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IMPROVING THE PROPERTY OF WEAR RATE AND HARDNESS BY ADDING HYBRID NANOMATERIALS TO AA7075

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Aluminum alloys have become an essential material in many modern applications, such as automobiles, marines and aviation industries. It is expected that more applications will heavily depend on aluminum alloys to reduce the weight and maintain safety standards, many previous studies have done in this regard. Numerous of these applications' parts could be subjected to different loading and environmental conditions. This includes wearing stress and loss of the surface properties. To address these issues, intensive researches have been conducted aiming to improve aluminum wear resistance. However, there is an increasing demand to provide a comprehensive understanding of the mechanisms of enhancing wear resistance. Preparation of nano-materials combined with aluminum alloy can be made in several known metallurgical methods. One of the most important difficulties and challenges faced in the manufacture of these nano-materials is to obtain a homogeneous mixture that does not have manufacturing defects. The present work aims to process and evaluate the Nano-hybrid composites of with different ratios of (Cu+Ti) mixed with AA7075 by using the liquid stir casting method by using (pin-on-disc) wear testing apparatus.

The results showed when using multiple speeds and different loads in practical experiments, that the volumetric wear loss increase from 2.8 mm^3 to 29.89 mm^3 for zero–Nano and from 0.889 mm^3 to 3.09 mm^3 for 0.8 %+0.3 % (Cu+Ti) composite at speed 100 to 300 respectively. And from 12.81 mm3 to 0.889 mm3 at 25 N. The coefficient of friction is reduced with the addition of reinforced material at 0.8 %+0.3 % (Cu+Ti) composite from 0.172 to 0.05. The hardness (BH) of the prepared composites increases with increasing the amount of hybrid Nano–reinforced materials. The enhancement percentage of 25.4 % is attained compared to the matrix material. These additions, which were in certain proportions, improved the mechanical properties

Keywords: AA7075, nano-hybrid material, wear rate, coefficient of friction, hardness test

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1. Introduction

Aluminum alloys have been widely used in many important applications. Many of these parts that are made of aluminum alloys are subjected to different types of loading systems that can result in many cases to wear of these parts which leads eventually to reduce the expected life of these parts. Here the need ascended to improve the mechanical properties of such alloys. This is actually achieved through several research in this area. Through the use of multiple and different nanomaterials and in certain proportions. Improving the wear resistance now becomes an urgent need with the expected expansion of aluminum utilization in different applications where high strength and low weight are required.

In confirmation of what was mentioned above, the insertion of alloys with reinforcing materials such as nanomaterial of certain types and in specific proportions increases the improvement of the mechanical properties. Therefore, copper and titanium were added as nanomaterial in certain proportions using the liquid stir casting method, and the volumetric wear loss of the metal, wear rate, hardness and coefficient of friction were considered.

Therefore, the research on the development the wear properties of aluminum alloy 7075 is relevant with a well-known nanoparticle addition.

2. Literature review and problem statement

There are many studies commerce with several aspects related to enhancing mechanical properties and particle distribution, which can effect on the material properties. Improving the aluminum wear resistance can be achieved by implying some metal elements with the aluminum matrix, by study [1] the results showed that nanomaterials added can be relied upon by answering questions related to additives according to the obtained results, and the reason may be to obtain a homogeneous mixture that meets the requirements of the research. This study found that Ni alloy can be more used when TiC as a nonomaterial is added.

And knowing the effect of two different nanomaterial when they are added to the aluminum alloy. The study by [2] is concerned with this field. This study specifically pointed an effect the dispersed Graphite and SiC in Al6061 alloy contributed in enhancing the tensile strength of the composites. The mechanism is varied depends on these elements' types, ratio, and the ability to be mixed with aluminum matrix. Studied on the Al6061-SiC & Al6061-SiC/Graphite hybrid composites by comparing their mechanical properties. The composites were prepared using the stir casting method in which the amount of reinforcement varied from 5–15 % in steps of 5 wt %. With the composites gathered in limited places, the microphotographs showed a uniform distribution of the particles in those compounds. In all compounds, the theoretical densities were more than the experimental densities. The tensile strength of the composites was improved through the effective contribution of silicon carbide and scattered Graphite in the aluminum alloy Al6061. This study specifically pointed an effect. The dispersed Graphite and SiC in Al6061 alloy contributed in enhancing the tensile strength of the composites.

