Hussain J. Alalkawi
University of Technology-Electromechanical Eng. Dep., Baghdad, Iraq
Alalkawi2012@yahoo.com

Huda A. Al-Salihi
University of Technology-Electromechanical Eng.Depat., Baghdad, Iraq
hazsht@yahoo.com

Received on: 17/1/2017
Accepted on: 23/11/2017

Mechanical Properties of Al 6061/Al_2O_3 Nanocomposite by Stir Casting

Abstract- *Present work deals with the examination of the mechanical properties of Al 6061 composites, which were successfully fabricated by stir casting technique and then reinforced by using different percentages of Al_2O_3 nanoparticles up to 10 wt%. The required samples were carefully prepared. Evaluation of the mechanical properties such as hardness, yield tensile stress and ultimate tensile stress were effectively obtained at various percentages of Al_2O_3 nanoparticles .It was found that the mechanical properties of 6061 /Al_2O_3 nanoparticles are critically influenced by the concentrations of the reinforced Al_2O_3 nanoparticle, since there was a substantial enhancement in the mechanical properties, as the fractions of Al_2O_3 nanoparticles increased. This improvement in the mechanical properties was attributed to the uniform distribution of reinforcement nanoparticles as well as the grain refinement of aluminum matrix with minimal porosity.*

Keywords- *Metal Matrix Composite, Aluminium alloy (Al 6061), Stir casting method, Mechanical properties.*

How to cite this article: H.J. Alalkawi and H.A. Al-Salihi, "Mechanical Properties of Al 6061/Al_2O_3 Nanocomposite by Stir Casting," *Engineering and Technology Journal*, Vol. 36, Part A, No. 3, pp. 328-332, 2018.

1. Introduction

Metal Matrix Composites (MMCs) are promising materials of recent interest, due to their lightness, low density, ductility, electrical, high thermal conductivity, and moderate casting temperature [1-2]. However, the demands for developing Metal Matrix Composites (MMCs) have been significantly increased. Hence, considerable work has been done in the recent years, to reinforce metal matrix composites to attain low friction, low wear rate and excellent mechanical properties [3-4].Among metal matrix composites particulate reinforced aluminum matrix composites which are becoming more attractive in the recent years, due to their superior strength to weight ratio, good ductility, high strength, excellent wear resistance, excellent corrosion resistance, high temperature creep resistance and better fatigue strength [5]. In fact, the particulate reinforced aluminum matrix composite has reached a sound position as advanced engineering materials, due to the enormous advantages like isotropic properties and the possibility of the fabrication of secondary components [1,3,6]. Among the various aluminum alloys, aluminum alloy 6061 reinforced by Al_2O_3 nanoparticles that are characterized as having cast ability, corrosion resistance and high strength-weight ratio. Aluminum 6061alloy is broadly utilized in several sectors such as aircraft, defence, automobiles and marine areas [5,7]. It is well known that stir casting method is one of the simplest production methods that have been used to produce particle-reinforced composites [8]. This method comprises melting the matrix alloy followed by stirring in the particulate reinforcement to create the composite which is then cast either into a useable form or to provide ingot material for consequent deformation processing [4]. Whereas, stir parameters such as casting temperature, stirring velocity, reinforcement content, stirring time should be optimized, in order to lower the porosity, particles agglomeration, oxide inclusions and interfacial reactions during stir casting [9]. Accordingly, processing parameters must be critically selected in the melt stir technique to achieve a high degree of microstructural reliability [8]. Present work examines the influence of various percentages of reinforced nanoparticles on specific mechanical properties of aluminum Al 6061-based metal matrix composite through stir casting process. Several investigations have been devoted to examining the effect of the nanoparticle size and the nanoparticle fractions on the mechanical properties of aluminum alloys that reinforced by Al_2O_3 nanoparticles. Anilkumar et al. [4], investigated the effect of nanoparticles size and their weight fraction on various mechanical properties of fly ash reinforced aluminium alloy (Al 6061) composite that successfully fabricated by stir casting method. Unreinforced Al6061 samples were also inspected. It was found that there was an obvious degradation in the mechanical properties of fly ash reinforced

https://doi.org/10.30684/etj.36.3A.12
2412-0758/University of Technology-Iraq, Baghdad, Iraq
This is an open access article under the CC BY 4.0 license http://creativecommons.org/licenses/by/4.0

