1. Introduction

From decades ago, the effectiveness of materials improved, new forms have played a key role in the development of science and technology. Advances in physics and technology are difficult without the use of advanced effective materials. To meet their needs, the researchers manufactured and handled materials in the development process. However, an appropriate correlation has not been settled between the properties of a quantity with materials of nanomaterials size. Thus, in current technology researchers are repetitively researching, investigating and trying to get used to new innovative materials. And the necessary scientific research has been conducted related to the improvement of mechanical properties and the factors that affect them, especially stirring temperature and geometric flexibility is a big challenge all the time. Each method of preparing AA6061/Al2O3 nanocomposites can provide different mechanical properties. In the present study, nine nanocomposites were prepared at three stirring temperatures (800, 850, and 900 °C) with the level of Al2O3 addition of 0, 5, 7, and 9 wt %. The results of tensile, hardness and fatigue tests revealed that the composite including 9 wt % Al2O3 with 850 °C stirring temperatures has the best properties. It was also revealed that the 850 °C stirring temperature (ST) with 9 wt % Al2O3 composite provide an increase in tensile strength, VHN and reduction in ductility by 20 %, 16 % and 36.8 % respectively, compared to zero-nano. Also, the fatigue life at the 90 MPa stress level increased by 17.4 % in comparison with 9 wt % nanocomposite at 800 °C (ST). Uniform distributions were observed for all nine microstructure compositions.

Keywords: 6061 aluminum alloy, Al2O3 nanoparticles, nanocomposites, stirring temperatures, stir casting method, mechanical and fatigue properties.
Furthermore, [4] investigated the influence of adding reinforcements into the metallic matrix on the mechanical properties. The major points derived from this study state that increasing the reinforcement ratio and decreasing the size of reinforcement particles considerably improve the properties of metal matrix composites. In addition, wear resistance and creep have been studied as other important factors that are not often discussed. Increasing the Al2O3 fraction reduces the fatigue toughness of AMCs. The addition of zircon advances the strength of AMCs. Moreover, in [5], 10 wt % of Al2O3 nanomaterial were added to AA6061 in applying the stir casting method for producing nanocomposites. The comparison between 6061 aluminum alloy metal matrix and 10 wt % Al2O3 nanocomposites revealed that there is a 12.8 % improvement in the fatigue strength at 10^7 cycles. The optimum conditions of stirring speed and pouring temperature for the 6061 aluminum alloy; 12.8 % improvement in the fatigue strength at 10^7 cycles. The Al2O3 nanoparticles cast have homogeneity in the primary phase by utilizing appropriate weak electromagnetic stirring and increasing pouring heat temperature, which produces a low superheat pouring. Moreover, they have found that at a certain limit, the mechanical properties change drastically in the direction of not getting better. Besides, [8] studied evaluation emphasizes the optimization of stirring speed and pouring temperature for the properties of aluminum matrix composites. Several heights of pouring temperatures at a constant pouring speed of 2.5 cm/s were studied as input parameters throughout. The experimental results indicate that a pouring temperature range of 700 °C to 750 °C and 400 to 600 °C stirring speed offered developed mechanical properties. So, the focus of this analysis is to optimize the stirring speed, the stirring speed and the pouring temperature for mechanical properties. In addition, [9] studied the optimum conditions for preparing composites reinforced with 5 wt % nanoparticles cast at 850 °C. The study concluded that the optimum conditions for the fabrication of composites after several experiments with reinforced nanoparticles cast have homogeneity in the micro-structures and exhibit increased mechanical properties such as hardness and tensile strength. That is why we found that the improvement takes place in a certain percentage, after which these properties change without improvement.

Based on previous studies, it can be concluded that the addition of nanocomposite materials in certain proportions with scientific manufacturing methods leads to an improvement of mechanical properties in general. The current study emphasizes this trend. Hence, in this investigation, an attempt was made for preparing three types of nanocomposites at three stirring temperatures (800 °C, 850 °C, and 900 °C) using the stir casting method. A detailed characterization, including the mechanical and fatigue properties of the three composites, is made and then the comparison is carried out between the prepared nanocomposites with detailed discussions.

3. The aim and objectives of the study

The aim of this study is to determine the effect of stirring temperature (ST) on the AA6061/Al2O3 nanocomposite.