In continuance of the previous study, the contribution of [3] the additives were increased to determine the extent of the effect of these additions. The influence of Zr-substitution on the magnetic properties of [(PrNd)0. 32La0.22Ce0.46]22.0Fe76.7-xZrxB1.3 (x=0, 2.5, 5, 7.5 wt %) melt-spun powders. The results showed that adding Zr-substitution could increase the volume fraction of the 2:14:1 phase and prevent the consistency of $CeFe_2$. Moreover, the grain sizes of α-Fe and 2:14:1 phase could refine by using Zr-substitution. In order to expand the study of the effect of added nanomaterials, the following two studies found and supported the effect of these materials under their different terms, reduce the $CeFe_2$ phase and the formation of the Fe_2Zr phase could develop the antioxidation. As the grain sizes reducing, the magnetic properties were enhanced and therefore the corrosion resistance of the nanocomposite magnets was lowered. This study showed that adding materials to improve the corrosion property had an opposite effect on improving the magnetizing property [4]. The magnetic properties and mechanical properties were investigated in addition to evaluating the microstructure of the aluminum matrix after it was manufactured by adding varying amounts of magnetic nanoparticles of nickel ferrite [5]. The results showed that the relative density of the composites decreased by increasing the reinforcement weight percent. Furthermore, the yield stress and ultimate tensile strength also increased by increasing the weight percentage of the reinforcement up to 5 wt %. In this study, it was proven that 5 wt % of the additives are more effective. This proves that the increase in additives is not always an optimal solution. In this next study, it gave a convincing impression through the results that adding one nanomaterial is better than two. Magnetic composites $SrFe_{12}O_{19}/ZnFe_2O_4$ intended specimens with a various molar ratio of $SrFe_{12}O_{19}$ to $ZnFe_2O_4$ were characterized and analysed by. It was found that adding one nanomaterial is better than adding two nanomaterials [6]. Results showed that the composites are highly crystalline with fewer impurities. The magnetic feature analysis detected that the coercivity of composites decreased clearly with an increase of the $ZnFe_2O_4$ phase.

As for the following two studies, the results of laboratory experiments and the results were in agreement with the previous study in terms of the noticeable improvement in properties, [7] studied how to change the magnetic property of a $BaTiO_3$-$CoFe_2O_4$ multiferroic composite film from soft to hard by varying the degree of phase dispersion of $CoFe_2O_4$. A tenable phase dispersion was achieved in this nanocomposite film as evidenced by the results of XRD and magnetic force microscopy, while the impact of phase dispersion on the magnetic property was analysed via alternating gradient magnetometer (AGM) measurements. In addition, [8] studied cobalt ferrite nanoparticles $CoFe_2O_4$ which were synthesized using the thermal decomposition method, they investigated the influence of the different dispersing agents on the structure and the magnetic properties of the $CoFe_2O_4/SiO_2$ nanocomposites. Structural characterization was carried (XRD), (FTIR), (TEM) and (SEM). Magnetic properties were evaluated using a vibrating sample magnetometer (VSM) at room temperature. The results revealed that the structural and magnetic properties of the $CoFe_2O_4/SiO_2$ nanocomposites were significantly different depending on the type of dispersing agents used before the surface modification with silica SiO_2. This is practically consistent with most scientific research with different nanomaterials added to alloys. Furthermore, several materials such as SiC, Al_2O_3, B_4C, TiB_2, ZrO_2, SiO_2 and graphite have been used as reinforcements to improve the properties of the Al- alloy. However, the Al_2O_3 or SiC particles are used to reinforce the aluminum alloy matrix composites, and this was widely used in automotive and aircraft industries in many places such as cylinder heads and connecting rods where the tribological properties of the materials were very important.

Continuation of the same approach, [9] studied that in the case of composites, a transition from the ductile to a brittle, intergranular fracture occurred in the zone of reinforcing particles, remember that aluminum is mainly ductile. Also, wear resistance of the composites reinforced with SiC particles was higher and coefficient of friction was lower than the wear resistance and coefficient of friction of the composite reinforced with Al_2O_3 particles due to the favourable arrangement of SiC reinforcing particles in the composite matrix.

Within the same path and based on the above-mentioned research, the study that is currently deliberating is a continuation of the practical research aimed at improving the mechanical properties of aluminum alloy 7075.

3. The aim and objectives of the study

The aim of this study is to determine the effect of the liquid stir casting method on Al 7075.

