Study the Effects of Titanium Dioxide nano particles reinforcement on the mechanical properties of Aluminum Alloys composite

Mamoon A. A. Al-Jaafari
University of Al-Mustansiriyah, Mechanical Eng. Department, Baghdad
dr.mamoonali@gmail.com

Abstract  Aluminum alloy 6061 and 6082 was used as base material to the Aluminum matrix nano composites (AMNC) and different Titanium Dioxide (TiO2) nano particles reinforcement wt. % of Ti(0.5, 1.0, 1.5 and 2.0), the size of Titania reinforced material particles is 10 Nano meter, were been fabricated by using stir casting method. The effects of added nano particles on the mechanical properties of MMNC been studded. It was observed that the nanomaterial reinforcement led to high improvement in ultimate strength (σu), yield stress (σy), hardness (BHN) and ductility. The maximum improvement in ultimate strength, yield stress and BHN hardness was observed at 1.5 wt % TiO2 for Aluminum alloy 6061 and 6082 while the maximum value of Elongation % was obtained at 0.5 wt. % TiO2 nano reinforcement for both Aluminum alloy 6061 and 6082.

1. Introduction
The resents day, especially in materials manufacturing technology, the world is rapidly evolving; engineers and scientists look forward to new materials characterized by lightweight and powerful results. Aluminium and its alloys are used significantly in modern engineering applications due to its high strength and lightweight [1-2]. However, their hardness and low wear and chemical resistance limit their operated in various applications.

The widespread use of Aluminium Metal Matrix Composites (AMCs) in automotive, construction and aerospace applications is due to the ideal features of its properties, such as specific rigidity, thermic conductivity, rising wear resistance, corrosion resistance, and low density.[3-6]

Ceramic nano particulate (CNPs) reinforced are considered the favourable option for aluminium to impart high strength and therefore adequate wear resistance. There are different ways where are made aluminium metal nano-composites (AMNCs), such as stir casting, metallurgy of powder, squeeze casting, etc. Among them, stir casting well recognized for its cost-effectiveness and simplicity. Stir casting process mostly worked in the manufacture of AMNCs as it produces composites with uniform reinforcement distribution. The Aluminium as base metal for matrix the preparation method involves the incorporation of metallic or ceramics such as ZrO2, Al2O3, Sic, or TiO2 to increase mechanical properties and resistance to wear [6-9].

For Aluminium matrix nano composite AMNCs, TiO2 is one of the best choices because of its perfect hardness, low density, high melting temperature, elevated wear resistance, and high chemical stability. Wear resistance has shown to increase by raising the percentage Ceramics particles in Al. This is due to the rigidity and high strength of the reinforcement level. However, Multi-Wall Carbon Nano Tubes (MWCNTs) were been recognized as one of the good potential nano-reinforcements with excellent mechanical characteristics. As far as composites of Al-MWCNTs are concerned, their
tribology characteristics were been determined by the percentage of CNT by stir casting method [10-12].

Alalkawi et al, They observed that the collect of Al2O3 nano particle to reinforced the 2024AA was improved the hardness, ultimate translate stress , 0.2 yield stress and ductility of 2024 nano composites, designate that The extreme improvement was detect at 0.40 wt.% of nano particles. The best refinement was 15.781% hardness, 18.10% ultimate translate stress, 12.860% yield stress and 25.71% elongation.[13]

Al-Quutub et al studied the composite reinforced Aluminium alloy 6061 matrix made by ball milling technology and plasma sintering for tribology high properties. Because of the study, Al6061 composite reinforced with 1 wt. percent CNTs showed a lower friction coefficient and wear rate compared to the pure Al6061 alloy. , it was make clear that the wear conduct of Aluminium /CNT composites is largely have an effect on the applied load and there occur at critical load further on CNTs could have negative effects on the wear resistance of aluminium alloy.[14]

Al- Jaafari studied the effects different ratio Silicon Carbide on the fatigue properties for Aluminium metal matrix nano composite made by stir casting method for AA6061. The improvements in the fatigue strength and life was been noticeable on each value of the reinforcement , The elevated strength and life for fatigue were take place at .2wt. % nano particles due to reasonably uniform distribution reinforcement of nano particles and minimal the porosity . The improvements percentage in endurance fatigue limits are (11.48%) for (107) cycle % and (11.05) % for (5*108 ) cycle for metal matrix nano composite.[15].