To achieve this aim, the following objectives are accomplished:
- to improve the mechanical properties, including the hardness, tensile strength and fatigue strength of 6061 aluminum alloy;
- to prepare nanocomposites at three stirring temperatures with a uniform distribution in certain cases.

4. Materials and methods

6061 aluminum alloy is applied in the present study as it is widely utilized for different purposes in the aerospace and transportation industries. The chemical composition of AA6061 is as follows: Cu 0.31, Mg 0.98, Zn 0.17, Cr 0.22, Ti 0.09, Fe 0.52, Mn 0.11, Si 0.66, and Al balance. The reinforcement nanomaterial Al2O3 had a density of 3.62 gm/cm^3 and a particle size between 20 and 30 nm [11].

The stir casting method adopted for fabricating nanocomposites is as follows: AA6061 was cut into cubes with 1 to 2 cm^3, then washed with alcohol and followed by distilled water five times. The washed parts were then dried by the stream of hot air at a temperature of 100 °C, later the dried parts were heated to approximately 200 °C using an electric heater. Argon gas was pumped into the oven and heated to 800, 850 and 900 °C stirring temperature, and preheated the Al2O3 particles to 200 °C. Then finally, nanomaterials were added into the molten aluminum alloy with a gas pump. The furnace temperature was initially elevated over the liquid temperature of aluminum about 800, 850, and 900 °C. The first 800 °C, the second sample was heated to about 850 °C and the third sample was mixed at 900±10 °C to melt the aluminum alloy totally and then cooled down just below 650 °C.

The stirring time was designed for 4 minutes at 450 rpm stirring speed. The Al2O3 particles were added to the melt in the furnace, and then the mixing temperature was raised to 800 °C±10 °C. The liquid was poured into molds to acquire an aluminum rod for the composites that are shaped in the
form of a cylinder of 14 mm external diameter and length of 160 mm. The equipment used for the stir casting method is shown in Fig. 1. Furthermore, Table 1 shows the rule of the mixture using AA6061 as a metal matrix.

| Rule of the mixture adopted in this work |
|------------------------------------------|
| Al₂O₃ wt % | Al₂O₃ (gm) | AA6061 (gm) | Total nanocomposite (gm) |
|-----------|-----------|-------------|-------------------------|
| 5 %       | 50        | 950         | 1,000                   |
| 7 %       | 70        | 930         | 1,000                   |
| 9 %       | 90        | 910         | 1,000                   |

The tensile test was carried out using a WDW-100 tensile machine that has a maximum capacity of 100 kN. Eighteen specimens were used from the fabricated round rods of diameter (d)=10 mm and length (L)=160 mm. The deformations were recorded by measuring devices and automatic control. The data were plotted by the plot device. The tensile curves (stress-strain) were employed for predicting the material behavior under different loading.

The standard tensile specimens were made according to the American Society for Testing and Materials (ASTM E8/E8M-09), as shown in Fig. 2, where all the appeared dimensions were measured in (mm). While the tensile test rig is illustrated in Fig. 3. In this paper, Vickers hardness numbers (VHN) were measured using polished samples with different stirring temperatures (800, 850, and 900 °C).

All fatigue tests were carried using a rotating fatigue test rig (ISTRON) as presented in Fig. 3.

The measurements of mechanical properties were carried out at 800, 850, and 900 °C stirring temperatures. Table 2 outlines the results of mechanical properties of AA6061 and nanocomposites with wt % variations of 0, 5, 7 and 9 % Al₂O₃ using stirring temperatures of 800, 850, and 900 °C.

It can be noticed from Table 2 that the mechanical properties of nanocomposites are influenced by stirring temperature and wt % Al₂O₃ nanoparticles. The results of UTS of this investigation applying stirring temperatures of 800, 850, and 900 °C are summarized in Fig. 4–6, respectively. Obviously, the UTS of the nanocomposites increases from 156 to 196 MPa and YS increases from 141 to 164 MPa while the VHN increases from 99 to 118. However, the ductility reduces from 15.2 % to 9.6 % for the best stirring temperature (ST) of 850 °C and 9 wt % of Al₂O₃. Furthermore, an improvement percentage was recorded to be 20.4 %, 14 %, and 19.2 % for UTS, YS, and VHN respectively, while the enhancement percentage in ductility was reported to be 36.8 %. So far, the outcomes are in the same trend as [12]. As they blended AA7075/Al₂O₃ nanocomposites using the stir casting technique at 850 °C stirring temperature with 0, 1, 3, and 5 wt % of Al₂O₃.

