Fatigue Behavior of Aluminum SiC Nano Composites Material with Different Reinforcement Ratio

Mamoon A. A. Al-Jaafari*1

1University of Al-Mustansiriyah, Mechanical Eng. Department, Baghdad

Abstract. The fatigue properties of The Aluminum alloy (6061) metal matrix Nano composites (MMNCs), with different ratio of SiC wt nano particles (0.5, 1.0, 1.5, 2.0 and 2.5%), to fabricated by stir casting were been investigated with rotating bending type of load and the stress ratio(R=-1) at room temperature. The composite were reinforced by SiC of 10 Nanometer in grain size to. The fatigue strength and life were been obtained experimentally by using S-N curves for different ratio wt % nano particles. The highest fatigue strength and life were occurred at 2.0 wt. % nano particles due to reasonably uniform distribution reinforcement of nano particles and minimal the porosity. The enhancement percentage in endurance fatigue limits are 11.48 % and 11.05% for 107 and 5*108 cycles respectively.

1. Introduction

the Nano-technology applications in metal had showing remarkable growth leads to metal matrix nano composite (MMNC). This is results of two factors: 1) increases the violability of nano- materials, like various types of nano-metal particles, and nano-oxide 2) advancements in processes which control mixing at the nano-scale.[1-4]

Nano-particles enable significant improvement in mechanical properties, i.e. Ultimate stress, yield stress, ductility. the different type of nano-fillers, such as nm-particles, nm-tubes, and nm-nets, are being incorporated into MMNC to enhance mechanical properties due to the reinforcement of high strength and high modulus of elasticity particles like Sic, Al2O3, B4C and ZrO2.[5]

Aluminums Metal Matrix Nano Composites (AMNCs) are widely used for high performance applications. The methods production of these composites can be solid state, semisolid and liquid methods, the solid state methods can be classified into powder metallurgy, alloying by machine and diffusion methods. The semi-solid process are consists of both mixes of matrix contain the solid and liquid state, Liquid metallurgy is the economical of the available routes for mixing metal matrix nano composite production and generally the stir casting method, compared to the other types of melt process have many important advantages,, the wide selection of Aluminum families , best metals matrix–reinforcement particles bonding, easier control structure the of matrix and low cost processing.[6]

H.R. Ezatpour, et.al., Investigated by Experimentall work the Al6061/ Al2O3 nano-composites with a different nano weight (0.5, 1 and 1.5 wt%) are produced by stir-casting process. The nano-composites were then be extruded at hight temperature (550)0C. Mechanical tests results indicated that the base metal (as-cast),the ultimate strength both of ( ultimate tensile and ultimate compression) increase but the ductility decrease by increased more renforcement particle per centage. An extrusion process effect
improved the physicals properties in the nano-composites with increasing the amount of nano reinforcement. [7]

C. Kaynak et.al, Investigated the Fatigue parameters on Aluminum reinforced by SiC particulates. Comparison has been mode based on the matrix Aluminum alloy containing Silicon. Different weight percentages of (SiC) reinforcement particulate in the size and different nano-material shap were used. Fatigue tests indicated that the nano-composite fatigue strength and life increased by increases of weight percentages ( SiC) particulates.( SiC) particulates improved fatigue strength and life which acting as barriers to cracks growth plane leads to the crack propagation rates decreased.[8]

L. Poovazhagan, et.al,. Studies the Hybrid nano-composites based on Aluminum alloy (6061) reinforced with different ratios of SiC (0.5, 1.0 and 1.5 vol. %) and( B4C) (0.5 vol. %) nanoparticles were fabricated used ultrasonic cavitation based on solidification process method . Compared to the as cast (unreinforced) alloy, at room temperature, the hardness and ultimate tensile strength of the hybrid composites increased significantly while ductility and impact strength are reduced. The combination of 1.0 volume percentage (SiC) and( 0.5) volume percentage( B4C) gives the best ultimate tensile strength.[9]

Amal E. Nassar, et.al, fabricated Aluminum (100%) composite reinforced by nano titanium dioxide which was produced by powder metallurgy method. results of ultimate tensile strength, hardness, and density shows that the porosity and the ultimate tensile strength of composites strength increased with an increase in volume fraction of the nano particles; however ductility of composites was decreased. Wear test shows that composites offer high wear resistance compared to alloy.[10]

