Dynamic Modeling of Three Links Robot Manipulator (Open Chain) with Spherical Wrist

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Abstract
The study here under describes the impact of adding a nano-scaled ceramic particles on the mechanical and fatigue behaviors of aluminum matrix composites AMCs containing 0.5, 1.0, 1.5, and 2 % wt. of nano-scaled B4C and Al2O3 particles were dispersed in molten aluminum by the stir-casting process. Vickers, tensile, and fatigue devices were utilized to evaluate the mechanical behavior of composites in the fabrication process. The results show that increasing the weight percentage of nano-ceramic particles increased the hardness, maximum tensile stress, and fatigue strengths of the base alloy. Furthermore, all of the above behaviors of AMCs reinforced with B4C particles are better than those of AMCs reinforced with Al2O3 particles.

Keywords: Hardness, Ultimate tensile stress, Aluminum matrix composites, nano-ceramic particles.

1. Introduction
Metal Matrix Composite (MMC) is a novel type of engineering material in which a strong ceramic reinforcement is dispersed into a metal matrix to enhance behaviors such as strength, elastic modulus, tribological characteristics, excellent corrosion resistance, and high fatigue properties that are impossible to obtain in bulk metals or super alloys[1][2]. MMCs are composed of metals or alloys as matrix phase and particles or whiskers, continuous or discontinuous fibers as reinforcement. There are many reinforcements that have been used as functional reinforcement for promoting the mechanical properties of aluminum-based alloys AlN [3], TiO2[4], Al2O3 [5], SiC [6], and B4C [7].

MMCs combine the metallic features of matrix alloys (ductility and toughness) with the ceramic behaviors of reinforcements (high strength and modulus), resulting in increased shear and compression strength [8].

MMCs can be fabricated by different manufacturing processes, including mechanical alloying [9], powder metallurgy and various melting processes [10]. Melting process which includes the dispersion of ceramic reinforced particles into molten metals and alloys offers certain significant advantages, such as stronger matrix-particle bonding, easier matrix structure control, simplicity, and cheap processing cost when compared with the powder metallurgy. However, the melting process has two
fundamental problems which are first, the poor wet ability between the molten metal matrix and ceramic particles, and secondly, the ceramic particles tend to be float over the surface of the molten matrix and this due to their low density in compare with the liquid metal, hence, the dispersion of the ceramic particles will not be uniformly as required.

AMCs strengthened with dispersion ceramic particles such as SiC, B4C or Al2O3 are gradually grown and increasingly employed in variety of new applications. They are considered competitive to other materials in many industry fields such as automotive industries like (connecting rods, pistons, cylinder heads), and airplanes due to their improvement against the fatigue failure.[11].

Fatigue failure usually occurs in a numerous of machine components as well as structures subjected to dynamic and variable loads. Under these conditions, the failure can occur at a stress level that is much lower than the tensile or yield strength for a static load. Furthermore, it is both catastrophic and insidious, happening very quickly without forewarning[12][13].

2. Literature review:

A lot of researches have been done to study the mechanical characteristics of AMCs reinforced with nano-ceramic and their fabrication. Alalkawi et al. [14][touched upon using the stir casting technique to manufacture a 10% wt% of Al2O3 nano-composites by adding 50nm Al2O3 nano-ceramic particles to the 6061 Al alloy. The experimental results observed that the addition of 10 wt% Al2O3 improved constant and cumulative fatigue. The experimental outcomes displayed that the dispersion of 10 wt% Al2O3 enhance constant and cumulative fatigue. While Faisal and Kumar [15] studied the effect of the presence of nano-SiC on the mechanical and tribological behaviors of AMCs containing 0, 0.5, 1, 1.5, 2, and 2.5 wt.% of nano scaled SiC which are added by mechanical stirring. The results showed that adding these particles had increased wear resistance, tensile strength, elastic modulus, shear modulus, and flexural shear modulus, as well as increased brittleness behavior. Meanwhile, Venkatesh and Deoghare [16] created an aluminum-kaoline composite using a powder metallurgical method.