To achieve this aim, the following objectives are being solved:

– study of sliding speed effect on tribological properties;
– study of applied load effect on tribological properties.

4. Materials and methods of the study

4. 1. Object of the study

The object of the study is the use of aluminum alloy 7075 after adding known nanomaterial's that improve the mechanical properties of the alloy, where the liquid stir casting method was used and (pin-on-disc) wear testing samples,.

The hypothesis that the mixture is homogeneous was taken into account. And that the process of preparing a homogeneous mixture was under controlled laboratory conditions in terms of the quality of the nanomaterials added and the thermal factors that were used in the preparation indicating that the practical aspect was dominant in this study.

4. 2. AA7075 Metal matrix

AA7075 was selected to be used as a metal matrix. The chemical analysis of the matrix is shown in Table 1 while the experimental mechanical properties are given in Table 2.

Table 1

Experimental and standard chemical composition of AA7075

Material	Chemical composition, %								
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Standard	0.4	0.5	1.22.0	0.3	2.1–2.9	0.18–0.28	5.1–6.1	0.2	Balance
Experimental	0.36	0.46	1.9	0.25	2.65	0.21	5.7	0.17	Balance

Table 2

Mechanical properties of AA 7075

Property	σ_u (MPa)	σ_y (MPa)	E (GPa)	μ	∈, %	HB
Experimental	228	111	72	0.3	18	55

Tables 3, 4 below represent the general properties of the additives, which are nano-titanium and nano-copper.

Table 3

Analysis of Nano-titanium [10]

Material	Purity %	APS	Specific surface area (SSA)	True density	Morphology	Color
Nano-titanium (Ti)	99.9+ % (metal basis)	30–50 nm	50 m^2/g	4.506 g/cm^3	Spherical	Black grey

Table 4

Analysis of Nano-copper [11]

Material	Purity %	APS	Specific surface area (SSA)	Volume density	Density	Crystal form	Color
Nano-copper (Cu)	>99.9	15 nm	15	0.2 g/cm^3	8.9 g/cm^3	Sphere	Brown

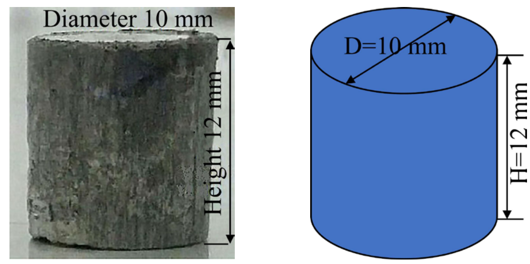
The physical and chemical analyses were also given in Tables 3, 4 as hybrid nanomaterial's, which were then added to the aluminum alloy 7075.

4. 3. Manufacturing of the composite and specimen test

In this study, the aluminum metal matrix composite (AMMCs) was fabricated by using the stir casting route. This route is an economical technique to enhance the mechanical, electrical and tribological properties of the composites. In comparison with other routes, the melting process has important advantages, such as: a large choice of materials, easier control of the matrix structure, best matrix-strengthening bond, a simple and inexpensive treatment. The procedure of this method can be summarized by the following steps:

1. Melting the AA7075 using an electrical furnace at 850 °C for 25 minutes (furnace capacity of one kg).
2. Heat the Nano-hybrids reinforced materials (Ti and Cu) with particle size (15–50 nm titanium and 15 nm for copper) to 200 °C and added to the melt of AA7075.
3. Moving the mixture at a stirring speed of 450 rpm for 4 minutes using a graphite mixer.
4. Heat the mold at 250 °C then poured the mixture into the mold.
5. The cast-iron mold (14 mm diameter and 180 mm in length) gives the shape and geometry of the billet composite.

Supplement to the practical side Fig. 1 represents shows the hardness and wear specimens.



a *b*

Fig. 1. Prepared samples: *a* — test samples for hardness; *b* — pin on disc wear

Test samples were prepared for a pin on disc wear test and HB hardness by a conventional lathe machine.

4. 4. Wear test

The adhesive wear tests were performed using a (pin-on-disc) wear testing apparatus. Base metal and nanocomposites specimens were tested to obtain the required tribological properties. This was under 10 N load with a linear speed of 52.5 cm/s based on the speed of 100 RPM for 15 min at room temperature according to ASTM G99 standard using a steel alloy disc of high hardness type (52100). The end of cylindrical specimens, which is 10 mm diameter and 12 mm height as shown in Fig. 1, was fixed in chuck jaws to prevent the rotation of specimens during the test. Each specimen was weighed before and after the test in order to determine weight loss, wear rate, and coefficient of friction by employing a digital balance having high accuracy of ±0.0001 g. The adopted device of wear test is shown in Fig. 2.