The optimal Ultimate Tensile Strength (UTS) of 196.542 MPa and Yield Stress (YS) of 164.435 MPa are obtained from the nanocomposite with 9 % Al₂O₃ at 850 °C and 4 min. stirring time as presented in Fig. 6. The increasing degrees of UTS and YS of 20.4 % and 14 %, respectively, compared to zero-nano (matrix component).

The uniform distribution of Al₂O₃ into a matrix and relatively lower porosity in the casting led to high-density dislocations leading to an enhancement of mechanical properties. It can be concluded that 6061 Al alloy-based composites with 9 % Al₂O₃ possess better mechanical properties. All the fabricated nanocomposites show improvement in hardness and ductility. The 9 % Al₂O₃ composite shows an optimal improvement in hardness and ductility at 850 °C stirring temperature. The hardness of 9 % Al₂O₃ at 850 °C increased by 16 %, while the ductility enhanced by 36.8 %. These findings are somehow aligned with [13], where they fabricated and examined 2024/Al₂O₃ nanocomposites to obtain the improvement in mechanical properties.
The results of the VHN hardness of the matrix are shown in Fig. 7. Important developments in mechanical properties and hardness were recorded from adding Al₂O₃ in the matrix. The reason could be that Al₂O₃ particles act as obstacles to the motion of dislocations and Al₂O₃ particles work as a barrier to crack initiation and slip band [14, 15]. In addition, Al₂O₃ particles are harder than those of the base metal leading to the improvement of mechanical properties and VHN of the composites. The fairly distributed particles of Al₂O₃ resulted in the development of the mechanical properties of the composites [16].

The results of ductility tests show that an increase in Al₂O₃ leads to ductility reduction. The maximum decrease occurred for the composite including 9 wt % Al₂O₃ achieved at 850 °C stirring temperatures. Once again, the result is confirmed by [17], who have found that increasing the amount of Al₂O₃ improves UTS and VHN. Nevertheless, the ductility tends to reduce, and the peak reduction is obtained at 6 wt % Al₂O₃ with 850 °C stirring temperature. An improvement in mechanical properties and hardness with a reduction in ductility may be due to the thermal mismatch between the base metal and Al₂O₃ particles [18, 19].

The specimen has a round cross-section and is affected by the employed load from the perpendicular axis to the right side of the workpiece, improving the bending moment. Hence, the surface of the workpiece is under compression and tension stress when it rotates. Three samples were tested for each stress level. The results showed that the samples manufactured at 850 °C (ST) have a longer fatigue life than others, as shown in Table 3. The outcome of these experiments can be applied to the relationship between the stresses used and the number of cycles to failure.

### Table 2

| Al₂O₃, wt %  | UTS (MPa) | YS (MPa) | VHN | Ductility |
|--------------|-----------|----------|-----|-----------|
| 800 °C       |           |          |     |           |
| 850 °C       | 151.22    | 170.55   | 156.75 | 145.46    |
| 850 °C       | 178.56    | 182.23   | 177.28 | 176.65    |
| 850 °C       | 186.23    | 196.54   | 181.24 | 176.65    |
| 900 °C       | 151.22    | 170.55   | 156.75 | 145.46    |
| 900 °C       | 178.56    | 182.23   | 177.28 | 176.65    |
| 900 °C       | 186.23    | 196.54   | 181.24 | 176.65    |

Fig. 4. UTS, YS, with the percentage at stir casting Temp. 800 °C of the weight percentage of Al₂O₃

Fig. 5. UTS, YS, with the percentage at stir casting Temp. 850 °C of the weight percentage of Al₂O₃

Fig. 6. UTS, YS, with the percentage at stir casting temp. 900 °C of the weight percentage of Al₂O₃

The results of the VHN hardness of the matrix are shown in Fig. 7. Important developments in mechanical properties and hardness were recorded from adding Al₂O₃ in the matrix. The reason could be that Al₂O₃ particles act as obstacles to the motion of dislocations and Al₂O₃ particles work as a barrier to crack initiation and slip band [14, 15]. In addition, Al₂O₃ particles are harder than those of the base metal leading to the improvement of mechanical properties and VHN of the composites. The fairly distributed particles of Al₂O₃ resulted in the development of the mechanical properties of the composites [16].