Dewangan et al has been studied The mechanical performance of Aluminium alloy 6061 reinforced by multi weight percent 0.5, 1, and 1.5 wt. percent CNTs composites given by hybrid casting The study results showed improvements in the hardness and ultimate tensile stress of the nano composite with the increasing CNT material. The uniform dispersal of the reinforcement material in the Al6061 alloy matrix was also demonstrated in the scanning electron microscope micrograph developed, shows a raise in mechanical properties in the existence of nano material and its value raise even further with raise in weight percentage of nano material.[16] Nassar et al has focused on evaluating the structural, wear, and mechanical properties of Al/TiO2 nano composite provided by powder metallurgy. The consequence of the test showed proper dispersal within the Al matrix with a small degree of porosity of the Nano-TiO2 particles. The results also demonstrated that the yield power, wear resistance, ultimate tensile strength, and hardness of the nano composite improved with increases in nano-sized materials [17]. Simoes et al examined the microstructural and mechanical properties of Al matrix composites reinforced by different percentages of CNTs (0, 0.5, 0.75, 1, and 1.5 vol) and developed by the powder metallurgy process. The results of the study showed that nano-composites strengthened with 1 vol% of CNTs have strong efficiency of dispersion, making it the highest hardness value. Essential and attractive properties such as high-strength lightweight for fuel consumption reduction prioritized in modern engineering applications, especially in the aerospace and automotive industries. According to the literature survey of the present report, it is therefore clear that other research groups have not achieved dry sliding wear studies and other mechanical properties on Al-CNT reinforced nano-TiO2 particles produced by powder metallurgy routes for the aerospace and automotive industries.[18] P. S. Zangabad et al, study the fatigue properties of (AA5052) Aluminium metal nano-composites using friction stir processing technique (FSP). With different amounts of nanoparticles up to 6 stages were fabricated to get homogenous dispersion of nanoparticles inclusions. Microstructural studies of high resolution techniques showed that nano metric Al3/TiO2 with different nano-particles in size were scattered throughout a fine-grained Al matrix an improvement in the tensile strength and hardness was attained. They contrasted the result with the non-reinforcement alloys and FSP alloy with placing TiO2 particles. They shows that FSP of the AMMC improve the fatigue strength at endurance limits for about 28.0% and 32.0% compared with the unprocessed Aluminium alloys when the ratio of the reinforcement particles was 2.0 and 3.50) % volume units, respectively [19]. The aim of present work is to study the mechanical properties (ultimate and yield stress, ductility and elongation) under effects of nanomaterial as reinforcement with 6061 and 6082 Aluminium alloys as base material of the matrix. (0.5, 1.0, 1.5 and 2.0 wt %) of TiO2 nanoparticles were added to AA6061
and AA 6082 base matrix to man-made the Required composite material and test to find the mechanical properties of nano-composite. The use of the this composite can be in automotive industry.

2. Materials
2.1 Aluminum alloy

**Table 1** show chemical composition of (6061AA and 6082AA) Al-alloy in weight percentage

| Element       | 6061 Al-Alloy | 6082 Al-Alloy |
|---------------|---------------|---------------|
| Chromium      | Reference [20] | 0.22 Wt.% | Reference [21] | Max 0.25 Wt.% |
| Titanium      | 0.0-0.150     | 0.08         | 0-0.10         | 0.08          |
| Iron          | 0.0-0.70      | 0.55         | 0-0.5          | 0.41          |
| Magnesium     | 0.8-1.20      | 0.94         | 0.6-1.2        | 0.94          |
| Copper        | 0.15-0.40     | 0.33         | 0.0-0.10       | 0.08          |
| Silicon       | 0.4-0.8       | 0.67         | 0.7-1.3        | 0.97          |
| Zinc          | 0-0.25        | 0.15         | 0-0.20         | 0.14          |
| Manganese     | 0-0.15        | 0.12         | 0.4-1.0        | 0.51          |
| Others        | 0.05          | --           | 0.05           | 0.02          |
| Aluminum      | Balance       | Balance      | Balance        | Balance       |

The standard chemical analysis was taken from Ref[20] and [21] while the experimental analysis was done at SIER [state company for inspection and engineering rehabilitation in Iraq ] The majority of mechanical and properties physical of 6061 and 6082 Al-alloy were been listened in table 2.