A. Prasad Reddy et.al, study the properties of 2 wt.% of (SiC) wt.% of Gr (0, 0.5, 1, 1.5, 2, and 3) nanoparticles ,reinforced Al-6061 alloy fabricated through ultrasonically casting method . Microstructure, various nano particles , particle Size and phases are analyzed to understand the behavior of nano composites. Microstructural shows the uniform dispersion of SiC nano-reinforcements in the matrix. Density and hardness of Al6061–2SiC hybrid nano-composites decreased with the rise of nano material in the composite material.[11] The aim of this paper is to investigate the fatigue behavior considered technique stir casting under interaction of nano material as reinforcement with the 6061 Al alloy as base metal-matrix. 0.5, 1.0, 1.5, 2.0 and 2.5wt% Sic nanoparticles were added to Al 6061 metal matrix for manufactured the nano-composite and tested under fatigue conditions to determine the life and strength of nano-composite.

2. Materials

2.1. Aluminum alloy

The base metal matrix been used in the current work is 6061 AL-alloy which is widely uses in many applications such as Auto motive, aerospace, construction and electricity industries. The Chemical composition analysis of 6061 Aluminum alloy was down in (State Company for Inspection and Engineering Rehabilitation (SIER) in Baghdad,. The cooperation between the Standard ASTM B-211[12] and the results of this work , are listed in Table 1.

| Element     | Wt% Standard | Wt% Experimental | Element     | Wt% Standard | Wt% Experimental |
|-------------|--------------|------------------|-------------|--------------|------------------|
| Chromium    | 0.01-0.35    | 0.23             | Silicon     | 0.4-0.8      | 0.67             |
| Titanium    | Max 0.15     | 0.09             | Zinc        | Max 0.25     | 0.16             |
| Iron        | Max 0.7      | 0.54             | Manganese   | Max 0.15     | 0.11             |
| Magnesium   | 0.8-1.2      | 0.93             | Others      | 0.05         | _                |
| Copper      | 0.15-0.4     | 0.33             | Aluminum    | Balance      | Balance          |
The physical and mechanical properties of 6061 AL-alloy can be shown in Table 2.

### Table 2. Physical and mechanical properties of 6061 AA.

| Metal matrix   | Density gm/cm3 | Hardness HB | Tensile Strength (MPa) | Elastic modulus | Yield stress (MPa) | worker |
|----------------|----------------|-------------|------------------------|----------------|--------------------|--------|
| 6061 AL alloy  | 2.7            | 30          | 149.7                  | 70-80           | 183                | Ref[12]|
|                | 2.7            | 31          | 150.8                  | 73             | 183                | Current|
| ---            | 32             | 4.5         | 154                    | 74             | 184                | Ref[13]|

2.2. Nano material

The reinforcement material used in this work is (SiC) with an average size of (10 nm) and purity more than (99 wt. %) supplied by nanostructured and amorphous materials, Inc. (Houston, Texas, USA), was used as the reinforcement phase for the synthesis of Al-SiC nano-composites. The physical and mechanical properties of the (SiC) is given in Table 3.

### Table 3. Physical and mechanical properties of SiC nanomaterial

| Workers | Density gm/cm³ | Grains size (nm) | Hardness HB500 | Toughness (MPa. M0.5) | compression strength (MPa) |
|---------|----------------|------------------|---------------|------------------------|---------------------------|
| Ref[14] | 97.3-99.2      | 20-30            | --            | 6.2                    | 870                       |
| Current | 96.2           | 10               | 24.5-25       | --                     | 830                       |

2.3. Composites Preparation

The stir casting method be used to preparation the 6061Al/SiC composites. The SiC reinforced particles were preheated to 200°C before put into the melt metal. The stirrer speed was (450) r.p.m and the casting temperature was been 850°C. More details of the st rig which used to prepare the nano-composite can be seen elsewhere.[15]

2.4. Specimen Geometry

The composite materials of the specimens were received as 16mm in diameter and 160mm in length from the cast molds. The profile of the specimens been then machined using CNC lathe machines. The tensile and fatigue test specimens shape is shown in Figure 1.
Figure 1. Tensile and Fatigue test specimen.