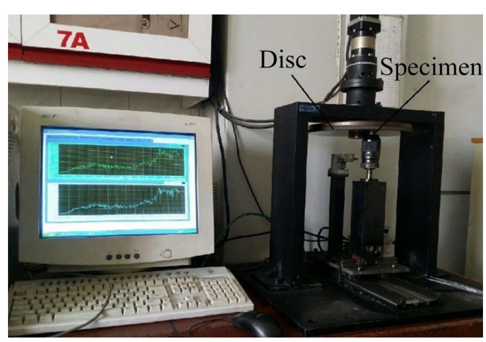


Fig. 2. Shows the device of wear test according to ASTM G99 standard

The obtained tribological results of weight loss, wear rate and coefficient of friction are presented and discussed in this study.

4. 5. Tribological study

Experimental wear tests were carried out using a pin on disc testing to study the tribological wear behaviour of the prepared samples. Wear tests were performed on AA7075 (matrix) and composites containing 0.4 %Cu+0.3 %Ti, 0.6 %Cu+0.3 %Ti and 0.8 %Cu+0.3 %Ti. Cylindrical samples for both matrix and composites of 10 mm diameter and 12 mm lengths were used. The Wear behaviour study was carried out under varying conditions of sliding speeds and load. Measurement of weight loss of the pin was used to estimate the volumetric wear loss (VWL). The load values used in the current work selected from 25 N to 35 N and then to 45 N while the disc speed varied from 100, 200 to 300 RPM. A track diameter of 100 mm as shown in Fig. 3, and a sliding time of 10 min were applied for all the wear experiments. Moreover, all the wear experiments were carried out at room temperature.

$$VWL=(\text{initial weight}-\text{final weight})/\text{material density}, \quad (1)$$

$$\text{Wear rate } (WR)=(VWL)/L\times N, \quad (2)$$

where L is the sliding distance in mm and N are the normal load in Newton.

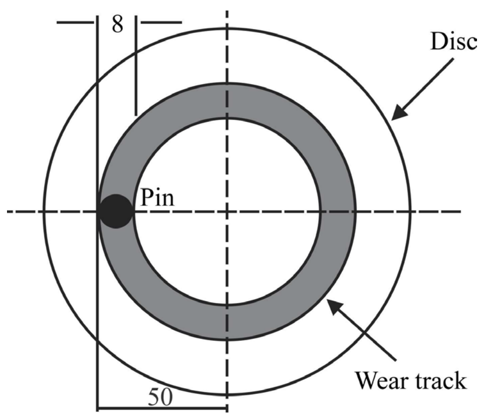


Fig. 3. Schematic configuration of pin-on-disc, all dimensions in millimetres

Then the volumetric wear loss (VWL) was calculated by applying equation (1). The wear rate can be also obtained from equation (2).

5. The results of the study of nanomaterials and their effects

5. 1. Sliding speed effect on tribological properties

Practical experiments were carried out with the load fixed at 25 N with different speeds. The speed used in the practical experiment was (100, 200, 300) rpm with hybrid composites, the results listed in Table 5 below.

Twelve specimens were tested to investigate the effect of sliding speed on the wear rate of AA7075 and composites. Fig. 4 shows the variation of wear rate as a function of the sliding angular speed.

And Fig. 5 shows the variation of Volumetric wear loss as a function of the sliding speed. Through Table 5 and the data obtained from it, the numerical numbers are represented in Fig. 4, 5, and through those figures, the effect of the additives on the alloy used can be observed, and the results will be discussed later.

Table 5

The wear test results of as-cast AA7075 and hybrid composites at different speed

Speed rpm	(Cu+Ti) content	Weight loss (gm)	Volume (mm^3)	Wear rate (WR) 10^{-3}
100	0	0.036	12.81	1.63
200		0.062	22.06	2.81
300		0.084	29.89	3.80
100	0.4 %+0.3 %	0.016	5.69	0.724
200		0.030	10.67	1.350
300		0.045	16.01	2.030
100	0.6 %+0.3 %	0.007	2.49	0.317
200		0.010	3.55	0.450
300		0.016	5.69	0.724
100	0.8 %+0.3 %	0.0025	0.889	0.113
200		0.0056	1.992	0.253
300		0.0087	3.090	0.393