They reported that the addition of hard ceramic particles like Al2O3 and SiO2 in Kaoline improved the hardness, tensile, and compression strength of the manufactured composite. Srivayas and Charoo [17] reviewed different reinforcements, fundamental mechanical and tribological behavior on AMCs in dry and lubricated sliding circumstances. It has been demonstrated that various metal matrix reinforcements may be used to reduce friction and wear in tribological implementations. Bodunrin et al. [18] tried to investigate the various reinforcing material blending used in the manufacture of hybrid AMCS. The findings of this study on different reinforcements are encouraging, since they showed a significant improvement in the properties of the composites produced when compared to the unreinforced alloy.

This study aims to investigate the mechanical and fatigue property of the Al6061 alloy strengthened with B4C and Al2O3 particles.

2. Experimental work

1- Materials

The matrix material in this study was Al6061 alloy, which has a wide range of uses, easy to fabricate[19], while 50nm B4C particles and 50nm Al2O3 particles with weight fractions (0.5, 1, 1.5, and 2) wt% were employed as reinforcements[20]. Spectro Spark Analyzer machine (CE, Gmb and KG Co., Germany, 2008) was used for the chemical analysis of the Al6061 alloy. The chemical analysis of materials is shown in Table 1.

<table>
<thead>
<tr>
<th>Element</th>
<th>Mg</th>
<th>Fe</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>V</th>
<th>Ti</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight %</td>
<td>2.2</td>
<td>0.1</td>
<td>0.9</td>
<td>0.3</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Weignt%</td>
<td>6</td>
<td>0.7</td>
<td>0.6</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

2. Composite Synthesis and Testing Procedure

Initially, 750 grams of Al6061 alloy were charged into the crucible in tiny cut pieces and heated in an electrical resistance furnace to 700 degrees. After melting 1% magnesium coated with aluminum foil was added to molten alloy with the aim of increasing more wettability of the alloy[21][22]. Also, 0.5, 1, 1.5, and 2% of preheated nano-scaled B4C were added to the molten mixture and mixed with mechanical stirring until the mixture reached semi-past stage with the goal of achieving good particle distribution in the molten alloy. Finally, the mixture was poured into metallic mold. The billets were air cooled to room temperature after fabrication. Al2O3 particles were used in the same way[23]. The resulted composites and unreinforced base alloy billets were machined out to tensile tests ASTM and fatigue samples on CNC lathe machine showed in Figs (1) and (2). The surface of samples was grinded on 1000 grit abrasive papers X-ray diffraction XRD and scanning electron microscope were used for recognizing the base alloy and investigation changes in its structure after adding and dispersion reinforcements in it. Micro-hardness testing for the produced composites was performed using a vickers diamond indenter. The load was applied for 15 seconds. The test was done three times, with the average being kept. While tensile testing machine was used for measuring tensile strengths of base alloy and composite samples. Fatigue samples were tested on fatigue tester machine MT3012, Germany. The tester is driven by an induction squirrel cage motor 3000 r.p.m. On one side, the motor is coupled to a counter mechanism that reads a seven-digit number, and on
the other side, it is tied to a shaft with a conical fixture for holding fatigue samples.

![Fatigue Sample](image1)

**Fig. (1):** shows tensile sample

The loading device is made up of a spherical ball bearing and a tiny switch that shuts down the motor when a failure occurs.

The loading on the test sample is increased by turning the loading wheel clockwise. The loading is measured using a spring balance (F). The value of (F) was discovered to be as follows.

\[ \sigma_{bending} = \frac{FL}{d^3} \]  \[\text{[24]}\]  
\[ \sigma_{bending} = 0.4 \sigma_{\max} \]  \[\text{[25]}\]

Where:
- \( \sigma_{bending} \) is the bending stress in MPa
- F is the applied load in N at the free end of the samples
- L and d are the length and diameter of the fatigue sample
- \( \sigma_{\max} \) is the ultimate tensile stress in MPa for aluminum alloy = 310 MPa.

Fatigue samples subjected to different stresses 50, 100, 150, 200, 250, 300, 350 and 400 MPa. On the other hand, the number of cycles during which the test samples were subjected to fracture was recorded.

