CUMULATIVE FATIGUE DAMAGE OF 7075 ALUMINUM ALLOY REINFORCED WITH ALUMINA AL_2O_3

Qusay Khalid Mohammed
qusaykhalid60@gmail.com
Electromechanical Engineering Department, University of Technology, Baghdad, Iraq

ABSTRACT

The reinforcement of Aluminum alloys opens a wide range of industrial application for these alloys in areas where reduction of weight has first priority, in General this operation known as metal matrix composite (MMC). In this study the nanocomposite material were fabricated using stirring time for 6 minutes at 450 rpm stirring speed .Al-7075 alloy was the base metal and the reinforcement nanocomposite material was the Alumina Al_2O_3 of 10 nanometer in grain size , which is used as weight percentage (wt%) for 0.3,0.5,0.7 wt% Al_2O_3. The results show that the best enhancement in fatigue life and strength were occurred at 0.3 wt% of Al_2O_3.

KEYWORDS : Cumulative Fatigue, Al-7075, Alumina Al_2O_3, Composite Materials, S-N curves.

تلف الكلال التراكمي لسبيكة الالمونيوم 7075المقوى بالالوميناAL_2O_3

قصي خالد محمد.
قسم الهندسة الكهروميكانيكية – الجامعة التكنولوجية

الخلاصة

فتحت عملية تقوية سبائك الالمنيوم المجال واسعا للكثير من التطبيقات في المجالات الصناعية والتي من اولوياتها ان يكون وزن المعدن او السبيكة خفيفا ، بصورة عامة فان هذه العملية تعرف Metal Matrix Composite (MMC) . تم في هذا البحث تصنيع المادة النانوية باستخدام طريقة المزج بالتحريك بسرعة 450 دورة / دقيقة وبزمن مقداره 6 دقائق . سبيكة الالمنيوم Al-7075 كانت هي المعدن الاساس اما المادة المساعدة فكانت الالومينا AL_2O_3 بحجم حبيبي مقداره 10 نانوميتر ، اما نسب الخلط فكانت 0.7,0.5,0.3 % من الوزن. اثبت النتائج ان افضل نسبة من حيث عمر ومقاومة الكلال كانت عند نسبة 0.3% .

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INTRODUCTION

Composite materials is a mixture of two or more distinct materials, the presence of interface can be identified between them. The Composites are used not only structural characteristics, but also for electrical applications, thermal, environmental and tribological, M.Dinesh[2016]. Composite materials are generally used for buildings, bridges and structures such as boat hulls, swimming pool panels, racecar bodies, shower stalls, bathtubs, storage tanks, imitation granite and marble sinks and counter tops, V.Balaji [2015]. According to the chemical nature of the matrix phase, composites are classified as metal matrix composite (MMC), polymer matrix composite (PMC), ceramic matrix composite (CMC), Himanshu [2014]. Aluminum is widely preferred as metal in these areas because of its light weight. In recent decades (AMC) have been used to produce high performance products in aerospace, architectural, marine and mineral processing industries. Aluminum is highly resistant to most chemical agents and atmosphere because of the it's oxide film which provides higher inert and protective characteristics to the metal surface ,Vignesh. [2014]. The uniform distributions of reinforced particles in the matrix are very important for better properties such as high stiffness with superior strength.

A variety of processing techniques have evolved over the last two decades in an effort to optimize the structures and properties of MMC's. Accordingly, these can be classified into liquid state fabrication of metal matrix composites, solid-state fabrication of metal matrix composites, fabrication of metal matrix composites by co-deposition, Tony Thomas [2014]. There are various techniques involved for manufacturing of AMC's such as stir casting, powder metallurgy, squeeze casting, spray casting etc. Among the available manufacturing techniques for AMC's stir casting techniques is preferred because of its simplicity, can be used for large production economical, etc.

The reinforcement of metals can have many different objectives. The reinforcement of light metals opens up the possibility of application of these materials in areas where weight reduction has first priority. The precondition here is the improvement of the component properties. The development objectives for light metal composite materials are:

- Increase in (σ_y) yield strength and (σ_t) tensile strength at and above room temperature.
- Increase in creep resistance at higher temperatures compared to that of conventional alloys.
- Increase in fatigue strength, especially at higher temperatures.
- Improvement in resistance of thermal shock.
- Improvement in resistance of corrosion.