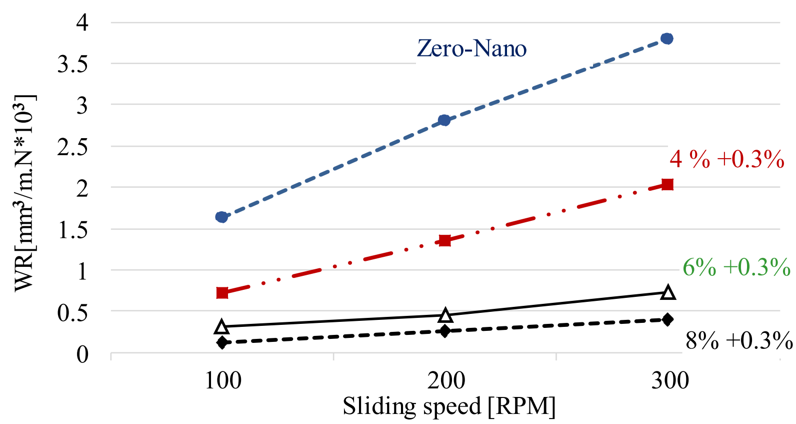


Fig. 4. A wear rate against sliding speed of AA7075 and nanocomposites at constant load

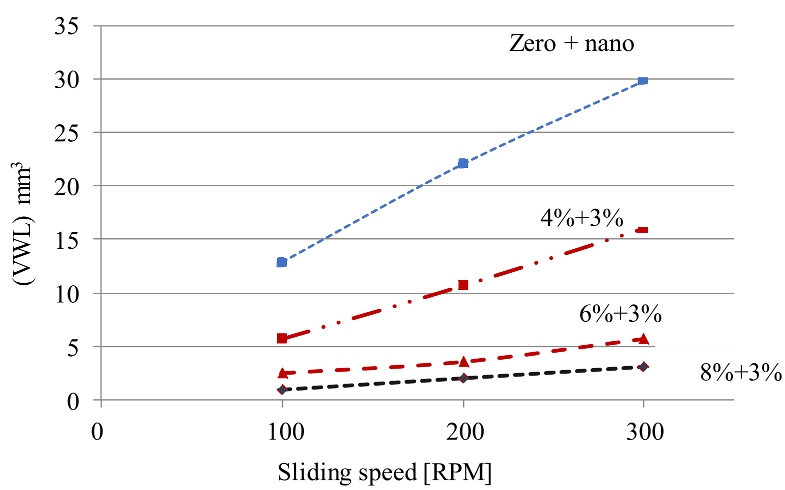


Fig. 5. Volumetric wear loss against sliding speed of AA7075

5. 2. Applied load effect on tribological properties

Experiments were carried out to observe the influence of varying loads on volumetric wear loss (VWL) and wear rate (WR). The tests were conducted at a constant sliding speed of 100 RPM and a varying load of 25 N, 30 N and 35 N. Table 6 gives the experimental results for varying applied loads. Then the results from Table 6 are represented in Fig. 6, 7 for better illustration.

As for Fig. 8, 9, it shows the effect of the amount of additives on the mechanical properties to be studied.

Table 6

Varying applied loads of 25N, 30N and 35N

Load (N)	Nano-hybrid content of Cu+Ti	Weight loss (gm)	Volumetric wear loss (VWL) mm^3	Wear rate (WR) $mm^3/m.N\times10^{-3}$
25	Zero	0.036	12.81	1.631
	0.4 %+0.3 %	0.016	5.69	0.0724
	0.6 %+0.3 %	0.007	2.491	0.0317
	0.8 %+0.3 %	0.0025	0.889	0.01132
30	Zero	0.067	23.84	2.35
	0.4 %+0.3 %	0.052	18.505	1.964
	0.6 %+0.3 %	0.044	15.65	1.661
	0.8 %+0.3 %	0.032	11.387	1.20
35	Zero	0.089	31.67	2.881
	0.4 %+0.3 %	0.072	25.62	2.331
	0.6 %+0.3 %	0.066	23.487	2.137
	0.8 %+0.3 %	0.053	18.861	1.716

