The Iraqi Journal For Mechanical And Material Engineering, Vol.21, No3,Sept. 2021

INVESTIGATION OF COMPOSITE METAL MATRIX REINFORCED WITH CARBON NANOTUBES

Merivt Mahdi Hanoos
130044 @uotechnology.edu.iq
University of Technology- Department of Materials Engineering - Bagdad, Iraq.

ABSTRACT

This work focuses on studying the effect of adding nanoparticles on the mechanical properties of the alloy (Al-4%Si) reinforced with carbon nanotube at a different weight percentage (0.25,0.5 and 1%wt). prepared the base alloy and the reinforced materials in a casting followed by solution heat treatment in the furnace at temperature 520ºC for 2 hr. , then artificially aged immediately at the temperature of 185 Cº for (2-8 hr.). A detailed characterization of the composite metal matrix structure has performed using XRD, microhardness and wear rate measurements. The results demonstrated that the values of the hardness test increase with an increasing weight percentage of CNTs, this enhancement wear properties of the base alloy reinforced for all percentage of carbon nanotubes additive especially at the weight percentage of 0.5%.

Keywords: composite materials, Al-Si alloys, Nanoparticles, CNTs and wear rate.

تقييم المتراكبات ذات اساس معدني مدعمة بكاربون نانوي

ميرفت مهدي حنوص

الخلاصة

يركز هذا العمل على دراسة تأثير إضافة الجسيمات النانوية على الخواص الميكانيكية لسبيكة (المنيوم- 4% سليكون) المقواة بكاربون نانوي بنسب وزنية مختلفة (0.25و 0.5 و 1٪) يتم تصنيعها عن طريق عملية الصب تليها المعالجة الحرارية المحلولية في الفرن عند درجة حرارة 520 درجة مئوية لمدة ساعتين ، ثم يتم التعتيق الصناعي على الفور عند درجة حرارة 185 درجة مئوية لمدة (2-8 ساعات) تفاصيل توصيف للبنية التركيبية للمواد المتراكبة ذات الاساس المعدني تمت باستخدام قياسات الاشعة السينية والصلادة الدقيقة ومعدل البلى أظهرت النتائج أن تأثير الأنابيب النانوية الكربونية في متراكبات الألمنيوم انعكست بالاختلافات في قمم شدة الذروة لأطوار المادة الاساس ، يتولد نتيجة الترابط والتفاعل القوي بين (الألمنيوم) وكاربيد المادة الاساس والأنابيب الكاربونية المتناهية في الصغر.(Al_4C_3) .تزداد قيم الصلادة مع زيادة النسبة المئوية الوزنية للمادة المضافة ، وهذا يعزز خصائص البلى للسبيكة الأساس المقواة ولجميع النسبة المئوية المضافة من دقائق الكاربون المتناهية في الصغرو خاصة عند النسبة المئوية للوزنية 0.5.

Received : 15-11 -2020
Accepted : 27-12-2020

INTRODUCTION

Aluminum alloys with Si as the main alloying element forming a grade of materials and account for the most important part of all casting materials Hadi Ebrahim Fathabadi (2017). Due to the perfect incorporation of castability and good properties as well as best wear& corrosion resistance, Aluminum alloys have wide applications in the aerospace and automotive parts H. Fredriksson(2012). Adding a small amount of alloying elements can improve the mechanical and physical properties and make the alloy respond to heat Suneel D(2009), it is becoming increasingly important to reduce vehicle weight. R. Gadow(2007), Jean-Paul Salvetat-Delmottea(2002) composite materials, which have a low cost along with excellent mechanical properties, are extensively used. Great advantages are obtained when incorporating low-density aluminum alloy with the extraordinary mechanical properties of carbon nanotubes (CNTs). Numerous explores or researches were centred around the corrosion and wear properties problem in corrosive media of metal (aluminum) base matrix composite strengthened with unique Nanoceramic particles D.M. Stefanescu(2002). Many studies have shown that the content of CNTs has a great influence on the properties of composites Haitham R.(2010). CNTs have a very small volume and size, large aspect ratio and specific surface area. Therefore, CNTs are very prone to entanglement or reunion in their application Bienas, J., (2003). Therefore, a proper amount of CNTs can greatly improve the properties of composites. Excessive CNTs will reduce the properties of composites. Xiaomin Y. et at. Xiaomin Y. (2019) studied the effect of CNT contents on the properties of composites on microscopic morphology and hardness, show the values of the microhardness increased with the increase of the carbon nanotube content, the number of pores on the surface of the composite increases. Bruni et al. Farzan B.(2019) produced an insitu Aluminum-based cast nanocomposite via the addition of 2 wt.% nanoparticles of amorphous SiO_2 to the aluminum alloy melt and reported improvements in the mechanical properties by the introduction of the particles, as a result of the secondary phases produced during the casting process. Huang et al. Huang, D.(2011) synthesized in situ composite by adding SiO_2 to the Al melt and addressed the possible thermodynamic reactions of the ceramic particle with the melt. In this study, involving preparation of composite metal matrix base of(Al-4%Si) reinforced by carbon nanotube (CNTs) with different weight percentages (1%, 0.5%,0.25%) specimens were synthesized by the stir casting process.