The tensile specimens was made according to E8/E8M-09,( ASTM),[16] The fatigue specimen shape and the dimensions are taken according to E466-07/E466M, ( ASTM)[17].where both listed in Table 4.

Table 4. Dimensions of the Tensile and the Fatigue Test Specimen.

| No. | Dimension         | Tensile Specimen(mm) | Fatigue Specimen(mm) |
|-----|-------------------|-----------------------|-----------------------|
|     | Basic             | Tolerance             | Basic                 | Tolerance             |
| 1   | G - Gauge length  | 30.00                 | 0.06                  | 45.00 _ 0.06         | 0.06                  |
| 2   | D - Diameter      | 06.00                 | 0.10                  | 09.00 _ 0.10         | 0.10                  |
| 3   | R - Radius of fillet | 6                     | 6                     | 36                     | 54                     |

3. Results and discussion

3.1. Hardness results

Type of test: HB (Brinell hardness testing), Applied force: HB 31.25 Kgf, Ball diameter: 2.5 mm. Laboratory environmental conditions; Test temperature: 24 °moisture: 28%. Test was done under the scope of ASTM E10[18]. Applied force time: (10 – 15) Sec. Sample Name: Cast Al 6061, Nano composite Al 6061 / SiC – 0.5%, 1.0%, 1'5%, 2.0% and 2.5%wt. The test results of HB hardness are plotted in Figure 2.
Figure 2. B-Hardness against SiC wt. %.

The Figure 2. revealed that the BHN hardness of the MMCs specimens increased with increases of the weight percentage of the reinforcement nano material, the reason may be the MMCs has low porosity and the nanoparticles have uniform distribution leading to high BHN compared to 0.0wt.% value of SiC (as cast).

Bharath et al. [19] concluded that increasing of nano reinforcement weight percentage resulting in increase of VHN hardness of 6061 Aluminum based composite.

Mohson et al. [20] investigate MMCs composite of the Al-Si Aluminum alloy as nano metal matrix. They found that the BHN hardness increased with increasing the vol. % nano reinforcement but the hardness was absent at volume percentage.

3.2. Tensile strength

Figure 3. shows the stress-strain curves for six types of specimens starting from zero SiC, 0.1%, 1.5%, 2%, and 2.5%. The ultimate tensile strength results from the experimental work observed that the ultimate tensile strength of the MMNCs increase with increasing the amount of SiC. The higher ultimate tensile strength of the MMNCs could be attributed to the fact that SiC particle act as obstacles to the dislocation movement, kok [21] reported that the introducing nano reinforcement particles into the aluminum matrix resulted in raising the mechanical properties.
Form the experimental work, Bharath et al.[19] and Mohsen et al.[20], it is reported that the tensile strength of nano composites metal matrix is enhanced with an increasing in the nano reinforcement particles wt.% or vol.% . The experimental analysis of the current work showed that the highest tensile strength occurred with (2 wt.% of nano particles SiC).

3.3. Fatigue Test

The rotating- bending fatigue testing machine Schencke product type KFG8 is used to fatigue tests, with constant amplitude. The fatigue specimen which used is shown in Figure 4.

The fatigue specimen has circled cross sections shape and was subjected to the load form the right side of perpendiculars axis of specimen, this load leads to been bending moment. Therefore the specimen's surface was under tension and compression stress respectively when it was to rotate. The value applied...
load to the specimen for a known value of stress ($\sigma$) measured by (N/mm$^2$) and used from applying the relation below:

$$\sigma = \frac{(32 \times 125.7 \times P)}{(\pi \times D^3)} \quad (1)[22]$$

Where $D$ is the diameter of the specimen (mm), $P$ is load by Newton (N), force arm is equal to 125.7mm, and stress ($\sigma$) measured by (N/mm$^2$). The fatigue test rig is shown in Figure 5.

![Fatigue test machine](image.png)

Figure 5. Fatigue test machine.