4. Results and Discussion:

The fabricating AMCs which containing ceramic particles during casting process is typically problematic due to poor wettability and agglomeration of nanoparticles in the melting alloy. Figure (3) XRD pattern shows Al6061 aluminum solid solution. While figure (4), SEM shows the developed AMCs. Regular distribution and dispersion of nanoparticles besides agglomerated nanoparticles of B\(_4\)C were seen in the base matrix.

XRD pattern of the Al\(_2\)O\(_3\) reinforced composite presented in Figure (5). It shows that the fabricated composite is consisting of aluminum and Al\(_2\)O\(_3\) in addition to spinel (Al\(_2\)Al\(_2\)O\(_6\)Mg). These phases are formed after the casting and fabrication of the AMCs which all shall modify the properties of the composite.

Figs. (6) and (7) show the result of micro-Vickers hardness number and the ultimate tensile stress of base alloy and composites versus weight fraction of ceramic particles. It was recorded that the hardness and maximum tensile stress of composites are higher than the base alloy because of the function of nano-ceramic reinforcements in the aluminum. These particles act as: firstly, the ceramic particles tend to prevent the mobility of the grain boundaries and limit the grain growth. Secondly, the change in deformation of hard ceramic particles and soft aluminum matrix during plastic deformation assists in the fragmentation of grains. It was also shown that hardness and maximum tensile stress of B\(_4\)C reinforced composite is higher than Al\(_2\)O\(_3\) because the hardness and stiffness of B\(_4\)C higher than Al\(_2\)O\(_3\).
Furthermore, the thermal expansion coefficients of B₄C are different. Additionally, the variation in the coefficient of thermal expansion for B₄C and Al₂O₃ (4.5 * 10⁻⁶ °C⁻¹ for B₄C and 8.8 * 10⁻⁶ °C⁻¹ for Al₂O₃) also is another factor in reducing the hardness.

Fig. (8), Fig. (9) and Fig. (10) indicate the result of cycles to failure versus composites weight fraction of nano-ceramic particles. The number of cycles to failure increase with increasing of weight percentage of reinforcement due to addition and dispersion of these reinforcement particles in the base alloy. These particles block the movement of dislocations and produce a definite strengthening effect. The average block increase with increasing weight fractions of reinforcement. Also, it was shown that the cycles to failure of AMCs reinforced with B₄C are slightly greater than AMCs reinforced with Al₂O₃ particles. This is attributed to the high mechanical properties of B₄C particles compared with Al₂O₃ particles in which the ultimate tensile strength of B₄C and Al₂O₃ is 6.5 GPa and 1.5 GPa. At the same time Vickers hardness for B₄C and Al₂O₃ is 2500 kg/mm² and 1100 kg/mm² respectively.

Figures (11) and (12) indicated the relation between the cycles to failure versus fluctuating stress for the base alloy and AMCs. Increasing cycles to failure result from elastic–plastic fracture mechanism. This mechanism causes the nucleation and growth of a crack due to the applied cyclic stress. Due to this reason the fatigue failures seem occur so suddenly that the bulk of the changes in the material are not visible. Also, it seems that the unreinforced base alloy and AMCs do not have a fatigue limit because of external factors (such as: the internal structure of material, the alignment of sample, the general shape the sample test, the surface roughness of the sample under stress), in addition to the external factors (fabricating and specifications).
Fig (11): Alternating stress versus cycles to failure for AMCs strengthened with B₄C particles

Fig (12): Alternating stress versus cycles to failure for AMCs strengthened with Al₂O₃ particles

5. Conclusions

In this investigation, the impact of addition 0.5%,1%,1.5%,2% B₄C and Al₂O₃ nano-scaled ceramic on mechanical properties and fatigue behavior of AA6061 alloy were studied. The ceramic inclusion had shown noticeable improvements in mechanical behaviors (i.e., hardness and maximum tensile stress), and fatigue behavior.

- The hardness value of AMCs increased with increasing of wt% of ceramic particles.
- The maximum tensile stress of AMCs increased up to 303 MPa.
- The hardness value and maximum tensile stress of AMCs reinforced with nano-scaled B₄C is a little bit higher than nano-scaled Al₂O₃.
- The addition of 0.5%,1%,1.5%,2% B₄C and Al₂O₃ nano-scaled ceramic cause improvement in the fatigue life of the AA6061.

6. References

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