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5.2. Uniformity of AA6061/Al2O3 nanocomposites

After preparing the nanomaterials according to weight and inserting them into the alloy, the Al2O3 nanoparticles acted as barriers of dislocations leading to improved fatigue behavior and mechanical properties. Moreover, the interaction between the nanoparticles and dislocations plays a significant role in developing the mechanical and fatigue properties [20].

Concerning the scanning electron microscope (SEM) testing, Fig. 11 presents the SEM photographs of: a) zero-nanoparticles at 850 °C, b) 9 wt % Al2O3 at 850 °C, and c) 9 wt % Al2O3 at 900 °C.

Fig. 11. The main signature: a – as received; b – 9 wt % Al2O3 at 850 °C; c – 9 wt % Al2O3 at 900 °C (ST), for SEM photographs of AA6061/Al2O3

The research can be considered useful, as the results have given important indications to the improvement of many properties compared to the untreated alloy. Because of this improvement, this alloy can be used in numerous applications, which use AA6061.

This research is a continuation of many research studies in which many kinds of nanomaterials have been used in different proportions and multiple methods of preparation. These studies were concerned with the improvement of the mechanical properties of alloys. The development of this method can be used for various aluminum alloys, which may enhance the mechanical and fatigue properties with different quantities of nanomaterials depending on the interaction between the aluminum alloys and the ratio of nanoparticles.

6. Discussion of experimental results of determining the effect of stirring temperature (ST) on the AA6061/Al2O3 nanocomposite

The findings refer to the improvement of the properties by reassuring that the Al2O3 nanoparticles acted as dislocation barriers leading to improved fatigue behavior and mechanical properties. The features of the proposed method indicate that the properties of the new composites give an improvement in the exact case. This was observed in Fig. 5. It is possible to observe the significant increase in ultimate tensile strength (UTS) and yield stress (YS). The results of the VHN hardness of the matrix shown in Fig. 7 can also be observed enhancing up to 16%, while the ductility enhanced by 36.8%, as shown in Fig. 8. The maximum enhancement for ultimate tensile strength, yield stress, hardness and ductility occurs when the composite is produced with the addition of 9 wt % of the nanomaterial to a mixture at 850 °C.

This method can be considered a great advantage in improving mechanical properties. But the nature, purity and cost of nanomaterials can be an impediment to successful outcomes. Therefore, research and studies must be conducted to obtain pure and cost-effective nanomaterials.

The limitations of this method can be represented in obtaining a uniform distribution of nanomaterials unless there is an in-depth study of the molecular structure, which enhances the results gained.

One of the focal disadvantages related to nanomaterials is considered to be inhalation exposure. This concern stems from studies in humans that suggest that nanomaterials can cause adverse effects on the lungs. Therefore, caution should be taken when conducting experiments.

The research can be considered useful, as the results have given important indications to the improvement of many properties compared to the untreated alloy. Because of this improvement, this alloy can be used in numerous applications, which use AA6061.

This research is a continuation of many research studies in which many kinds of nanomaterials have been used in different proportions and multiple methods of preparation. These studies were concerned with the improvement of the mechanical properties of alloys. The development of this method can be used for various aluminum alloys, which may enhance the mechanical and fatigue properties with different quantities of nanomaterials depending on the interaction between the aluminum alloys and the ratio of nanoparticles.

7. Conclusions

1. The present investigation revealed with an indication of qualitative or quantitative indicators of research results that the 850 °C stirring temperature with 9 wt % Al2O3 compos-
ites provides better mechanical properties, hardness and fatigue properties than the other stirring temperature of 800 °C and 900 °C and the stirring temperature has an important effect on the above properties. The composite with 9 wt % Al\textsubscript{2}O\textsubscript{3} stirring at 850 °C exhibits the highest hardness and lowest elongation compared to the other stirring temperature.

2. Analysis of SEM showed evidence for incorporating the Al\textsubscript{2}O\textsubscript{3} nanoparticles with the metal matrix. And the AA6069 / wt % Al\textsubscript{2}O\textsubscript{3} nanocomposite with 850 °C (ST) exhibited high strength and fatigue life compared to the other produced nanocomposites and base metal.

Acknowledgments

The authors acknowledge the Iraqi Ministry of Higher Education and Scientific Research for their support of this research.

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