al_2O_3 γ and Al 7100 alloy

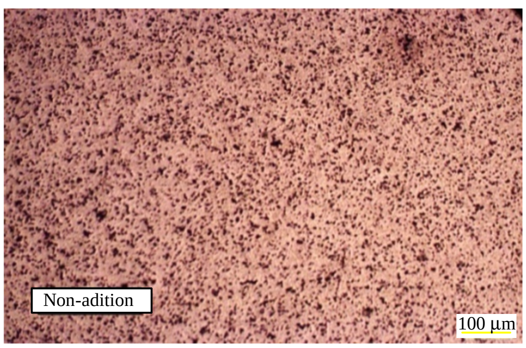

Fig. 3: Al 7100 base metal

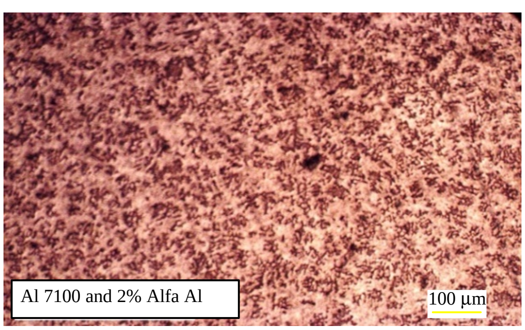

Fig. 4: Al 7100 and 2% Alfa Al_2O_3

α and γ Al_2O_3. A significant increase in HV can be observed with addition of $\alpha/Al_2O_3/4$ wt.% and γ/Al_2O_3 6 wt.% as shown Fig. 9.

Aluminum alloy is a soft material and the Al_2O_3 particles especially, ceramics reinforcement being hard as given in Table 3.