**Table 2** mechanical and physical properties of 6061AA and 6082AA Base-alloy

| Properties                | 6061 Al-Alloy | 6082 Al-Alloy |
|---------------------------|---------------|---------------|
| Density gm/cm³            | Reference [20] | 2.7           | Reference [21] | 2.7           |
| Hardness (BHN)            | 30            | 31            | 40             | 41            |
| Ultimate Stress (MPa)     | 149.7         | 150.8         | 140            | 143           |
| Modulus of Elasticity(GPa) | 70-80        | 73            | 69             | 71            |
| Yield stress(MPa)         | 83            | 83            | 85             | 84            |

2.2 Reinforcement material

The nano particle material was been used in current work is TiO₂. The maximum size of particle was 15 nm and te purity was about (99.6 weight percentage) supplied by nanostructured and amorphous materials, Inc. (HOUSTON, TEXAS, USA), were been used as strength phase for the production of Al-TiO composites materials. The mechanical and physical properties of the (TiO₂) was shown in table 3.
Table 3 mechanical and physical properties of TiO\textsubscript{2} nanomaterial

| Property                      | Reference [20] | Current work |
|-------------------------------|----------------|--------------|
| Density gm/cm\textsuperscript{3} | 3.97           | 4.05         |
| Energy Content MJ/kg          | 100            | 150          |
| Bulk Modulus GPa              | 209.1          | 218.1        |
| Compressive Strength MPa      | 660            | 675          |
| Elastic Limit MPa             | 333.3          | 367.5        |
| Poisson's Ratio               | 0.27           | 0.29         |
| Shear Modulus MPa             | 90             | 112.5        |
| Young's Modulus GPa           | 230            | 288          |
| Fracture Toughness MPa.m\textsuperscript{0.5} | 2.4           | 3.3          |

2.3 Preparation of Composites
The method used was stir casting to prepare the 6061/TiO\textsubscript{2} and 6082/TiO\textsubscript{2} metal matrix composites. The TiO\textsubscript{2} strengthened particles was heated up to 200°C before added to the melting Aluminum alloys. The stir angler velocity at the rat (450) revolution per minute and 850°C was casted temperature. More details of the elaboration of Composites rig expended to prepare the composite can got at another place [23]. Figure 1 shows tensile test specimen the dimensions of specimens ASTM A-370.

![Figure 1](image)

Figure 1. Geometric shape of tensile test specimen.

In table 4 shown dimensions of the tensile test specimen, these dimensions of specimens were according to ASTM E-8 and E-8M. [22]

Table 4. the Dimensions Tensile Test Specimen.

| Dimensions                       | Test (mm) |
|----------------------------------|-----------|
| Gauge length (G)                 | 16        |
| Reduced section Diameter (D1)    | 4         |
| Radius of curvature(R)           | 4         |
| Grip diameter(D2)                | 8         |
| Distance between holders (B)     | 28        |
| reduced section Length(A)        | 20        |

3. Results
3.1 Hardness test results
In the current work for hardness test we choose Brinall hardness test, table 5 shows the experimental results for average of test on the central of the samples, while figure 2 shows the experimental results of Brinell hardness against the weight percentage of TiO\textsubscript{2} particles. It is clear that a significant increase in hardness of the MMCs when adding the TiO\textsubscript{2} particles, that may be the highest hardness of the nano particles, or by the enhancement of the bond in the crystal latest. [23].
Table 5 Hardness test results of 6061AA and 6082AA Base-alloy and nano composites

| Location  | Average Value (HB) | Location  | Average Value (HB) |
|-----------|--------------------|-----------|--------------------|
| As Cast   | Centre 31.0        | Centre    | 41.0               |
| Al / TiO₂ 0.5% | Centre 33.0       | Centre    | 43.5               |
| Al / TiO₂ 1.0% | Centre 34.8       | Centre    | 45.0               |
| Al / TiO₂ 1.5% | Centre 37.8       | Centre    | 48.5               |
| Al/TiO₂ 2.0% | Centre 35.9       | Centre    | 46.0               |

Figure 2. Experimental results of Hardness against the weight percentage of TiO₂ particles.