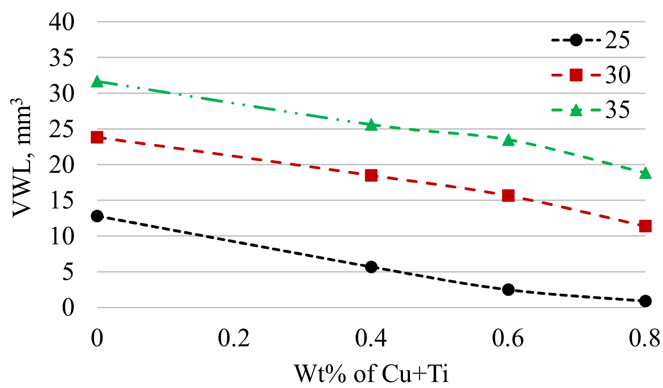


Fig. 8. The wt % of Cu+Ti particulates with volumetric wear loss

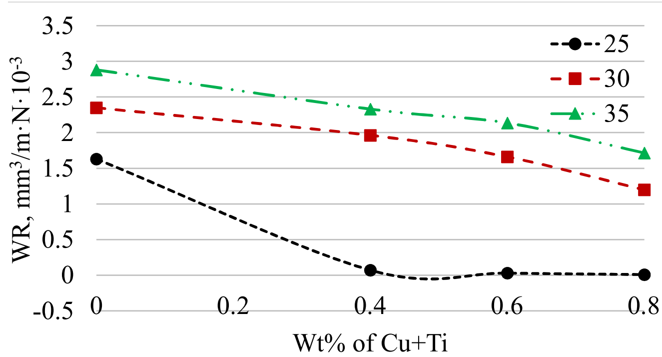


Fig. 9. The wt % of Cu+Ti particulates with Wear rate WR

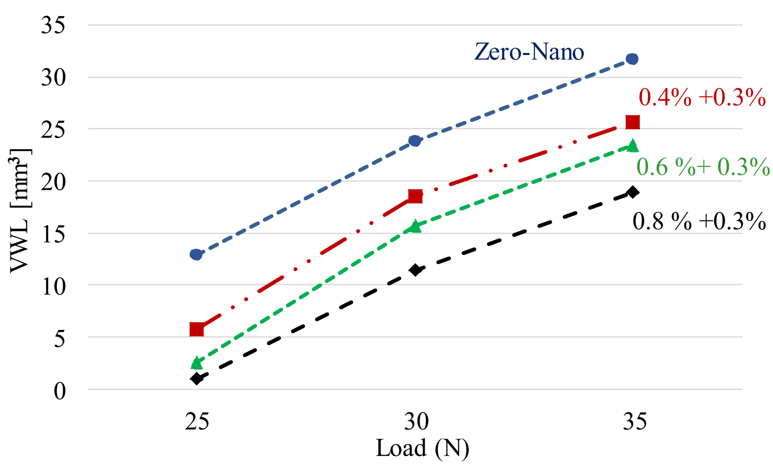


Fig. 6.Volumetric wear loss (VWL) against load for constant speed

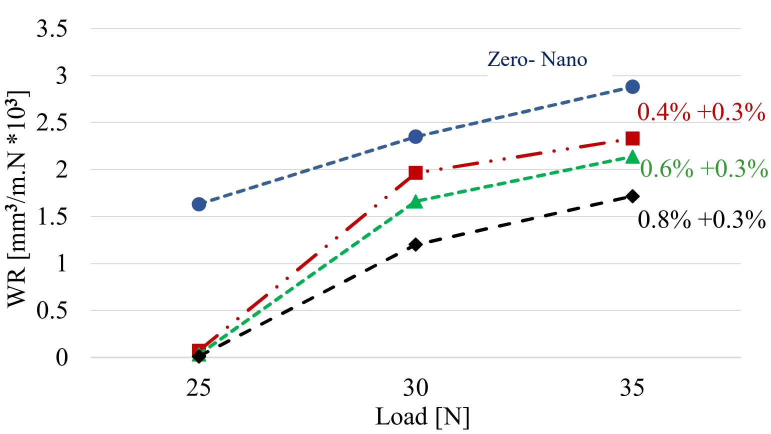


Fig. 7. A wear rate (WR) against load for constant speed

The coefficient of friction (COF) against hybrid Nano-reinforcement as shown in Fig. 10, which indicates that the COF decreases when the hybrid Nano amount increases. For the cast alloy AA7075, the COF is 0.172 and it gradually decreases to 0.05 in (0.8+0.3) wt % of (Cu+Ti). The wear specimens was tested by varying wt % ratio of zirconium (ZrO_2) Nano-particles 0.5, 1, 1.5 and 2 % [12]. They found that COF reduced from 0.48 to 0.37 at zero-Nano and 2wt % ZrO_2 respectively. This reinforces and matches obtained in this research with the different additives in both researches.