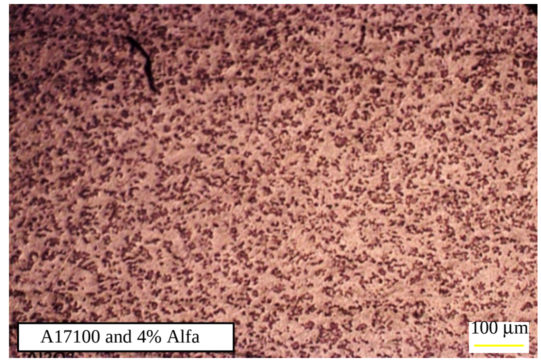

Fig. 5: Al 7100 and 2% Gama Al_2O_3

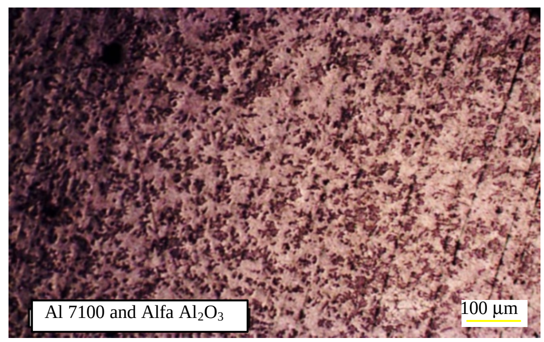

Fig. 6: Al 7100 and 4% Alfa Al_2O_3

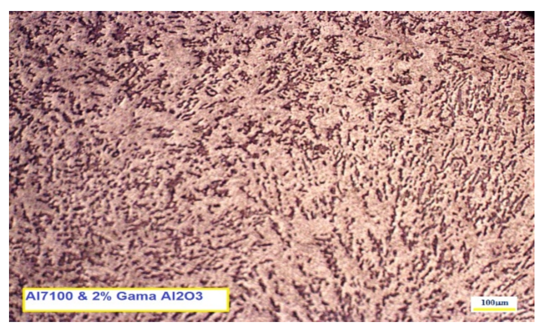

Fig. 7: Al 7100 and 4% Gama Al_2O_3

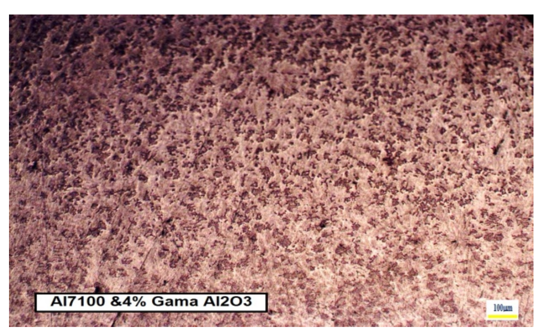

Fig. 8: Al 7100 and 6% Alfa Al_2O_3

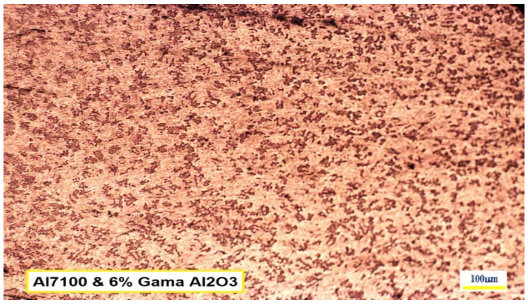

Fig. 9: Al 7100 and 6% Gama Al_2O_3

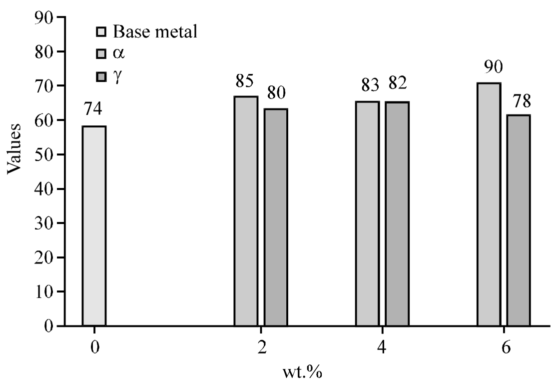

Fig. 10: Effect of α and γ Al_2O_3 on hardness Vickers

This property leads to increase the Vicker hardness from 76 for the metal matrix to 90.546 for α-Al_2O_3 at 4 wt.% Al_2O_3. The Improvement Percentage (IP) recorded to be 19%. While for γ-Al_2O_3 the (IP) calculated to be 7.89 % at 6 wt.% Al_2O_3. The presence of harder Al_2O_3 attributed to be relatively high hardness of composites. It is also clear that the HV of composites for both cases i-e α and γ Al_2O_3 was higher than the metal matrix.

Figure 10 illustrates comparison in HV values against increasing wt.% of Nano alumina content for both types of Al_2O_3. The value of HV increased with increase in α-Al_2O_3 particles from 2-4% and then decreased. The maximum HV is experimentally obtained including the 4 wt.% Al_2O_3 .

Khorshid *et al*. (2010) tested two aluminum matrix composites using two sizes of alumina particles (35 and 0.3 mm) and they found that increasing the nano particles content resulted in increase in hardness and strength of the nanocomposites first and then decrease when the amount of the nanoparticle exceeds 4.0 wt.%. This finding is agreed with the current finding obtained in this research (Khorshid *et al*., 2010).

Tensile strength (UTS), Yield Stress (YS) and Modules of Elasticity (ME): The effect of level of nanomaterial addition on the Ultimate Tensile Strength (UTS), Yield

