Research Article

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Nano reinforcement technique as a tool for enhancement the mechanical and fatigue properties

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Abstract: For the past three decades, AA7075 based metal matrix composite materials showed more attraction due to their enhanced mechanical and fatigue properties. The mechanical and fatigue behaviour of nano composites needs more investigation for their applications. In the present study, stir casting route based AA7075 reinforced with nano – sized, Al_2O_3 particles (average size 35 nm). The evaluation of mechanical and fatigue properties in the nano cast composites and matrix were carried out at room temperature (RT). The composites and base metal were subjected to high and low cycle fatigue. Scanning Electron Microscope was used to estimate fatigue behaviour of nano composites samples. The mechanical and fatigue properties was enhanced by the nano Al_2O_3, when compared to the matrix. The microsite evaluation showed uniform distribution of Al_2O_3 particles into the matrix and few porosity was recorded. The improvement of the properties above is attributed to the grain refinement and to the distribution of the Al_2O_3.

Keywords: Al_2O_3, fatigue properties AA7075, stir casting, mechanical and fatigue properties, nano composites, metal matrix composites

1 Introduction

Al-Salihi *et al.* [1] studied the characterization of AA6061/Al_2O_3 nanocomposite with different weight of Al_2O_3 nanoparticles (5, 10, and 15wt%) also with particle size of 40 nm were examined. The Al_2O_3 were refined and uniformly distributed in AA6061 matrix. The microstructure of AA6061/Al_2O_3 nanocomposite was studied by using SEM, and the mechanical properties of AA6061/Al_2O_3 nanocomposites were inspected. Hamzah *et al.* [2] studied the influence of the tensile properties for the rod metal of AA5182 by the speed of pull or strain rate. The investigation of the effect of speed of pull (0.5, 1.5, 2.5 and 3.5 mm/min) corresponding to strain rates (0.00833, 0.0249, 0.0333 and 0.0583) S^{-1} was done using uniaxial tensile tests. They showed that the increasing the speed of pull or strain rates were not significantly affected to ultimate tensile strength, modulus of elasticity, fatigue strength exponent, and modulus of rigidity. Qusay [3] tested AA7075/AL_2O_3 composites of 0.3, 0.5 and 0.7wt% of Al_2O_3 under tensile and fatigue tests using stir casting route. The experimental results revealed that the best enhancement was found in 0.3% Al_2O_3 composite. Al-Alkawi *et al.* [4] fabricated nano composite of 6wt% Al_2O_3 using AA7100 metal matrix by using stir casting process. This nano composite was tested under constant fatigue load amplitude. They found that the fatigue endurance limit at 107 cycles increase from 46 MPa to 50.8 MPa and the fatigue life improved about twice at the endurance limit stress level. Abdulridah *et al.* [5] investigated the mechanical and fatigue properties of nano composites AA2024/ Al_2O_3 fabricated by stir casting method with (0.3, 0.5, 0.7 and 0.9wt%) AL_2O_3 under cryogenic temperature (CT). It was recorded that the nano composite with 0.9% AL_2O_3 showed best improvement in the mechanical and fatigue properties. Suresh *et al.* [6] demanded new materials at national and international level. The metal matrix nano-composites was used in aerospace, automobile, armed forces, and in different commercial industry, due to its lightweight and cost-effectiveness. The various hybrid compositions, nano-Al_2O_3 (20–30 nm), nano-SiC (50 nm), and Mg 1wt%, were used as reinforcement materials. The mechanical behaviour increased by using the reinforcement of nanoparticles in AA7075 matrix when compared with the base metal. Pugalethi *et al.* [7] showed that aluminium-based metal matrix composites

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with aluminium matrix and non-metallic reinforcements was used in automotive, aerospace and defence fields due to their good mechanical properties and to the high ratio of strength to weight. Also composite materials was used in structural applications. The hybrid composite is obtained by using aluminium alloy, which is reinforced with 3, 5, 7, 9wt% of Al_2O_3 and 2wt% of SiC. The micro hardness and tensile strength of Al7075 alloy increase with the addition of SiC and Al_2O_3 reinforcements.