Fig. (1) shows the types of composite materials, Karl Ulrich [2010]. It was there considerable a great deal of studies researchers have conducted a mechanical determination and fatigue properties of (AMC), Veeresh Kumar [2010].Studies have also been conducted in determining parameters affecting surface finish during machining of Al MMC's, Radhakrishnan [2011]. M. J. Hadianfard et al. (2006) evaluated the low cycle fatigue (LCF) resistance of two different 6061 Al/20 vol% alumina particulate metal matrix composites (MMCs) in a peaked-aged condition underfully reversed strain control testing. Test results were combined with scanning electron and optical microscopy investigations to determine the effects of reinforcement particles and strain amplitude on the LCF behaviour of these MMCs, M. J. HADIANFARD [2006]. Sajjadi etal. (2011) studied the mechanical properties of the stir cast Al (A356)/ Al_2O_3 composite. The author has revealed that the hardness and compressive strength of the composite increased with increasing the weight percentage of Al_2O_3 and by decreasing the particle size S.A., Sajjadi [2011].

Mazaheri et al (2013) conducted comparison of the mechanical qualities of Al-TiC,Al-B_4C hybrid. The author revealed Al/TiC/ B_4C composite possesses higher rigidity, higher resistance to yield and showed tensile strength by Al- B_4C composite, Al-TiC showed maximum elongation, Y. Mazaheri [2013].B. M. Faisal et al (2016) estimated the mechanical properties of aluminum alloys and composite material under tensile load to find static properties and fatigue test to find dynamic properties. The fatigue test achieved by using reversed bending test machine under constant stress amplitude and stress ratio of (R = - 1). It was found that there is a reduction ratio in fatigue limits of Glass polyester composite as compared it with that of aluminum alloy. This reduction ratio is about of (1.35-1.54), B. M. Faisal [2016]. W. ASGHAR et al (2016) investigated the tensile strength, fatigue life and fracture toughness values of 2/1 configuration carbon reinforced aluminum laminate (CARALL), aramid reinforced aluminum laminate and glass laminate aluminum reinforced epoxy specimens. It was observed that CARALL shows very superior tensile and fatigue strength because of stress distribution during failure. W. Asghar,[2016].

Alalkawi et al (2017) expalnied the great improvement in fatigue strength and life could be to the good distribution of nano Al_2O_3 particles and low degree of porosity, Alalkawi H.J.M., Sheren F.A. [2017]. Alalkawi et al (2017) carried out the manufacturing of nano composites reinforced 2024 Al Alloy matrix via stir casting method. The purpose were to examine the influence of nanomaterial Al_2O_3 wt% reinforcement on the mechanical properties of composites, Alalkawi H.J.M., Ibithal A [2017]. Alalkawi H.J (2017) explained the behaviour of Aluminum alloy 2024 /Al_2O_3 nonocomposite which was fabricated by stir casting at 450 r.p.m and casting temerature of 850^o . The expermintal results analysis revealed that the fatigue strength of nanocomposite are improved by 0.53% and the fatigue transition life increased by 16.02% compared to the metal matrix, Alalkawi H.J.M., Ibithal A [2017]. The present work aims to study the mechanical and cumulative fatigue properties of metal matrix composites reinforced by different amount of Al_2O_3 compared to the base metal.

EXPERIMENTAL DETAILS

Material Selection

Aluminum alloys are composition of various materials like zinc, magnesium, copper, titanium, etc. Al 7075 means zinc as primary elements and having excellent properties like good fatigue strength, average machinability and strong with strength (having tensile strength 270-280 MPa) comparable to many steels. The chemical compositions details and mechanical properties of aluminum matrix alloys have been shown in table: 1&2.

Reinforcement Material

The reinforcement material selected is alumina (Al_2O_3). It is more stable with aluminum and withstands high temperature. It is an oxide ceramic having low affinity for the oxygen to form oxides. The particulate form of the reinforcement has better distribution in the matrix to provide isotropic property for the composite. The chemical compositions details and mechanical properties of alumina is as shown in Tables (3) and (4), M.Dinesh [2016].

Fabrication of composite

Stir Casting

Stir casting method is one of the outstanding and economical route for improvement and processing of metal matrix composites materials. M.Dinesh [2016]. Stir casting process has been in use for several years for preparing asymmetrical particle of strengthened metal matrix composites. S. Nallusamy [2016]. Various process parameters of stir casting should be properly controlled to obtain good metallurgical properties of AMMC's:
1. Stirrer design.
2. Stirrer speed.
3. Stirring temperature.
4. Stirring time (Holding time).
5. Preheat temperature of reinforcement.

The stirring action should be slow to prevent the formation of vortex at the surface of the melt, and care must be taken not to break the surface too often, Khalid Almadhoni [2015]. Stir casting is the simplest and the most effective method of liquid state method, Tony Thomas [2014]. Fig. (2) shows the stir casting process. The Al-7075 composite reinforced through 0.3, 0.5 and 0.7 wt. % of alumina Al_2O_3.Table (4) shows the material composition in percentage of weight

Preparation of Composites

All the specimens (tensile and fatigue specimens) are fabricated using stir casting technique. Aluminum alloy 7075 is machined to be [2-3] cm3 in size. Washing these parts by alcohol and distilled water several times. Dry the parts and heated then to 200C^o using electrical heater. Putting these parts into the oven lid and close the lid tightly. Alarcon gas is pumped into the oven and heat the oven to 800C^o. Preheat the nanoparticles to 200C^o and add them to the molten with gas pump. Design the stirring time for 6 minutes at 450 rpm stirring speed. After completion of stirring and mixing, the molten is poured in preheated steel molds at 800C^o. The final product is 160 mm in length and 12 mm in diameter.