aluminium alloy (Al 6061) composites, as the size of fly ash particle increased. Whereas, increasing weight fraction of the fly ash particles resulted in a great enhancement in the mechanical properties like hardness and ultimate tensile strength [4]. Mahagundappa et al. [10], studied the effect of reinforcement and thermal aging on the corrosion resistance for the aluminium 6061 alloy reinforced with ceramic materials as cast and heat-treated. Experimental results revealed that corrosion resistances of the reinforced matrix alloy and the heat-treated composites were improved significantly with duration of exposure to the corroding. This enhancement in the corrosion resistance was attributed to the heat treatment of hybrid composites, which resulted in the formation of a protective surface layer, which gradually develops and subsequently reaches a steady state with time [10]. Hajizamani and Baharvandi [11], studied the mechanical behavior of aluminium alloy (Al 356) reinforced with Al_2O_3-10% ZrO2 nanoparticles. This alloy fabricated by stirring casting at 850°C. It was found that there was a significant decrease in the density as the reinforcement content increased. Whereas, the yield stress, ultimate tensile strength, and compressive strength were noticeably increased. The mechanical properties for Al6061-SiC and Al6061-SiC/Graphite hybrid composites were effectively studied by Krishnaa and Xaviorb [12]. Significant improvements in the tensile strength of the composites were observed, due to the contribution of the dispersed Graphite and SiC in Al6061 alloy [12]. Reza Ezatpour et al. [13], inspected the microstructural evolution and mechanical properties of Al6061-nanocomposite. After fabrication by stir casting, the nanocomposites were extruded at 550ºC. This investigation was used a ball milling machine. Milled nano Al_2O_3/Al composite powder was injected into the Al6061 melt by argon gas and stirred to produce a homogeneous mixture. This study confirmed that there was a significant enhancement in the yield strength for both conditions (as cast or extruded samples), since there was an obvious increase in the yield stress observed, as the amounts of Al_2O_3 nanoparticles increased.

2. Experimental Procedures

Aluminum alloy Al6061 was chosen as a matrix alloy. Aluminum alloy (6061) was effectively reinforced by Al_2O_3-10% nanoparticles by stir casting with particle size 50 nanomicron in the fabrication of samples. The analysis of the chemical composition of Al 6061 is presented in Table 1. After casting the Al (6061) based hybrid composites by stir casting which is broadly used among various processing methods. The material was received from the casting mould as 12 mm in diameter and 100mm length. 12 specimens with Al_2O_3 nanoparticles were tested.

I. The Reinforced Material

Present investigation was successfully fabricated aluminum alloy Al6061 with Al_2O_3-10% nanoparticles as a reinforced material with the particle size of 50nm. Table 2 displays the chemical analysis of the reinforced material.

II. Composites Preparation

The stir casting method was used for preparing the 6061Al/Al_2O_3 composites. The reinforced particles were preheated to 200ºC before putting into the melt. The stirrer speed of 450 rpm and the casting temperature was 850ºC. More details of the test rig, which used to prepare the nanocomposite can be seen elsewhere [16]. Thus, the cast nanocomposite of 10% Al_2O_3 was obtained in the form of a rod of diameter 12 mm and length of about 100mm. Aluminum alloy Al6061 was chosen as a matrix alloy. Aluminum alloy (6061) was effectively reinforced by Al_2O_3-10% nanoparticles by stir casting with particle size 50 nanomicron in the fabrication of samples. The analysis of the chemical composition of Al 6061 is presented in Table 1.After casting the Al (6061) based hybrid composites by stir casting which is broadly used among various processing methods. The material was received from the casting mould as 12 mm in diameter and 100mm length. 12 specimens with Al_2O_3 nanoparticles were tested.

III. Mechanical Properties Inspection

The specimens are prepared according to ASTM [17] standard values, as shown in Fig.1.

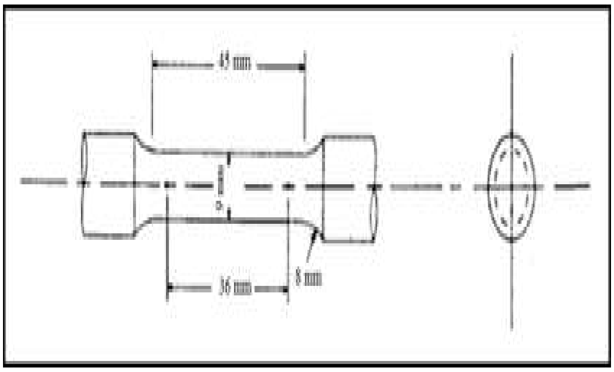

Figure 1: Tensile Specimen with Dimensions in (mm)

Table 1: Chemical Composition of 6061 Al alloy ASTM.