Baradeswaran and Elaya Perumal [8] studied the effect of graphite on the wear resistance of AA7075/Al_2O_3/5wt% graphite hybrid composite. AA7075 reinforced with Al_2O_3– graphite were investigated. The composites were fabricated using liquid metallurgy route. Increasing the weight percentage of ceramic phase improve the mechanical properties of AA7075/Al_2O_3–graphite hybrid composites such as hardness, tensile strength and flexural strength. Fathy *et al.* [9] studied the effect of iron addition on microstructure and mechanical properties of Al-matrix composite. They conclude that the Al_2O_3 Nano particles create strong bonds among particles which delay the crack initiation during deformation.

Tabandeh *et al.* [10] investigated the effect of nano and submicron-sized Al_2O_3 particulates developed by wet attrition milling and hot extrusion on the mechanical properties of tri-modal Al matrix composites. Their results showed that, increasing the nano content will increase the strength and hardness of the composites at first and then will decrease when the amount of nano reinforcement more than 4wt%. Kadhim [11] demonstrates that the nano composite containing 5wt% TiO_2 has higher tensile strength, yield stress, hardness and ductility for the AA5052/5wt% TiO_2 composite and the improvement percentages were recorded to be 18.03, 17.96, 11.76, and 111.66%, respectively.

Raju *et al.* [12] used Al_2O_3 as a reinforced material for AA2024 base metal with various amount of Al_2O_3. They found that the fatigue life of 1.5wt% Al_2O_3 composite has a superior improvement compared to the matrix life. Divagar *et al.* [13] Fabricated AA7075-T651/SiC hybrid nano composites with 5, 10, and 15wt% Al_2O_3 constant amount using stir casting method. The samples were tested under constant fatigue loading. They found that the composite including AA7075/T651 with 10wt% of SiC and 5wt% Al_2O_3 has high fatigue strength and life compared to base metal and other composites. Also they concluded that the minimal porosity and uniformly distributed of hybrid nanoparticles into the matrix are the main reasons for improving the mechanical and fatigue properties. Senthilkumar *et al.* [14] tested nano and micro composites of AA2014/Al_2O_3 with different weight percentage of Al_2O_3. They examined the samples by (SEM) and optical micrograph. Their observations of the microstructures indicated that the Al_2O_3 nano particles distributed in uniform manner in aluminum matrix.

The aim of this research is to get a matrix composite of 0-9wt% Al_2O_3 AA7075 by stir casting route. Also, the main objective is to investigate the influence of Al_2O_3 content on mechanical, fatigue and microstructure properties of AA7075 matrix composites.

In this research, the chemical composition of the samples that will be used in the tensile and fatigue tests was examined. The tensile and fatigue samples were prepared according to the internationally approved standard dimensions. The mechanical properties, hardness and ductility of the samples were calculated from the tensile test. The endurance limits and fatigue life of the samples were also obtained from the fatigue tests. Moreover, scanning electron microscope device was used to obtain the microstructure of AA7075 with (0, 3, 6, and 9wt%) of Al_2O_3.

2 Experiments

Practical experiments include the preparation of samples for tensile testing and fatigue testing. It also includes knowledge of the chemical composition of the AA7075 base metal. The SEM device was also used to study the microstructure of Al_2O_3 with different grades of aluminium alloys.

2.1 Chemical composition

The chemical composition of AA7075 Base metal in this work is examined at state company for inspection and engineering rehabilitation in Iraq (SIER). The weight percentage is 5.5Zn, 0.23Fe, 0.17SI, 0.21Mn, 1.52Cu, 0.22Cr, 2.7Mg, 0.13Ti and Balanced Aluminium. AA7075 reinforced with nano Al_2O_3 particles of 35nm size. The wt% of 3, 6 and 9 are taken to produce composite specimens by using mechanical stir casting process. AA7075 was melted at a temperature of 800°C which is higher than the melting temperature of aluminium alloy. Flux agent was used to remove the impurities and degassing with dry nitrogen gas. Then, stirring the aluminium alloy melt for 10 minutes and adding the pre – heated Al_2O_3 nano particles with various weight percentage to the melt of base metal. After the addition of nano particles Al_2O_3 to the AA7075, the melting mixture was powered into the die. The die was made from mild steel in the shape of cylindrical rods (14 mm diameter and 180 mm length).