Tensile test

Tensile tests of composites were evaluated using TINLUS OLSEN K-1000 tensile testing machine according to E8/E8M-09, ASTM, 2017standards at maximum capacity of 1000 KN, the test was conducted in Department of Mechanical and Aerospace Engineering at New Mexico State University. The shape and dimensions of tensile testing specimen is shown in Fig. (3) and Table (6).

Fatigue Test

In this work the fatigue test done by using UBM machine type 116 four point rotating bending test with stress ratio (R=-1) at room temperature (24 ^{o}C) with (60 Hz) frequency and relative humidity (40%). The fatigue specimen is shown in Fig. (4). The shape and the dimensions are taken according to ISO 1143, ISO , The Standard [2010].

EXPERIMENTAL RESULTS

Mechanical Properties

Experimental results of mechanical properties represented in table (7) with respect to different compositions, Brinell hardness number (BHN), ultimate tensile strength (MPa), yield strength (MPa), and ductility. Fig. (5) (a to d)) shows the variation of mechanical properties according to different Alumina (Al_2O_3) percentage of weight. The maximum value of these properties was found at 0.3 wt.% of Al_2O_3while ductility found decrease at the same wt. % of Al_2O_3.

Fatigue Test

In order to get the influence of the reinforcement material content on the fatigue life (S-N) curve, several fatigue tests were carried out at a stress ratio R= -1 using a servo-hydraulic universal testing machine Instron 8874. All tests were performed at room temperature, in laboratory environment. Tests were performed till final fracture.

S-N Curves Results

The experimental results of S-N curves for the metal matrix and composite of different Nano reinforcement material can be seen in Table (8). Fig. (6) shows the S-N curves for Al-7075 alloy and the Nano composites of stress vs. number of cycles to failure. It should be noted that the stress is the stress till failure (S_f). All the S-N curves are similar in shape and have scatter stress region. 48 specimens were tested to get the S-N curves, 12 specimens without reinforced material for as cast Al-7075. Alloy each 12 specimens for 0.3, 0.5 and 0.7 wt. % of Al_2O_3 . The S-N curves equations for the above materials are shown in table (9). The S-N curves equations were calculated according to Basquin equation of the form ($S_f = A\ N_f^b$) where A and b are material constant. The equations listed in table (9) were obtained by curve fitting the experimental data of fatigue tests. Also, the material constant A, b with correlation coefficient (R^2) are given in the same table. It is noted that the S-N curve equation have good (R^2) which proved that the experimental data are well described by Basquin formula. For example, the fatigue strength or fatigue endurance limit (S_{EL}) for Al-7075 is 162.7 MPa and 150.53 MPa for 10^7 and $5*10^8$ cycles respectively, while the Nanocompsite are improved by 5.7% to 3.9% i-e the maximum improvement in (S_{EL}) is occurred at 0.3 wt. % Al_2O_3 , i-e the (SEL) enhanced from 162.7 MPa to 172.1 MPa. The enhancement of (S_{EL}) is illustrated in Fig. (7) and (8). The uniform distribution of Al_2O_3 particles and the presence of minimal porosity in the composite indicated to increasing the fatigue strength and life. All the fatigue properties, strength and life improved with increase in wt. % of nanoparticles. The maximum fatigue properties were occurred in nanocomposite including 0.3 wt. % Al_2O_3 using stir casting for manufacturing the composites. The addition of nanoparticles results in significant improvement in fatigue strength.

Microstructure Analysis

Examination of the microstructure by SEM can be used to understand the microscopic structure of the composites allowing improvements to performance of the composites or rejection. The first step is carefully selecting a small sample of the material to undergo microstructure analysis. This step is followed by sectioning, mounting, grinding, polishing and etching to reveal accurate microstructure. Fig. (9) shows the microstructure of the metal base 7075 Al alloy and 3% wt. Al_2O_3 the best improvement case. It is revelated that the distribution of Al_2O_3 has uniformly and less level of porosity. The improvement in mechanical and fatigue properties may be coming from the above uniform distribution and the Al_2O_3 itself has high mechanical properties. Fig. (10) shows the specimens materials. Fig.(11) shows the specimen after manufacturing while Fig.(12) shows the specimen before and after fraction.