Elements wt.%	Cr	Zn	Co	Si	Ti	Ma	Mg	Fe	Others	Al
Standard [A]	0.04-0.35	Max 0.25	0.15 -0.4	0.4-0.8	Max 0.15	0.8-1.2	Max 0.15	Max 0.7	0.05	Balance
Experimental measured according to SIER	0.18	0.13	0.28	0.61	0.08	0.96	0.11	0.54	-	Balance

Element	C_2O	TiO_2	Fe_2O_3	Others	Alumina
Wt. %	1.1	1.8	0.8	0.02	93

Table 2: Chemical Composition of Al_2O_3 wt%

Tensile specimens with diameter 9 mm and gauge length 36 mm were fabricated from the cast composites. The total length of the reduced section is 45 mm. Tensile tests were carried out at room temperature. The surfaces of all specimens were well polished using 260, 300, 400, 600, 800, and 1000 silicon carbide papers followed by three different diamond laps, course 3/2 micron, fine 1 micron and finally extra-fine 1/4 micron. All specimen surfaces were well polished with 1µm diamond paste. Hardness tests were carried out in Vickers's micro hardness tester. The total load that applied to the specimen was 100gm for 15 seconds. The mechanical properties data given in this paper are the average of three tensile experiments.

3.Results and Discussion

Table 3 shows the ultimate tensile strength, yield strength, and hardness of cast 6061Al/Al_2O_3 nanocomopsite of the produced casting that reinforced by Al_2O_3 nanoparticles. Mechanical properties results revealed that the existence of nanoparticles was improved Vickers hardness, ultimate tensile flow stress, and yield stress through all nanoparticle concentrations, since there was a an increase in the hardness, ultimate strength and yield strength values as the percentage of the nanoparticle of Al_2O_3 were increased. The experimental results showed that there is a slight increase in the hardness with increasing the fraction of nanoparticles (0-4) Al_2O_3 %wt (Figure 2). A noticeable increase in the hardness values, as the concentrations reached (6-10) %.It is apparent that the hardness and tensile strength values improved when Al_2O_3 nanoparticles spread in the alloy matrix. As expected, the higher value of hardness was observed at 10 wt%, which indicates that the existence of the nanoparticles in the matrix improved the hardness significantly, which attributed to the two main reasons: First reason is associated with the inherent characteristics of the Al_2O_3 nanoparticles, since there is a strong ionic interfacial bonding between the Al alloy and Al_2O_3 interfaces, which giving rise to its desired material properties such as hardness and tensile strength [2]. However, the stable hexagonal alpha phase Al_2O_3 which is the strongest and stiffest could be the second reason for increasing the hardness [2,18]. Mechanical properties of Al 6061 were also examined by tensile tests. It is obvious to see the significant improvement in both yield and ultimate tensile strength as the nano Al_2O_3 nanoparticles fraction increased, at room temperature. Fig.3 illustrates the proportional rise in the yield stress values with increasing the fractions of Al_2O_3 nanoparticle.
Similarly with ultimate tensile stress (Fig.4), which shows a linear growing in the ultimate strength values with Al_2O_3 nanoparticle concentration.

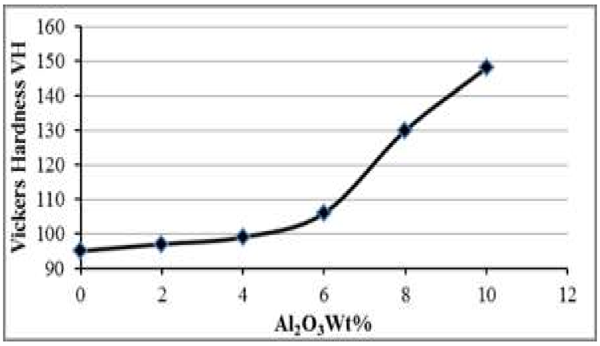

Figure 2: Relationship between Vickers Hardness (VH) and Al_2O_3 Nanoparticle Concentrations Wt%