The experimental hybrid nanocomposites specimens revealed an increasing trend in BH with an increase in the hybrid Nano-particles as shown in Fig. 11. The BH increases from 55 to 69 at zero Nano and 0.8 %+0.3 % composites respectively, resulted in a 25.4 % improvement in BH hardness. The influence of (TiB_2+Al_2O_3) with AA6061 as composites, containing various amounts of hybrid reinforcements studied by [13]. They obtained that the HV hardness to be 60.1 HV at 0 wt % and 122HV at 15 wt %. This result leads to a 102.9 % enhancement in HV hardness.

The good interface and proper distribution of both particles with base metal refined the grain of composites and contributed to the improvement of hardness property.

To provide depth information about the influence of the reinforced material on the surface properties, SEM was used as an effective tool of enhancing what was obtained through the practical side.

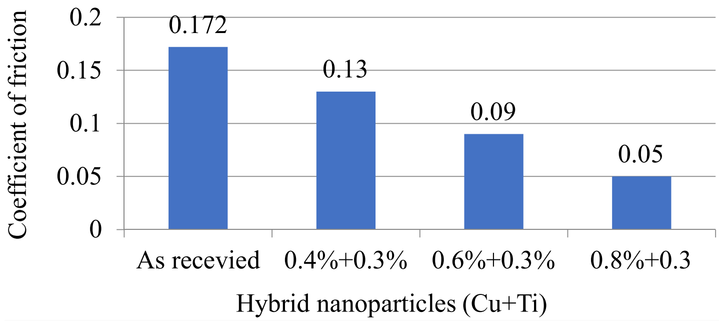


Fig. 10. The coefficient of friction with nanohybrid weight percentage

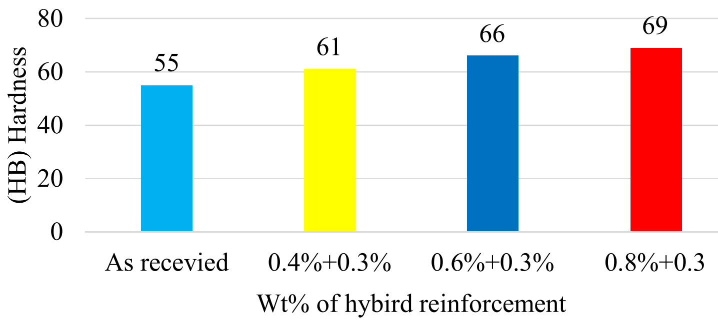
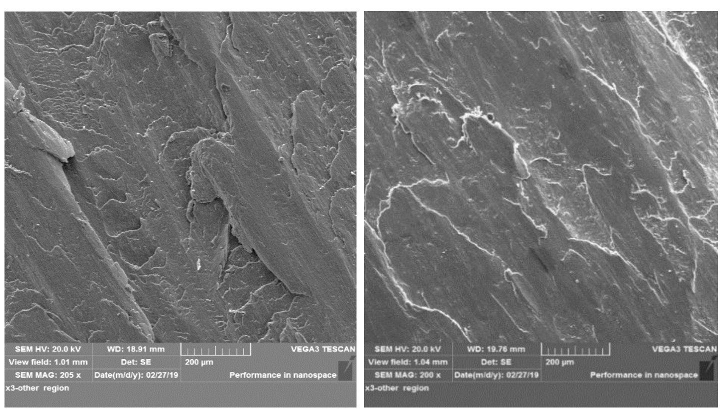


Fig. 11. BH hardness vs wt % hybrid reinforcement



a *b*

Fig. 12. Image for: *a* – microphotograph of the worn surface of as-cast AA7075 after wear testing – X200; *b* – microphotograph of worn surface of hybrid Nano-composite AA7075/0.8 % +0.3 % (Cu+Ti) after wear testing – X200

The SEM analysis is used as shown in Fig. 12, for AA7075 and AA7075 with 0.8 %+0.3 % (Cu+Ti) hybrid-Nano-composite samples.