The specimens were tested under constant amplitude fatigue, stress at room temperature, to estimate the stress–numbers of cycles curves. The results of this test are illustrated in Table 5.

| No. of series | Applied stress (MPa) | number of cycles to failure | Average no. of Cycles (4 specimen) |
|---------------|----------------------|-----------------------------|-----------------------------------|
| 1A,1A-,1A--,1A--- | 140               | 7943 8760 9986 7023 | 8428 |
| 1B,1B-,1B--,1B--- | 120               | 20679 24789 21987 17895 | 236160 |
| 1C,1C-,1C--,1C--- | 100               | 39875 42138 50981 42345 | 43834 |
| 1D,1D-,1D--,1D--- | 80                | 145871 128421 134567 179654 | 147128 |
| 1E,1E-,1E--,1E--- | 60                | 396783 419867 406532 378321 | 400375 |
| 2A,2A-,2A--,2A--- | 140               | 9073 8757 9657 9988 | 9368 |
| 2B,2B-,2B--,2B--- | 120               | 23080 22897 27329 21989 | 23823 |
| 2C,2C-,2C--,2C--- | 100               | 47245 43962.19 46457 50983 | 47161 |
| 2D,2D-,2D--,2D--- | 80                | 159708 160822.8 141584.2 134569 | 149171 |
| 2E,2E-,2E--,2E--- | 60                | 432993 437453 462903 465634 | 434970 |
| 3A,3A-,3A--,3A--- | 140               | 9572 9282 10139 10787 | 9945 |
| 3B,3B-,3B--,3B--- | 120               | 24349.4 24270.82 28695.45 23748 | 25265 |
| 3C,3C-,3C--,3C--- | 100               | 49843 46599 48779 55061 | 50070 |
| 3D,3D-,3D--,3D--- | 80                | 168491 170472 148663 145334 | 158240 |
| 3E,3E-,3E--,3E--- | 60                | 456807 463700 486048 439056 | 461402 |
| 4A,4A-,4A--,4A--- | 140               | 10645 10098 11649 9838 | 10557 |
The (stress-number of cycles) curves of the 6061Al alloy and the aluminum metal matrix composites of applied stress against numbers of failure cycles to were generated and are shown in Figure 4. It should be noted that the stresses is the applied stress till failure (σf). All the (S-N) curves are similar in shape. 120 specimens were tested to get the (S-N) curves, 20 specimens without reinforced material for as cast 6061 Al. alloy, 100 specimens for 0.5, 1.0, 1.5, 2.0 and 2.5 wt. % of SiC. The S-N curves equations for the each material are shown in Table (6). The (S-N) curves equations are calculated according to Basquin equation of the form (σf = A Nf b) where A and b are material constant. The equations listed in Table (6) are obtained by curve fitting the experimental data of fatigue test. Also material constants A, b with correlation coefficient (R2) are given in the same Table 6. The S-N curve equations have well (R2) which proved that the experimental data were good described by Basquin formula.

### Table 6. Fatigue Parameters for Various wt. % SiC Nanoparticles.

| No. | Wt. % SiC | A    | b    | Equation  | Stress at 107 and 5*108 cycle | Changed in σe (R2) |
|-----|-----------|------|------|-----------|-------------------------------|--------------------|
| 1   | 0.0       | 1027.8 | -0.219 | σf = 1027.8 Nf -0.219 | 30.123720, 12.788929 | 0.989              |
| 2   | 0.5       | 1084.2 | -0.221 | σf = 1084.20 Nf -0.221 | 30.768718, 12.960955 | 0.989              |
| 3   | 1.0       | 1099.02 | -0.221 | σf = 1099.02 Nf -2219 | 31.189297, 13.138120 | 0.989              |
| 4   | 1.5       | 1113.94 | -0.221 | σf = 1113.94 Nf -0.221 | 31.612715, 13.316479 | 0.989              |
| 5   | 2.0       | 1164.45 | -0.220 | σf = 1164.45 Nf -0.221 | 33.583104, 14.201932 | 0.988              |
| 6   | 2.5       | 1134.15 | -0.219 | σf = 1134.15 Nf -0.219 | 33.240725, 14.112243 | 0.988              |
The endurance limit of fatigue improvement at 10^7 and 5*10^8 cycles for different SiC contents is illustrated in Figure 7.
value of 6061 Al/Sic nano composite.

4. Conclusions
The basic understanding of the mechanism which leads to the enhancement in mechanical and fatigue properties the following remarks from this study are;
1. Results showed that adding 2 wt. % of SiC particles to Aluminum as a metal matrix improves Brinell hardness (BHN) by 32%, and ultimate tensile strength by 12.1%.
2. The fatigue strength of 2.0wt% SiC nano-composite at 10^7 cycles was improved by 11.48 % compared to as cast base Al 6061 alloy.
3. The improvements of the nano composite can from either uniform distribution, less porosity and high bonding between SiC and Al alloy, or high dislocation density, high mechanical properties of SiC itself.