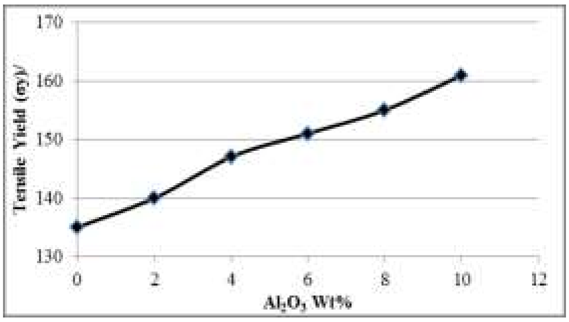

Figure 3: Yield Tensile Stress (σu) and Al_2O_3 nanoparticle Wt%

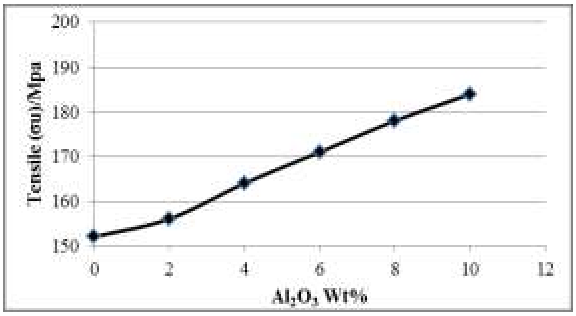

Figure 4: Relationship between Ultimate Tensile Strength (σu) and Al_2O_3 nanoparticle Concentrations

The maximum and minimum tensile strength of the composite samples were 156 and 184 MPa respectively. This increase is extremely related to the presence of Al_2O_3 nanoparticles, which act to refine the grain size of aluminum casting composites by nucleating small grains during the solidification process in the cast conditions. In addition, the enhancement in the yield and ultimate tensile strength could also be attributed to the substantial rise in the dislocation density, since Al 6061 alloy deformed plastically to accommodate the volume expansion .As a result, the dislocation density increases noticeably as the volume fraction of reinforcement particles increases [18]. It seems that the better tensile properties could be attained as the grain refinement of the aluminum matrix and of Al_2O_3 reinforcement nanoparticles were well distributed in the base matrix. In fact, there are several factors effect on the homogeneity of the Aluminum 6061alloy based metal matrix composite by stir casting, such as the uniform distribution of reinforcement materials, porosity in the cast metal matrix nanocomposite, and chemical reactions between the cast metal matrix alloy and reinforcement particles. The uniform distribution of reinforcement materials is very dependent on the density differences between reinforcement particles and matrix alloy melt, since agglomeration alumina particles cause stress concentration and subsequently local fracture [9].

Porosity levels on the other hand, also have a considerable effect on the homogeneity, since the homogeneity is achieved in the Al6061/Alumina composite at room temperature, as the porosity decreased. In fact, the porosity can be detrimental to the corrosion resistance of the casting and subsequent could be affected on the mechanical properties. The high amount of porosity is extremely reliant on the air bubbles that might be entering the melts reinforcing particles either independently or as an air envelope. Accordingly, the porosity should be remained at the lowest level, as this kind of a composite defect [11].

4.Conclusions

The significant conclusions were obtained by analyzing all the results through various tests and experiments. Various mechanical properties of the cast specimens were tested and concluded that the addition of Al_2O_3 nanoparticle to the aluminium, Al 6061 matrix had improved its mechanical properties effectively. The important conclusions of this research could be summarized, as follow :

1-Mechanical properties such as yield strength, ultimate tensile strength and hardness of Al 6061 composites increased predominantly by the increase of Al_2O_3 wt% nanoparticles reinforcement, and all the above properties of the nanocomopsites are higher that the metal base properties .

2- It was observed from the experimental results that the HV is enhanced by 55.7%, ultimate strength by 21% and the yield stress by 19.25% at the addition of 10 wt % Al_2O_3 compared to the base metal 6061 Al alloy .

3-The above improvement in the mechanical properties of the composites may be due to the following -:

a) The presence of stiffer and harder Al2O3 reinforcement leads to increase in constraint to plastic deformation of the matrix during the hardness test. Thus, increase of hardness of composite could be attributed to the relatively high hardness of Al_2O_3 itself [7].

b) The thermal mismatch between the metal matrix and the reinforcement is the major mechanism for increasing the dislocation density of the matrix and therefore increasing the composite strength (ultimate and yield strengths. Also, the less porosity and uniform distribution of Al_2O_3 into the matrix leads to enhance the mechanical properties of composites [11].

References

[1] A. Saravanakumara, P. Sasikumar and S. Sivasankaranc "Synthesis and Mechanical Behavior of AA 6063-x wt. % Al2O3- 1% Gr (x = 3, 6, and 12 wt. %) hybrid composites," 12th Global Congress on manufacturing and management, GCMM, 2014.

[2] A. Baradeswaran "Effect of Graphite Content on Tribological Behavior of Aluminium Alloy Graphite Composite," European Journal of Scientific Research, Vol.53 No.2, pp. (163- 170), 2011.