2.2 Nano reinforcement material

The Al_2O_3 was used with different grades of aluminium alloys. It was a available with low cost. Also Al_2O_3 has high mechanical, wear and hardness properties. The present work used α-Alumina (average 35 nm) size of particles; the chemical composition is illustrated in Table 1.

Table 1: Chemical composition of AL_2O_3 nano material [15]

Element	CaO	Fe_2O_3	TiO_3	α-aluminum	Other
Wt%	1.1	0.8	1.8	93	0.02

The final samples of 14 mm diameter and 180 mm length is shown in Figure 1.

Figure 1: Nano composite samples after manufacturing

2.3 Tensile specimen

The tensile specimens were fabricated using (ASTM 370) Standard specification which is shown in Figure 2:

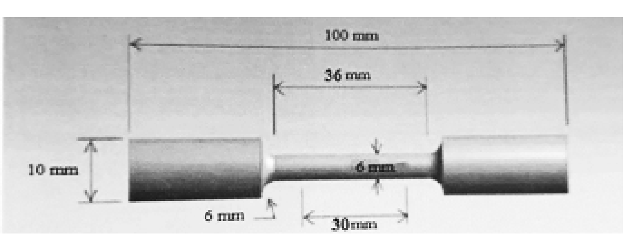


Figure 2: Computerized tensile specimen according to ASTM 370

2.4 Fatigue specimen

The fatigue specimen used in the test is shown in Figure 3. The dimensions of the specimen was chosen according to standard ASTM (E8/E8M-09).

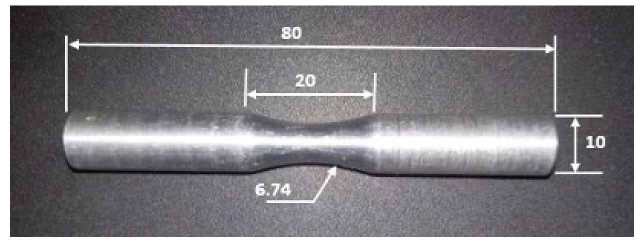


Figure 3: Fatigue specimen (all dimensions in mm)

2.5 Fatigue testing

Fatigue test for cantilever beam with rotating bending was carried out with constant and a variable load. The bending stress can be calculated by using the equation:

$$\sigma_b = \frac{32P(125.7)}{\pi d^3} \tag{1}$$

Where:
σ_b – bending stress measured in (MPa);
P – applied load measured in (N)
d – diameter of fatigue specimen (6.74 mm)

The arm of the force (P) is equal to 125.7 mm and the r.p.m. is 1420. The fatigue testing machine is shown in Figure 4.

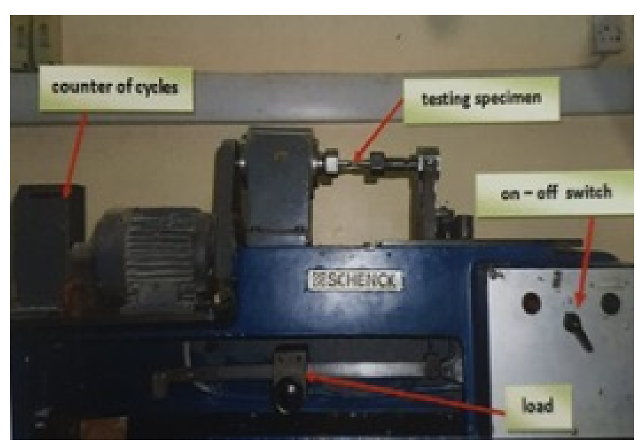


Figure 4: Fatigue testing machine

3 Results and discussion

The results of the tensile and fatigue tests of the nano alumina (Al_2O_3) with different grades of aluminium alloy will be presented and discussed. The effect of Al_2O_3 content on the mechanical properties and on the microstructure will also be discussed.