CONCLUSIONS

1- All fatigue strength and life were enhanced due to adding the nanomaterial.
2- The fatigue strength is improved by 5.7 % for 0.3 wt.% nanocomposite as maximum value while the least value is 4.3% for 0.7 wt.%.
3- The fatigue limit life is enhanced due to adding the Al_2O_3 for all the wt. % of reinforcement material. However, the maximum improvement is occurred at 0.3 wt. %Al_2O_3 and the least value was happen with 0.7 wt. % Al_2O_3.

Table (1) Chemical composition of aluminum alloy (Al 7075), Kalyan Kumar Singh [2016].

Materials (%by weight)	Si	Fe	Cu	Cr	Zn	Ti	Mn	Mg	Al	others
Standard	Max 0.35	0.55	1.1-2.1	0.2-0.26	5.0-6.2	0.3	0.4	1.9-2.9	86-92.5	0.15
Measured	0.29	0.51	1.61	0.22	5.35	0.28	0.28	2.1	balanced	-

Table (2) mechanical properties of aluminum alloy (Al 7075), MatWeb.com [2017].

Mechanical Properties	standard	measured
Hardness, Brinell (HB)	60 Kg/mm^2	59 Kg/mm^2
Ultimate tensile stress (σ_u)	228-276 MPa	235 MPa
Yield tensile stress (σ_y)	103-145 MPa	131 MPa
Elongation at beak	10-17%	15%
Young's Modulus (E)	71.7 GPa	72 GPa
Poisson Ratio (ν)	0.33	0.3
Machinability	70%	-
Rigidity modulus (G)	26.9 GPa	28 GPa
Shear stress	152 MPa	145 MPa

Table (3) Chemical composition of alumina Al_2O_3 , Vignesh. V. Shanbhaga [2014].

Chemical composition	SiO_2	Fe_2O_3	TiO_2	Na_2O	Al_2O_3
Wt %	0.15	0.05	0.15	0.45	Rem

Table (4) Mechanical properties of alumina (Al_2O_3), MatWeb.com [2017].

Mechanical Properties	Value
Hardness, Vickers	1365
Ultimate Tensile strength	300 MPa
Modulus of Elasticity	370 GPa
Poisson's Ratio	0.22
Shear Modulus	150 GPa
Flexural Strength	400 MPa

Table (5) Material composition in percentage

Specimen No.	Al-7075 wt %	Al_2O_3 wt %
1	0.97	0.3
2	0.95	0.5
3	0.93	0.7

Table (6) Experimental results of mechanical properties

Mechanical Properties	Zero % wt of Al_2O_3	0.3 % wt of Al_2O_3	0.5 % wt of Al_2O_3	0.7 % wt of Al_2O_3
BHN	58	76	74	72
UTS (MPa)	233	250	241	238
Yield strength (MPa)	120	134	128	126
Ductility	17	13	15	15.5

Table (7) Experimental results

Specimen No.	Applied Stress (MPa)	Number of cycles to failure N_f (cycles)	Average No. of cycles (3 specimens)
7075 Aluminum Alloy			
1,2,3	190	4820,3600,4026	4148
4,5,6	180	62600,55800,49600	56000
7,8,9	170	910600,850600,1026568	929256
10,11,12	160	17680000,22860000,19686680	20075560
7075 Aluminum Alloy +0.3% wt Al_2O_3			
13,14,15	190	22600,28800,26600	26000
16,17,18	180	88600,90150,102680	93810
19,20,21	170	1056680,1068660,9206860	3777400
22,23,24	160	21680000,24868660,26124656	24224438
7075 Aluminum Alloy +0.5% wt Al_2O_3			
25,26,27	190	42600,37886,45667	42051
28,29,30	180	105600,118886,109608	111364
31,32,33	170	1826861,1686725,2016568	1843384
34,35,36	160	30686867,28686760,31868723	30414116
7075 Aluminum Alloy +0.7% wt Al_2O_3			
37,38,39	190	11600,9860,10700	10720
40,41,42	180	90668,78600,82000	83756
43,44,45	170	1268660,1468872,916886	1218139
46,47,48	160	16860720,14860750,21606089	17775853

Table (8) Fatigue parameters for various wt. % Al_2O_3 nanoparticles

Specimen No.	Wt% of Al_2O_3	A	b	Equation $S_f = AN_f^b$	Stress at 10^7 and $5*10^8$	Changed in Se	(R^2)
1 →12	As cast	224.7	-0.02	$S_f = 224.7 \times N_f^{-0.02}$	162.7	--------	0.99
					150.53	--------	
13→24	0.3	237.6	-0.02	$S_f = 237.6 \times N_f^{-0.022}$	172.1	5.7 %	0.96
					159.1	5.69 %	
25→36	0.5	243.1	-0.02	$S_f = 243.1 \times N_f^{-0.02}$	170.5	4.79 %	0.97
					156.4	3.9 %	
37→48	0.7	234.3	-0.02	$S_f = 234.3 \times N_f^{-0.021}$	169.7	4.3 %	0.99
					157	4.3 %	