It is obvious, from the figure 2, that the hardness raise when the weight percentage of nanomaterial raise, the extreme raise of 21.9% for AA6061 and 18.29% for AA6068 happened at 1.5 % wt. TiO₂ contrast to as reserved. It is perceive from figure 2, the superior value of (BHN) was found at 1.5% weight percentage of TiO₂, but all the amount of Al / TiO₂ are higher than that of as reserved. The prime causes of this amelioration may be the followings: The high hardness of reinforcement particles TiO₂ could be refer to rise the hardness of Aluminium metal composite The low porosity and the identical distribution of reinforcement material cause high value of hardness. The most appropriate milling time leads to symmetric distribution of TiO₂ reinforcement nano-particles and decreased the volume of porosity led to in increase the hardness.

3.2 Tensile test UTS and yield Y.S (0.2% offset) strength
Test conditions; Temperature: 28 °c, Moisture: 48%, the tensile results obtained experimentally tabularized in table 6.

Table 6 Tensile (UTS) and yield (Y.S 0.2% offset) strengths

| Diameter (mm) | Area (mm²) | Gargle length (mm) | UTS (MPa) | Y.S (MPa) | Elongation % (ΔL/L) |
|---------------|------------|--------------------|-----------|-----------|---------------------|
| AsCast AA6061 | 6.04       | 28.72              | 30        | 150.8     | 83                  | 20.0                |
| AA6061/0.5wt. | 6.07       | 28.89              | 30        | 160.48    | 92.67               | 18.4                |
| AA6061/1.0wt. | 6.05       | 28.79              | 30        | 165.32    | 95.20               | 16.9                |
| AA6061/1.5wt. | 6.08       | 28.93              | 30        | 168.62    | 96.88               | 15.6                |
| AA6061/2.0wt. | 6.09       | 29.09              | 30        | 165.73    | 95.62               | 16.8                |
| AsCast AA6082 | 6.05       | 28.83              | 30        | 143.0     | 85                  | 18                  |
| AA6082/0.5wt. | 6.06       | 29.07              | 30        | 152.90    | 90.95               | 16.56               |
| AA6082/1.0wt. | 6.04       | 28.62              | 30        | 157.19    | 93.50               | 14.62               |
| AA6082/1.5wt. | 6.08       | 28.87              | 30        | 160.46    | 95.73               | 13.32               |
| AA6082/2.0wt. | 6.07       | 28.78              | 30        | 157.59    | 94.27               | 14.67               |
The result of Ultimate Tensile Stress test and Yield Stress test against wt. % nanoparticles (TiO$_2$) was plotted as showing in figure 3.

![Figure 3](image)

**Figure 3.** Experimental results of Tensile Stress and Yield Stress against nano particles reinforcement.

Aluminium metal matrix composites are exceedingly make use of for high rendering enforcement like aerospace, military, and the automotive industry. In request to get perfect mechanical properties the die and compression pressure in the casting process, is required [86]. Figure 4 shows the variation of UTS (Ultimate Tensile Strength) and 0.2 Y.S (Yield Stress) with the reinforcement material TiO$_2$ wt. %. It is clear that, the increasing wt.% of TiO$_2$ resulting in increase in the UTS and YS. However, the maximum increasing values occurred at 1.5 wt. % TiO$_2$ for both 6061 AA and 6082 AA 16.26% and 12.21% respectively compared to as cast for both of them. The strengthened properties may be due to the following purpose increase in dislocation density led to enhanced mechanical properties. The elevation of dislocation the density is coming from good inconsistency between the strengthened substance, and base material. The minimal porosity during manufacture, the nano composite performing lift up the ultimate tensile stress and yield stress properties.[26-27]. Figure 4 shows improvement in Ultimate Tensile Stress against (TiO$_2$) wt. % nano particles reinforcement, the improvement in Tensile Stress IP. = [(σ$_{uc}$ – σ$_r$)/σ$_r$] %, where; IP= improvements in ultimate tensile value, σ$_{uc}$ is Ultimate Tensile Stress of nano composite , σ$_r$ is Ultimate Tensile Stress of as cast materials.