3.1 Tensile results

Tensile test results of 3, 6, and 9wt% of nano alumina (Al_2O_3) (average size 35 mm) fabricated by stir casting routs with the initial results of AA7075 (matrix) are illustrated in Table 2.

Table 2: Mechanical properties of AA7075 (as received)

Properties	UTS (MPa) [16]	YS (MPa) [16]	BHN [17]	Ductility [17]
Standard	228	103	60	17
Experimental	231	105	61	17

The tensile results of composites can be listed in Table 3 and Figure 5.

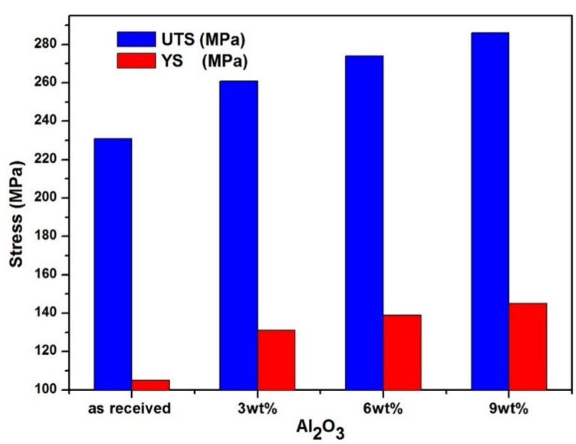


Figure 5: The variation of UTS and YS with Al_2O_3 wt% in comparison with the experimental

3.2 Effect of Al_2O_3 content on mechanical strength

To estimate the strength of the composites, tensile test was performed at room temperature. The tensile strength (UTS and YS) was significantly increased compared to the AA707S matrix, due to Al_2O_3 particles which improve the mechanical strength of AA7075 matrix. In particular 9 wt% Al_2O_3 composite exhibits UTS and YS of 286 and 186 MPa respectively. The tensile strength was increased with the increasing Al_2O_3 content from 0 up to 9% Al_2O_3. Al_2O_3 nano particles create strong bonds among particles which delay the crack initiation during deformation [9]. It can be denoted that increasing in Al_2O_3 from 0 to 9% the strength increase from 231 to 286 MPa for (UTS) and 105 to 145MPa for YS, resulting in 19.2% and 27.58% improvement percentage in (UTS) and (YS) respectively.

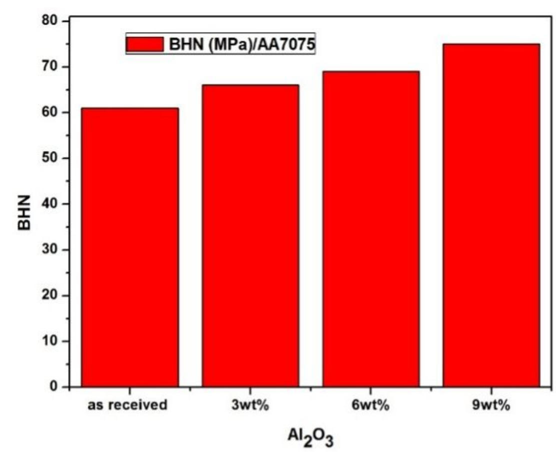


Figure 6: The variation of BHN with Al_2O_3 wt% in comparison with the experimental

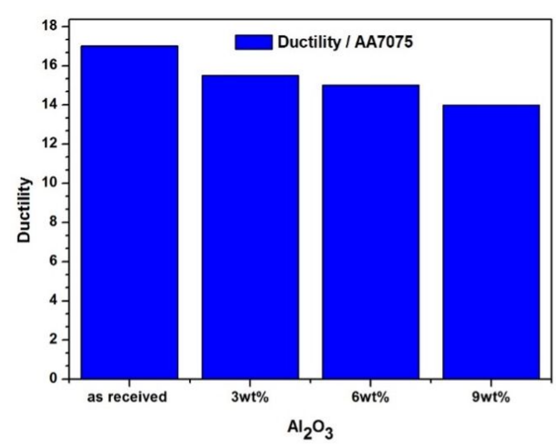


Figure 7: The variation of ductility with Al_2O_3 wt% in comparison with the experimental