Table (9) Predication life ratio on fatigue limit and improvement in life

Specimen No.	7075/ Al_2O_3	(Se) at 10^7 cycles			(Se) at 5×10^8 cycles		
		No. of cycles	Nf_c / Nf_n	[(Nf_n- Nf_c) / Nf_c]%	No. of cycles	Nf_c / Nf_n	[(Nf_n- Nf_c) / Nf_c] %
1→ 12	0.0 wt. %	10^7	---	---	5×10^8	---	---
13→24	0.3 wt.%	29881596	0.33	198.8 %	1023654487	0.48	104.7%
25→36	0.5 wt.%	18473899	0.54	84 %	938632461	0.53	87.7%
37→48	0.7 wt.%	83030333	0.12	7.3 %	4050058984	0.12	7.1 %

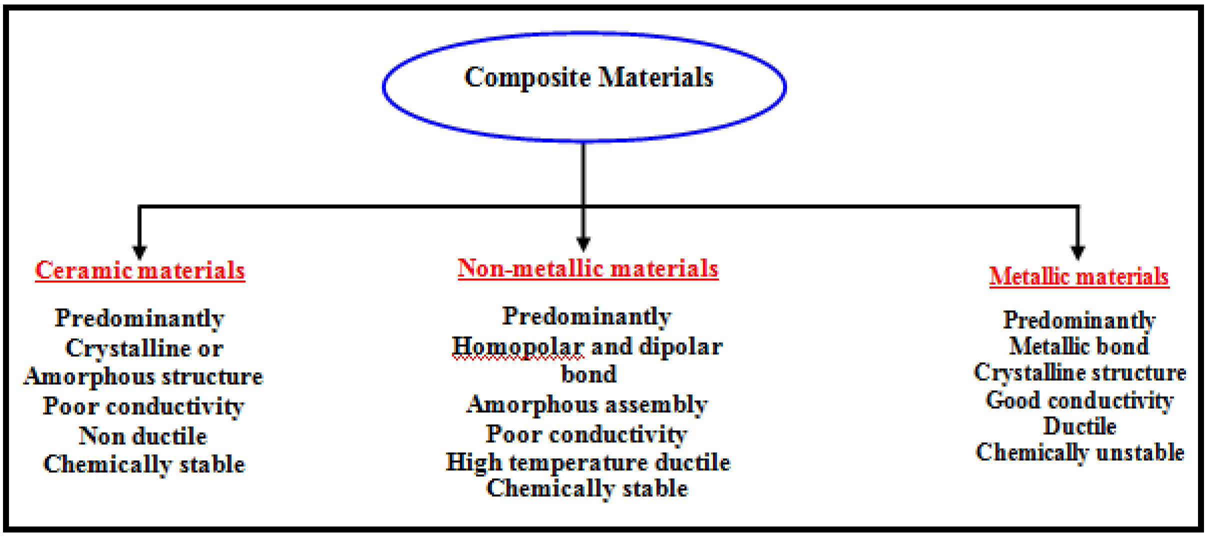

Fig. (1) Types of the composite materials

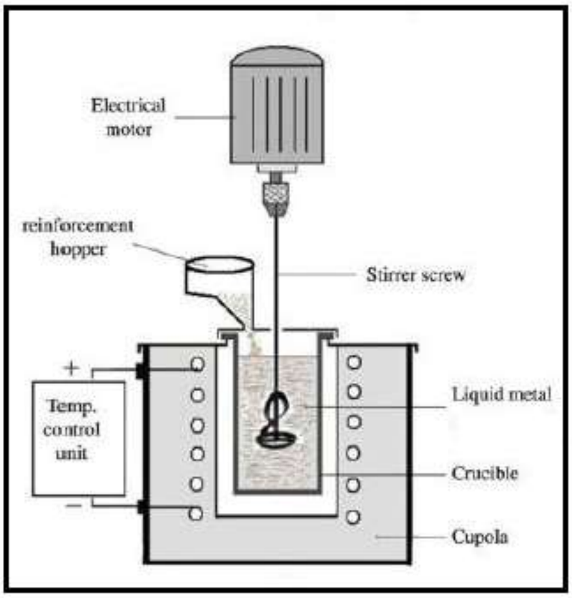

Fig. (2) Stir casting process, A. Chennakesava Reddy [2006]