![Figure 4](image)

**Figure 4** Improvement in Ultimate Tensile Stress against (TiO$_2$) wt. % nano particles reinforcement.
5.3.3 Ductility

Figure 5 shows the diversity of ductility with different weight percentage of TiO$_2$. It is clear that the ductility of AA 6061/TiO$_2$ diminution with increasing the reinforcement particles at all four stages of experimental work. Causing noticeable different compared to as cast. Based on the practical results obtained from the tests. It appears that there is a tendency in the ductility numbers towards a gradual decrease to reach a ratio of 1.5% to achieve the largest decrease. The reason for this decrease may be the increase in the bonding strength between the particles of the reinforced material with the substrate, which leads to the difficulty of sliding in the levels of the crystal lattice and thus the difficulty of formation. [25,27]

4. Conclusions

The understanding of the interaction between nano material and base metal matrix, which makes to improvement in mechanical properties, major remarks from this work are;
1. The best improvements in ultimate tensile stress was happened at 1.5% weight percentage of TiO$_2$ nanoparticle. The improvements were (16.29 %) and (12.21 %) for AA6061 and AA6082 respectively.
2- The consequence display that addition 1.5 wt. % of TiO$_2$ nano subdivisions to base metal alloys AA6061 and AA6082 as reinforcement increased(BHN) Brinell hardness by 32% for AA6061, and by 12.1% for AA6082.
3. The ductility of 1.5wt% TiO$_2$ nano-composite decrease by 32% for AA6061, and by 12.1% for AA6082.
4. The mechanical properties tended to improve may be due to increased cohesion between the alloy components of the nano composite can be either high bounding between TiO$_2$ and Aluminum, increased of the porosity of the master alloy, Or high dislocation density.

5. Reference

[1] Al-Alkawi H. J, M. Ibtihal A. Mahmood, Mamoon A. A. Al- Jaafari. 2018 Association of Arab Universities Journal of Engineering Sciences, 4 25.
[2] Zhang X, Zhou X, and Nilsson 2018 Corrosion behavior of AA6082 Al-Mg-Si alloy extrusion: Recrystallized and non-recrystallized structures, J O Corr. Sci. 144 163-17.
[3] Sun N and Apelian D 2019 Friction Stir Processing of Aluminum Alloy A206: Part II—Tensile and Fatigue Properties Int. J. Met 13 (2), 234
[4] Verma, N, Rao P, and Vettivel 2018 Characterization and experimental analysis of boron carbide and rice husk ash reinforced AA7075 aluminium alloy hybrid composite Journal of Alloys and Compounds 741, 981.
[5] P. A.shwathM. Anthony Xavior 2019, Compression and Diametric Tensile Strength Analysis of Grapheme–Al$_2$O$_3$ Reinforced AA 2024 and AA 2219 Hybrid Nanocomposites Advances in Micro and Nano Manufacturing and Surface Engineering p 19-32.
[6] Malaki, M.; Xu, W.; Kasar, A.K.; Menezes, P.L.; Dieringa, H.; Varma, R.S.; Gupta, M. Advanced Metal Matrix Nanocomposites .2019 Metals, 9, 330.
[7] Manikandan A, Omkumar M S, and Mohanavel V 2019. INFLUENCE OF ZrB2 ON THE MICROSTRUCTURAL CHARACTERISTICS OF AA6082/ZrB2 COMPOSITES Materials and technology 3, 327–332.

[8] Abbasi, M.; Sajjadi, S. 2018 Manufacturing of Al–Al2O3–Mg multilayered nanocomposites by accumulative roll bonding process and study of its microstructure, tensile, and bending properties. J. Compos. Material 52, 147–157.