[3] A. Ramesh, J.N. Prakash, A.S. Shiva Shankare Gowda, and S. Appaiah "Comparison of the Mechanical Properties of AL6061/Albite andAl6061/Graphite Metal Matrix Composites," Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.2, pp (93-106), 2009.

[4] H.C. Anilkumar, H.S. Hebbar and K.S. Ravishankar "Mechanical Properties of Fly Ash Reinforced Aluminium Alloy (Al6061) Composite," International Journal of Mechanical and Materials Engineering (IJMME), Vol.6 No.1, (41-45), 2011.

[5] G.B. Veeresh Kumar, C.S. Rao, N. Selvaraj, M. S. Bhagyashekar "Studies on Al6061-SiC and Al7075-Al_2O3 Metal Matrix Composites," Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.(43-55), 2010.

[6] D. Mohana Rao, M.E. Bapi Raju Bandam "Preparation and Characterization of AL-Fly Ash Metal Matrix Composite by Stir Casting Method," International Journal of Innovative Science and Modern Engineering (IJISME), ISSN: 2319-6386, Vol.3, Issue-1, 2014 .

[7] D. Aruria, K. Adepua, K. Adepub, K. Bazavadaa "Wear and Mechanical Properties of 6061-T6 Aluminum Alloy Surface Hybrid Composites [(SiC + Gr) and (SiC + Al2O3) Fabricated by Friction Stir Processing Studies on Al6061-SiC and Al7075-Al2O3 Metal Matrix Composites," Mater Res Technol. 2(4), pp (362–369), 2013.

[8] S.M. Quader, B.S. Murthy, P.R. Reddy "Processing and Mechanical Properties of Al_2O_3 and Red Mud Particle Reinforced AA6061 Hybrid Composites," Journal of Minerals and Materials Characterization and Engineering, Vol.4, pp (135-142), 2016.

[9] A. Praveen Kumar, S. Aadithya , K. Dhilepan and N.Nikhil "Influence of Nano Reinforced Particles on the Mechanical Properties of AluminiumHybird Metal Matrix Composite Fabricated By Ultrasonic Assisted Stir Casting," ARPN Journal of Engineering and Applied Sciences, Vol. 11, No. 2, 2016.

[10] M.B. Mahagundappa, H.K. Shivanand and N.V. Yoganandmurthy "Influence of Reinforcements and Thermal Ageing on Corrosion Characteristics of Al (6061) Based Hybrid Composites," IJME, January, Vol. 6, Issue 1, 2013.

[11] M. Hajizamani, H. Baharvandi "Fabrication and Studying the Mechanical Properties of A356 Alloy Reinforced with Al_2O_3-10% ZrO2 Nanoparticles Through Stir Casting," International Journal of Innovative Science and Modern Engineering (IJISME) ISSN: 2319-6386, Vol.3 Issue-1, December 2014.

[12] M.VamsiKrishnaa, A. Xaviorb "An Investigation on the Mechanical Properties of Hybrid MetalMatrixComposites," Procedia Engineering Vol. 97, pp (918 – 924), 2014.

[13] H. RezaEzatpour, S. AbolkarimSajjadi, M. HaddadSabzevar and Y. Huang "Investigation of Microstructure and Mechanical Properties of Al6061 Nanocomposite Fabricated by Stir Casting," Materials and Design Vol. 55, 921–928, 2014.

[14] V. Bharath, N. Mahadev, V. Auradi "Preparation Characterization and Mechanical Properties of Al2O3Reinforced 6061 Al Particular MMCs," International Journal of Eng. Research and Technology (IJERT) Vol.1, Issue 6, 2012.

[15] O.S. Mohsen, A. Mazhery "Aluminium-Matrix Nanocomposites Swarm Intelligence Optimization of the Microstructure and Mechanical Properties," Materials and Technology Vol.46, Issue. 6, 2012.

[16] H.J. Alalkawi, A.A. Alrasiaq, M.A. AlJaafari, "Performance Study on Mechanical Properties in 7075 Aluminum Alloy and Al_2O_3nanocomposite," Journal of Eng, and Tech., accepted for publication 2017.

[17] Standard Specification, Designation, ASTM A29/A29M-05-EDT, 2006.

[18] N. Radhika, T. V. Balaji, S. Palaniappan "Studies on Mechanical Properties and Tribological Bhaviour of LM25/SiC/Al_2O_3 Composites," Journal of Engineering Science and Technology, Vol.10, No.2, pp (134 – 144), 2015.