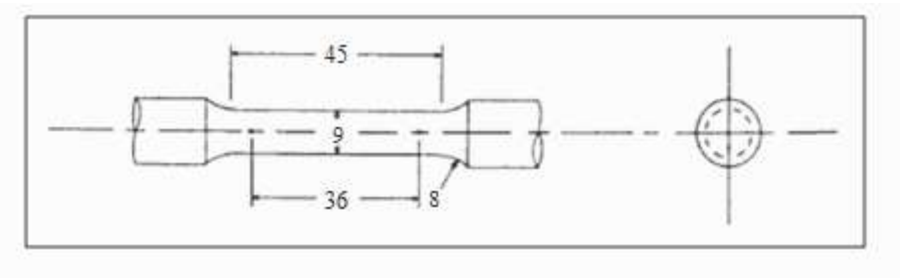

Fig. (3) Tensile specimen with dimensions in (mm), E8/E8M-09, ASTM [2010]

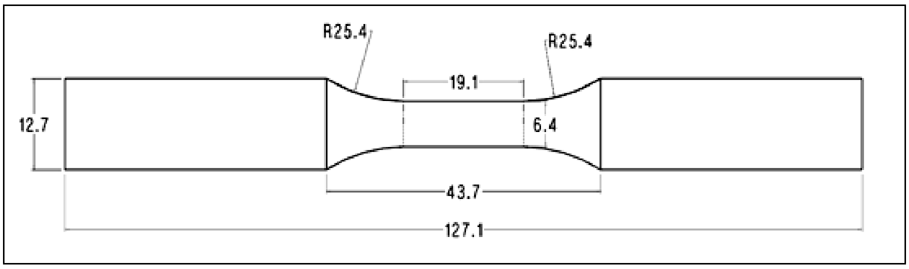

Fig. (4) Fatigue specimen (all dimensions in (mm))