Table 3: Mechanical properties of AA7075 (composite) with weight percentage of Al_2O_3

UTS(MPa)			YS(MPa)			BHN			Ductility		
3wt%	6wt%	9wt%	3wt%	6wt%	9wt%	3wt%	6wt%	9wt%	3wt%	6wt%	9wt%
261	274	286	131	139	145	66	69	75	15.5	15	14

3.3 Effect of Al_2O_3 content on BHN hardness and ductility

Table 3 and Figures 6 and 7 showed that the increasing the wt% of Al_2O_3 from 0 to 9; the BHN increases from 61 to 75. This is due to the effect of Al_2O_3 nanoparticles which prevent the dislocation movement in the matrix.

3.4 Fatigue results

The S-N Curve rotating bending fatigue test results are carried out to obtain the curves life of the matrix and the three nano composites. The fatigue results are shown in Table 4.

The S-N curves and its equations can be obtained to describe the fatigue behavior at constant applied load as shown in Figure 8.

It is observed from Table 4 and Figure 8, the fatigue life increases significantly with increasing the amount of reinforcements for AA7075/Al_2O_3 nanocomposite. The highest stress at which a nano failure is obtained is taken as the endurance fatigue limit where the life is about 10^7 cycles. The endurance fatigue limits with the S-N curve equations can be tabulated in Table 5.

From the table above, the maximum endurance limit with 9 wt% nano Al_2O_3 is 0.982 MPa compared with 0.965 MPa at zero nano. The improvement factor is 0.17% due to nano reinforcement.

Table 4: S-N curve life for base metal and nano composites

Spec. No.	Applied stress MPa	N_f Cycles (fatigue life at failure)	N_f Average
		Base metals AA7075 (as received)	
1, 2, 3	130	6000, 11000, 4600	7200
4, 5, 6	110	58000, 72600, 64800	65133
7, 8, 9	75	1068000, 1146600, 998620	1071073
		AA7075/3wt. Al_2O_3	
10, 11, 12	130	11006, 14600, 9800	11802
13, 14, 15	110	74800, 82000, 70860	75886
16, 17, 18	75	1159600, 1096800, 1264000	1173466
		AA7075/6wt. Al_2O_3	
19, 20, 21	130	21600, 26800, 19600	22666
22, 23, 24	110	101600, 118000, 109700	109766
25, 26, 27	75	1380000, 1468000, 1180000	1342666
		AA7075/9wt. Al_2O_3	
28, 29, 30	130	2360, 25800, 21900	16686
31, 32, 33	110	118600, 125600, 112800	119000
34, 35, 36	75	1488000, 1396800, 1259600	1381466

Table 5: The endurance limits with (life) equations

wt% Al_2O_3	Composite	Life equation	R^2	Endurance limit (MPa)
0	AA7075/0wt% Al_2O_3	$\sigma_f = 359N_f^{-0.111}$	0.965	60
3	AA7075/3wt% Al_2O_3	$\sigma_f = 424N_f^{-0.121}$	0.972	60.3
6	AA7075/6wt% Al_2O_3	$\sigma_f = 810N_f^{-0.16}$	0.968	61.4
9	AA7075/9wt% Al_2O_3	$\sigma_f = 560N_f^{-0.136}$	0.982	62.5