5. References
[1] Mohammed A-A H J, Rasiaq A A A- and Jaafari M A A A- 2018 Studying the effect of Different wt % AL2O3 Nanoparticles of 2024Al Alloy / AL2O3 Composites on Mechanical Properties Al-Khwarizmi Engineering Journal 14 7
[2] Paul D R and Robeson L M 2008 Polymer nanotechnology: Nanocomposites Polymer 49 3187-204
[3] Sung L-P, Comer J, Forster A M, Hu H, Floryancic B, Brickweg L and Fernando R H 2008 Scratch behavior of nano-alumina/polyurethane coatings Journal of Coatings Technology and Research 5 419-30
[4] Mohammed H J, Mahmood I A and Jaafari M A A A- 2018 An Estimation Study on Fatigue transition Life of Nanocomposites Reinforced by AL2O3 Association of Arab Universities Journal of Engineering Sciences 25 18
[5] Sajjadi S A, Ezatpour H R and Beygi H 2011 Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting Materials Science and Engineering: A 528 8765-71
[6] Rajesh N 2016 Recent Studies In Aluminium Metal Matrix Nano Composites (AMMNCS)--A Review Technology 7 618-23
[7] Ezatpour H R, Sajjadi S A, Sabzevar M H and Huang Y Z 2014 An investigation of the tensile and compressive properties of Al6061 and its nano composites in as-cast state and in extruded condition Materials Science and Engineering: A 607 589-95
[8] Kaynak C and Boylu S 2006 Effects of SiC Particulates on the Fatigue Behaviour of an Al-Alloy Matrix Composite Materials & Design - MATER DESIGN 27 776-82
[9] Poovazhagan L, Kalaichelvan K, Rajadurai A and Senthivelan V 2013 Characterization of Hybrid Silicon Carbide and Boron Carbide Nanoparticles-Reinforced Aluminum Alloy Composites Procedia Engineering 64 681-9
[10] Nassar A E and Nassar E E 2017 Properties of aluminum matrix Nano composites prepared by powder metallurgy processing Journal of King Saud University - Engineering Sciences 29 295-9
[11] Prasad Reddy A, Vamsi Krishna P and Rao R N 2019 Tribological Behaviour of Al6061–2SiC-xGr Hybrid Metal Matrix Nanocomposites Fabricated through Ultrasonically Assisted Stir Casting Technique Silicon 11 2853-71
[12] 2017 ASM (Aerospace Specification Metals) Material Data Sheet, asm.matweb.com
[13] 2017 International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys, Registrations recorded series 3
[14] 2010 International Organization for Standardization I.S.O, standard number, USA, N.M. 1143
[15] Jaafari M A A- 2017 Cryogenic treatment effect on fatigue behavior of nano composite. (Baghdad, Iraq: University of Technology)
[16] 2017 Designation: E8/E8M "Standard Test Methods for Tension Testing of Metallic Materials" ASTM International

[17] 2017 Designation: E466-07/E466M "Standard Test Methods for High cycle & low cycle fatigue Under force control of Metallic Materials" ASTM International

[18] 2017 Designation: E10/E10M " Standard Test Methods for hardness Testing of Metallic Materials " ASTM International

[19] Bharath V, Nagaral M and Auradi V 2012 Preparation characterization and mechanical properties of Al2O3 reinforced 6061Al particulate MMC's *International Journal of Engineering Research and Technology* 1-6

[20] Ostad Shabani M and Mazahery A 2012 Aluminum-matrix nanocomposites: Swarm-intelligence optimization of the microstructure and mechanical properties *Materiali in Tehnologije* 46 613-9

[21] Kok M 2005 Production and mechanical properties of Al2O3 particle-reinforced 2024 aluminium alloy composites *Journal of Materials Processing Technology* 161 381-7

[22] Hussain F, Abdullah S and Nuawi M 2016 Effect of temperature on fatigue life behaviour of aluminium alloy AA6061 using analytical approach *JOURNAL OF MECHANICAL ENGINEERING AND SCIENCES* 10 2324-35