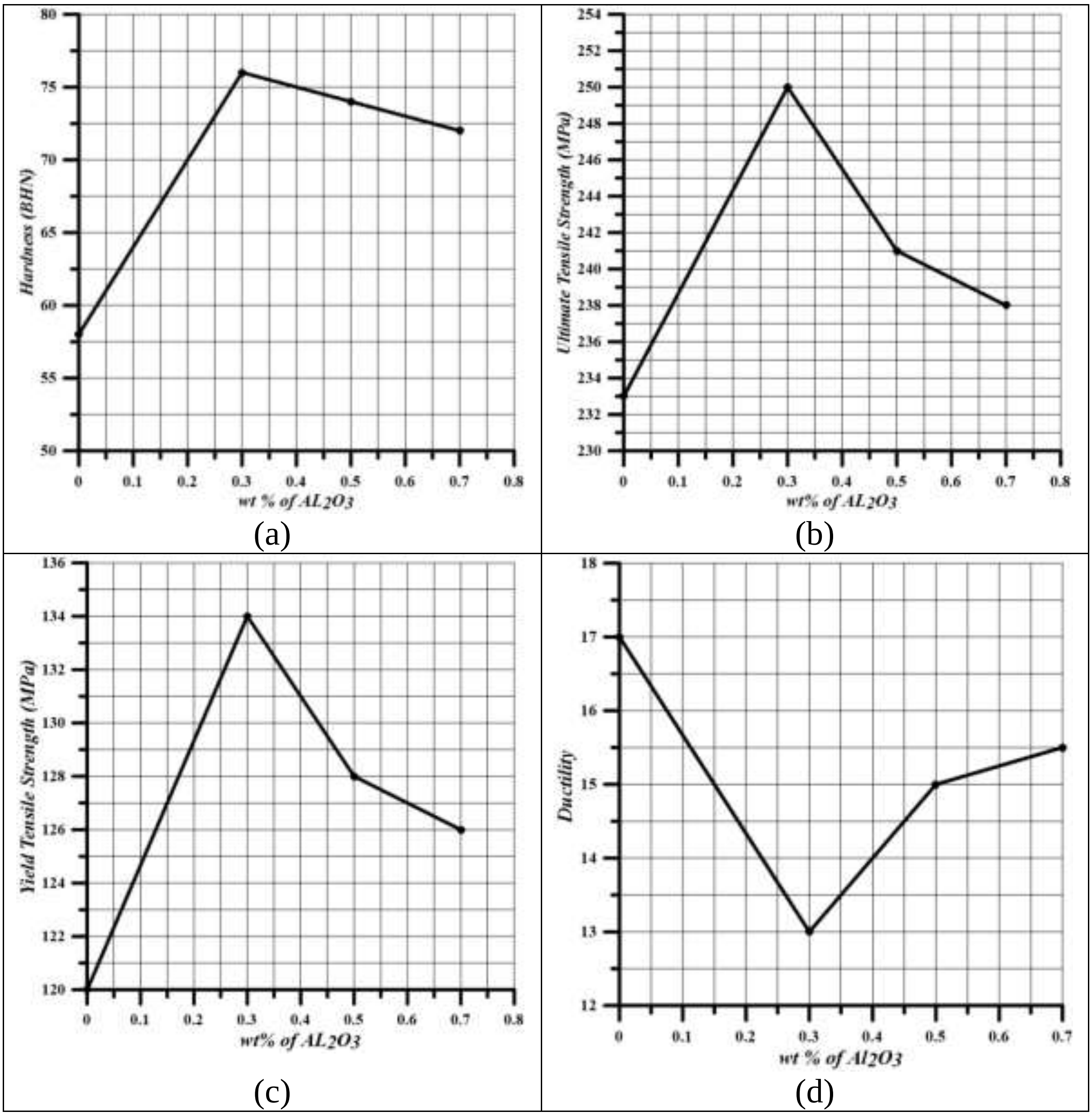

Fig. (5) Variation of mechanical properties with different alumina wt%

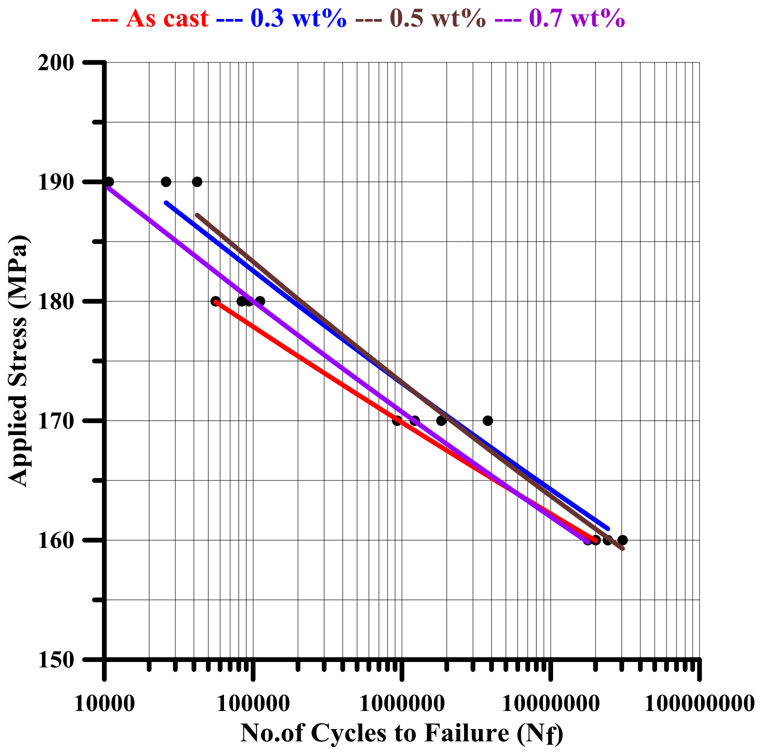

Fig. (6) S-N Curves of Al7075/Al_2O_3 nano composites with different ratio for high cycle fatigue (more than 10^4 Cycles)

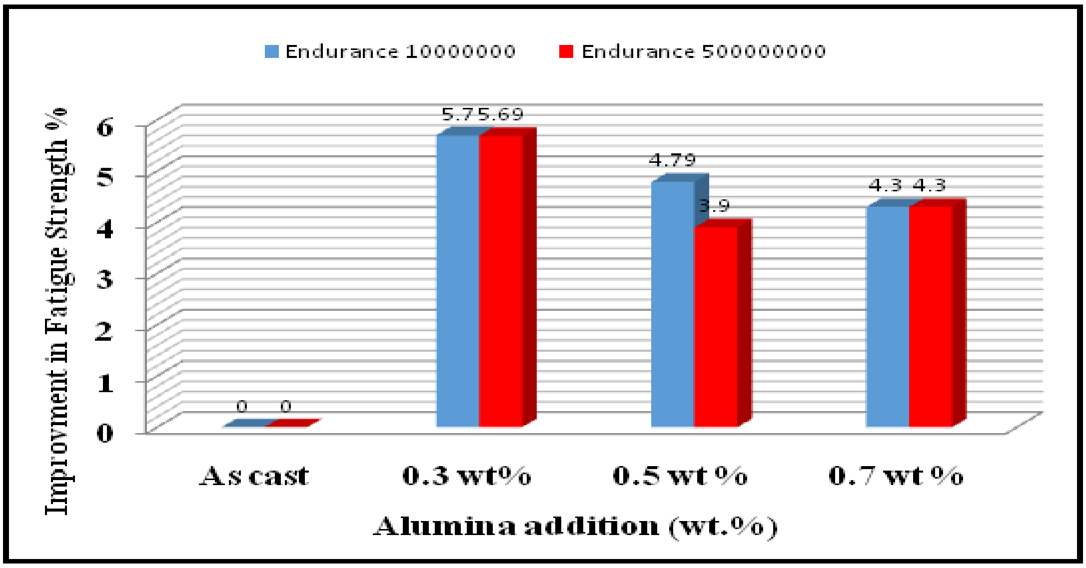

Fig. (7) Improvement in fatigue endurance limit at 10^7 and 5×10^8 cycles for various value of Al 7075/ Al_2O_3 nanocomposite