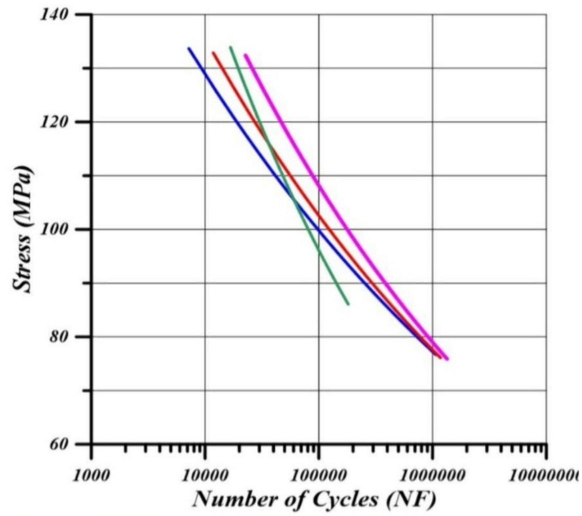
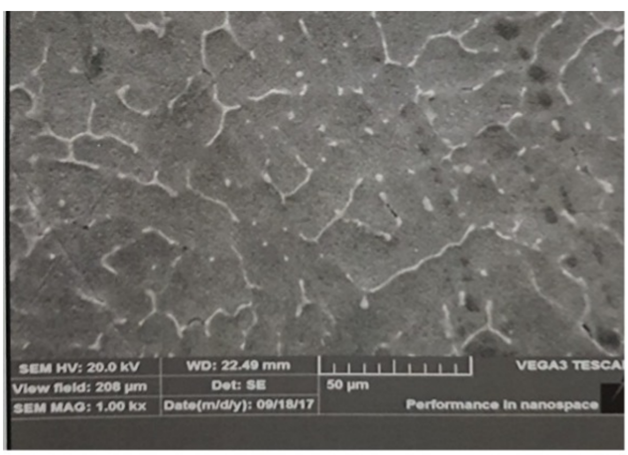
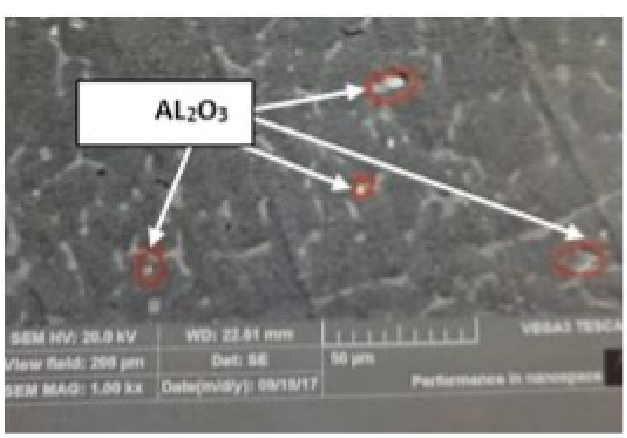


Figure 8: S-N curves for AA7075 with Al_2O_3 wt% in comparison with the experimental



(a)



(b)

Figure 9: Matrix and composites microstructure (a) zero nano-Al_2O_3 (b) 9 wt% nano-Al_2O_3

The reasons of the above improvement were due to the uniform distribution of Al_2O_3 into the matrix and due to good bounding between the particles of Al_2O_3 with the metal base.

3.5 Microstructure of AA7075 with different wt% Al_2O_3

Scanning electron microscope (SEM) examination of four samples to understand the behaviour of the microstructure AA7075/0%, AA7075/3 wt% Al_2O_3, AA7075/6 wt% Al_2O_3 and AA7075/9 wt% Al_2O_3. From the above Figures 9(a) and 9(b) it was observed that the uniformly distributed of Al_2O_3 particles and good interface between the Al_2O_3 hard particles and AA7075. The matrix can be attributed to improve the mechanical and fatigue behaviour of the base metal. It can be observed that the white spots are the Al_2O_3 particles in the AA7075 matrix phase.

4 Conclusions

The present study reported that the stir casting route is effective for enhancement in mechanical strength UTS, YS, BHN and ductility of AA7075 matrix nano Al_2O_3 reinforced composites. UTS, YS and BHN are higher in composites state compared to as – received properties. 9 wt% of nano Al_2O_3 reinforcement showed the best mechanical properties results among all the other composites and the matrix.

It was found that the fatigue strength and the fatigue life was improved when increase Al_2O_3 wt% and the maximum valves occurred with 9 wt% Al_2O_3 composite. The fatigue strength factor is recorded to be 4.0%MPa for the above composite. The microstructures observations using SEM showed that the Al_2O_3 nanoparticles distribution in AA7075 base metal is more uniformly and few agglomeration of particles results in porosity due to the coarser particles.

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