[9] Ma, C.; Chen, L.; Cao, C.; Li, X. 2017. Nanoparticle-induced unusual melting and solidification behaviours of metals. Nat. Commun. 8, 14178.

[10] Lv, Z.; Ren, X.; Hou, H. 2018 Application of Accumulative Roll Bonding Process for Manufacturing Mg/2 wt.% CNTs Nanocomposite with Superior Mechanical Properties. J. Nanosci. Nanotechnol. 17, 4022–4031

[11] Khabushan, J.K.; Bonabi, S.B. 2017 Investigating of the Microstructure and Mechanical Properties of Al-Based Composite Reinforced with Nano-Trioxide Tungsten via Accumulative Roll Bonding Process. Open J. Met. 7, 9.

[12] Lakhi, K.S.; Park, D.-H.; Al-Bahily, K.; Cha, W.; Viswanathan, B.; Choy, J.-H.; Vinu, A. Mesoporous 2017 carbon nitrides: Synthesis, functionalization, and applications. Chem. Soc. Rev. 46, 72–101.

[13] Mohammed A-A H J, Rasiaq A A A- and Al- Jaafari M A 2018 Studying the effect of Different wt % AL2O3 Nanoparticles of 2024AI Alloy / AL2O3 Composites on Mechanical Properties Al-Khwarizmi Engineering Journal 14 7.

[14] Al-Qutub AM, Khalil A, Saheb N. 2013 Wear and friction behavior of Al6061 alloy reinforced with carbon nanotubes. Wear 297: 752–761.

[15] Al- Jaafari M A. 2020. Fatigue Behavior of Aluminum SiC Nano Composites Material with Different Reinforcement Ratio.; Materials Science and Engineering 870 012159.

[16] Dewangan S, Ganguly SK, Banchhor R 2018 Analysis of Al 6061–TiO2–CNT metal matrix composites produced by stir casting process. IJEMR 8: 147–152.

[17] Nossar AE, Nossar EE 2017 Properties of aluminum matrix nano composites prepared by powder metallurgy processing. J King Saud Univ Sci 29: 295–299.

[18] Simoes, S.; Viana, F.; Reis, M.A.L.; Vieira, M.F. 2017. Aluminum and nickel matrix composites reinforced by CNTs: dispersion/mixture by ultra-sonication. Metals: 7, 279.

[19] Zangabad, p. Khodabakhshi, A. Simchi, A.H. Kokabi. 2016 ”Fatigue fracture of friction stir processed Al–Al 3 Ti–MgO hybrid nanocomposites", International Journal of Fatigue, 87, 266-278.

[20] ASM.2019 (Aerospace Specification Metals) Material Data Sheet, asm.matweb.com

[21] ] International Alloy, 2019, Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys, Registrations recorded series, 6,18.

[22] ISO.2019. International Organization for Standardization, recorded series 67. 210-211

[23] Al- Jaafari MA 2017’Cryogenic treatment effect on fatigue behavior of nano composite” Ph.D. Thesis, university of Technology.

[24] Designation:A-370 and E8/E8M "Standard Test Methods for Tension Testing of Metallic Materials " ASTM International, 8.11.

[25] Ravichandran M, Naveen SA, Anandakrishnan V 2015 Synthesis and forming characteristics of Al–TiO2 powder metallurgy composites during cold upsetting under plane stress state conditions. J Sandw Struct Mater 17: 278–294.

[26] Designation: 2019, E10/E10M "Standard Test Methods for hardness Testing of Metallic Materials” ASTM International,3,16.

[27] Nageswaran G, Natarajan S, Ramkumar KR 2018 Synthesis, structural characterization, mechanical and wear behaviour of Cu–TiO2–Gr hybrid composite through stir casting technique. J Alloy Compos 768: 733–741.

[28] Kumar CAV, Rajadurai JS .2016. Influence of rutile (TiO2) content on wear and microhardness characteristics of aluminium-based hybrid composites synthesized by powder metallurgy. T Nonferr Metal Soc 26: 63–73.