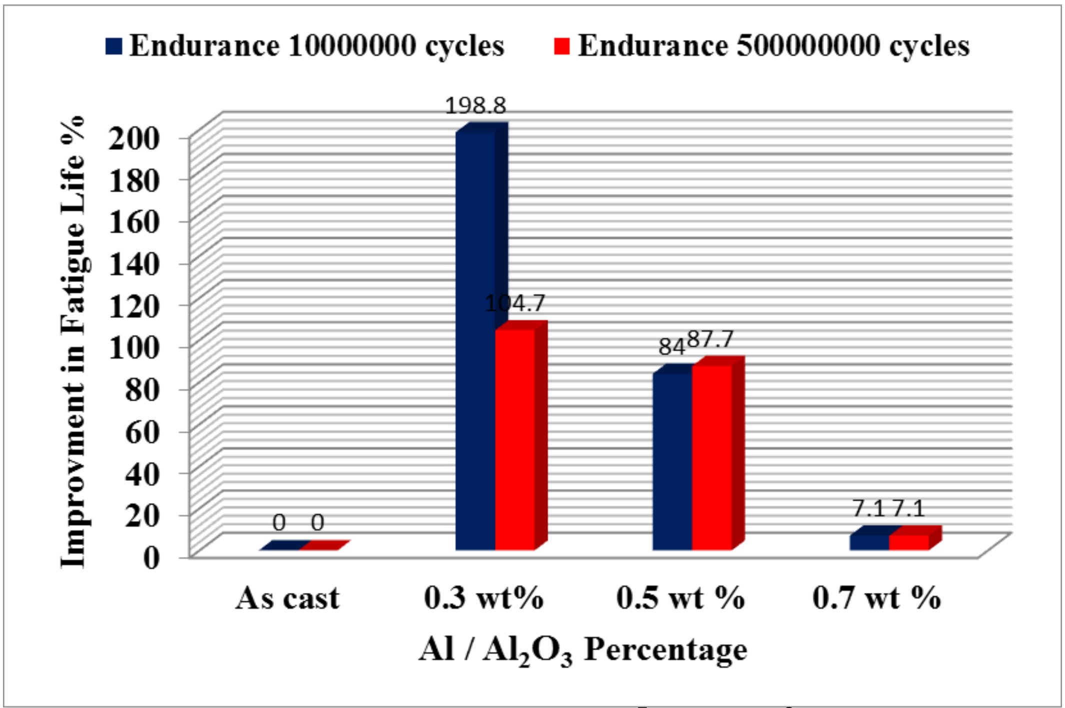

Fig. (8) Improvement percentage of fatigue life at 10^7 and 5×10^8 cycles for various value of nanoparticles reinforcement

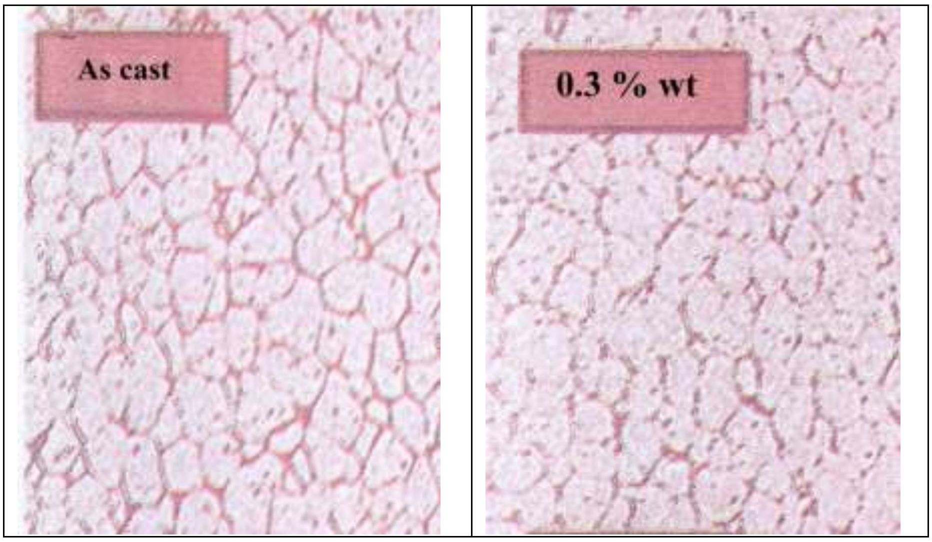

Fig. (9) Microstructure of the metal base 7075 Al alloy and 0.3% wt. Al_2O_3


Aluminum


copper


Magnesium


Manganese


Al_2O_3


Aluminum chloride

Fig. (10) Specimen's materials

Fig. (11) Specimens after manufacturing


before


after

Fig. (12) Specimens before and after fraction

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