6. Discussion of the results of the study of nanomaterials and their effects

In order to realize what has been included in the objectives of this study, Fig. 4 indicates that wear rate increases with an increase in sliding speed resulting in an improvement in wear resistance. Also, it is clear that by increasing wt % of Nano-reinforcements, the wear rate shows reducing trend leads to improve the wear resistance and the better wear resistance is observed in the composite containing (0.8 % Cu+0.3 % Cu). The material of Cu+Ti particles play an important factor to improve the wear resistance of AA7075. The effect of adding various amounts of CeO_2 on tribological properties using the powder metallurgy method studied by [14]. They observed that all the tribological characterizations were reduced for all the levels of addition in comparison with the matrix. The influence of hybrid Nano-reinforced materials Graphite (Gr) and boron carbide (B_4C) on wear rate and coefficient of friction investigated by [15]. It was revealed a significant reduction in wear properties resulted in improving the wear resistance. These results are somehow aligned with obtained from the results in this research, observing the difference of the added mineral substances.

From Fig. 5 it is clear that the volumetric wear loss increases when the sliding speed increase and the maximum wear loss is observed in base metal. A smaller amount of VWL is observed in composite when ratio of (0.8 %Cu+0.3 %Ti) due to hard particles leads to improve the wear resistance.

To show the effect of increased loads on the wear rate and the volumetric loss rate. It can be seen from Fig. 6, 7 that both VWL and WR increase with increasing load and an increasing trend is observed for base metal and composites. Variation of VWL and WR with the amount of hybrid Nano-reinforced material is shown in Fig. 6, 7.

To confirmation the effect of the amount of nanomaterials added to aluminum alloy 7075, Fig. 8, 9 reinforce this trend. The VWL and WR of composites are affected by increasing the reinforcement ratio of (Cu+Ti) from (0.4 %+0.3 %) to (0.8 %+0.3 %) as given in Fig. 8, 9. It can be noticed that the VWL and WR in the case of composites are decreased compared to the base metal AA7075. A further increase in the wt % of hybrid Nano-material decreases the VWL and WR.

Referring to the microscopic examination that enhances the results, Fig. 12, shows the surface morphology of the base metal while Fig. 12, *b* is the surface morphology of the Nano-hybrid composition 0.8 %+0.3 % (Cu+Ti). It is clear from Fig. 12, *b* that the tracks and surface delamination are evident, and the SEM inspection supports the argument of adding hard (Cu+Ti) particles improved the wear resistance of the composites. Thus, it is evident that the Hybrid Nano-composite with the highest percentage of 0.8 %+0.3 % of (Cu+Ti) has better wear resistance than the other combinations.

Through the results and figures above, it can be said that a clear improvement in the mechanical properties is attributed to the added nanomaterials that acted as dislocation barriers.

A major disadvantage associated with nanomaterials is considered to be inhalation exposure. This concern is the result of human studies that suggest that nanomaterials can have adverse effects on the lungs. Therefore, it is necessary to be careful when conducting experiments.

The limitations of this research lie in preparing the amount of additives and controlling the temperature of molds and alloys to obtain a uniform mixture. Therefore, there must be a thorough and in-depth study in this direction.

Based on the results of this research, the obtained results are considered useful, and because of this improvement in mechanical properties, it can be used in well-known industrial applications. This research is an extension of numerous research studies in which many forms of nanomaterials have been used in different proportions and in multiple preparation methods. Developing the results of this research using different aluminum alloys with the addition of multiple nanomaterials in certain proportions, then useful results can be obtained for the development of alloys.

7. Conclusions

1. This research is revealed with indication of qualitative or quantitative indicators of research results that for constant sliding speed, the volumetric wear loss (VWL) and wear rate (WR) increases when applied load increases. This can be attributed to the incorporation of nanomaterials added into the base alloy, which headed to an improvement in the properties mentioned above. The volumetric wear loss (VWL) increases from 2.8 mm^3 to 29.89 mm^3 for zero–Nano and from 0.889 mm^3 to 3.09 mm^3 for 0.8 %+0.3 % (Cu+Ti) composite. While the WR increase by 133 % for zero–Nano compared to 210 % in 0.8 %+0.3 % (Cu+Ti) composite at 100 RPM and 300 RPM sliding speed respectively.

2. The coefficient of friction reduces from 0.172 to 0.05 at zero reinforced material and 0.8 %+0.3 % (Cu+Ti) composites respectively. The hardness (BH) of the prepared composites increases by 25.4 % compared to the baseline condition by adding 0.8 %+0.3 % (Cu+Ti) of hybrid Nano-reinforced materials.

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