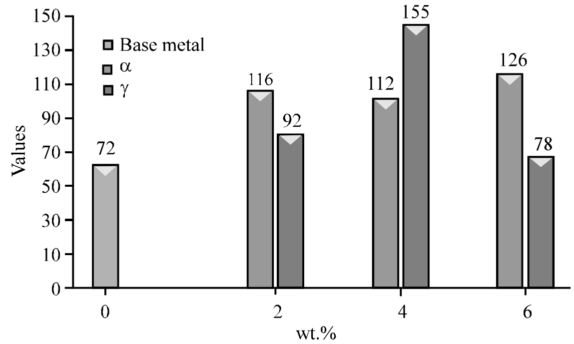

Fig. 11: Effect of α and γ|Al_2O_3 on σy

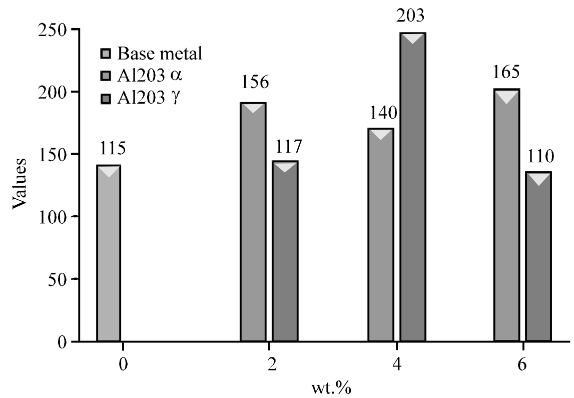

Fig. 12: Effect of α and γ|Al_2O_3 on σu

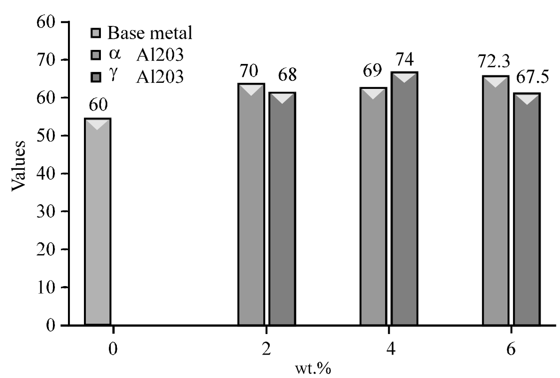

Fig. 13: Effect of α and γ|Al_2O_3 on young's modulus

Stress (YS) and Modules of Elasticity (ME) are summarized in Fig. 11-14). UTS of the alloy reached 164 MPa for α/Al_2O_3 at 6 wt.% Al_2O_3 and 203 MPa for γ/Al_2O_3 at 4 wt.% Al_2O_3.

The lower values of (UTS), (YS) and (ME) may be resulted from the clustering of Nano Al_2O_3 particles leading to non-uniform distribution of nanoparticles. It is believed that strong mechanical bounding made between

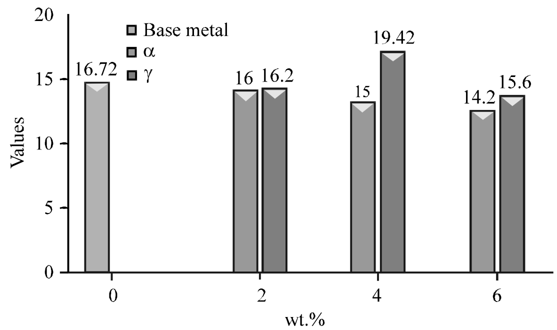

Fig. 14: Effect of α and γ|Al_2O_3 on elongation ratio

AA7100 and Al_2O_3 particles helps to disperse the nanoparticles more uniformly in the liquid during the fabrication of composite.

The variation in (UTS) and (YS) with weight percentage of Al_2O_3 are presented in Fig. 11-14. It's clear that the introducing alumina in to the 7100 alumina matrix resulted in increase in the above strengths. The higher hardness of the composites could be attributed to the fact that Al_2O_3 particles act as obstacles to the motion of dislocation. The hardness increment can also be attributed to reduced grain size resulted in increase the above mechanical properties (Al-Alalkawi *et al*., 2018).

In may also be noted that a significant amount of dislocation generated due to thermal mismatch stress or due to the plastic incompatibility. All the above reasons leads to increase the (UTS) (YS) and (ME) of the composites (Valibeygloo *et al*., 2013). The addition of Al_2O_3 caused a marginal increase in Elastic Modulus (ME) and significant increase in hardness, tensile and yield stress.

Ductility: Figure 14 illustrates the variation of ductility with the percentage amount of Al_2O_3 mechanical properties (UTS, YS, ME and ductility) were extracted from stress-strain. It is obvious that the composites of 4 wt.% Al_2O_3 type (α) and 6 wt.% Al_2O_3 type (γ) have lower ductility than that of unreinforced material. It is also clear from the tensile results that at 4 wt.% (α) type and 6 wt.% (γ) type the ductility reached lowest value compared to the base metal alloy thermal mismatch between metal matrix and Al_2O_3 is the major mechanism for increasing the dislocation density of the alloy and therefore increasing the mechanical properties, UTS, YS, ME and reducing the ductility.

CONCLUSION

Preparation of AA7100/Al_2O_3 for two types of alumina (α) and (γ) composites by stir casting method is attempted during this research.

Composites were fabricated by varying amount of Al_2O_3 (2, 4 and 6%). Better properties were obtained when the reinforced material percentage was 4% for (α) type and 6% for (γ) type.

SUGGESTIONS

It is suggested from microstructural study that the Al_2O_3 particles of both types are almost uniformly distributed in the matrix, although, some small cluster still exist in the matrix.

The hardness, UTS, YS, ME and ductility of composites improved and the maximum improvement was observed in composite including 4 wt.% Al_2O_3 for (α) type and 6 wt.% Al_2O_3 for (γ) type.

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