EXPERIMENTAL WORK

Metal matrix composites (MMCs) base Aluminum alloys reinforced by CNT(> 95% in purity, 30 nm in diameter, and 5 µm in length) are used as reinforcing materials, The chemical composition of (Al-4%Si) tested and certificated in the general company for an organization to examination and rehabilitation engineering is shown in table (1).

Utilized materials would be isolated in this study into matrix materials (Al-4%Si) and strengthened materials (CNTs > 95% in purity). Similarly as item name multi-walled carbon nanotubes with 20nm breadth with 20nm diameter and length (3-8 µm). The base alloy might have been prepared (Al-4%Si) by melting the of the matrix from alloy at 660°C in a carbonite furnace type, after fully melting a (CNTs) in three different weight per cent (0.25, 0.5, 1%wt). Similarly, as the dipping transform will be conveyed those melt may be blended ceaselessly with An steel bar those cauldron will have come back of the heater Also after those throwing is finished the will be repeater three times with transform guarantee those homogeneity. Then, the melt was whiskered with stirred in the furnace at 270 rpm speed and 10 min times to make a vortex to intersperse in the container. The thermocouple was used to control of temperature in front of spilling under carbon steel die after that the crucible melt is cast in the cylindrical shape of steel containers with of diminution (20mm in diameter) and (150mm in height) this show in the figure (1).

The specimens were ground eventually by (Ma-Pao 160E Grinder and Polisher) machine underwater on looking into rotating disk utilizing abrasive plates for expanding review dependent upon 1200 grid, then they polished utilizing (3µm) alumina pastes and degreased with acetone trichloroethylene and also cleaned in the same solution, which might make utilized for hardness and wear tests. After preparation specimens, takes the specimens alloy solution heat treatment in the furnace at temperature (520ºC) for (2hr.), then artificially aged immediately transformed to another resistance furnace at the temperature of (185Cº) for (2-8hr.) to prepare for mechanical properties (hardness and wear rate). The RWF fast wire chamber furnaces are accessible Previously**,** in three chamber sizes with maximum operating temperatures of (1100 or 1200°C). X-ray diffractometry (using Phillips Norelco X-Ray diffractometer) need been used to dissect and analyze the structural changes of sintered samples. Diffraction example patterns have been recorded utilizing CuKα (λ= 1.54178 Å) radiation at 40.0 kV and 30.0 mA over a 2θ range of 5–80°. Scanning speed is 0.04° (2θ) per second.

RESULTS AND DISCUSSION

XRD analysis

Figure(2) and (3) demonstrate XRD investigation of the composition of (Al-4%Si) alloy synthesized might have been determined through preparing and then measuring by X-Ray diffraction of pure Al-Si alloy (received alloy) and reinforcement alloy with nano-powders after heat treatment of the cast composite respectively, The diffraction angles of the peaks were used recognize those structure. The XRD scans showed no proof of a significant amount of substantial impurities, results represented aluminum exclusively because the add nano-powder was quite low in concentration. However, the effect of the CNT in the CNT-aluminum composite reflected shifting in top of peak intensities of the phases matrix (aluminum) and carbide (Al_4C_3, generated due to the reaction with strong bonding between the matrix and CNT. This bonding force is largely dependent on the wettability between the aluminum matrix and CNT, which is good wetting normally due to the surface energy rapprochement. The XRD pattern advancement of received alloy got after the heat treatment at 520C° of ageing at encompassing temperature shows that it may be an amorphous phase, during the manufacturing process, plays a crucial role for determining the phases.

The investigation to the reinforcement samples exhibits that addition of CNTs have a considerable effect on alloy morphology. The XRD pattern obviously demonstrates that two main peaks of composition which corresponds to (101),(110),(111) and (220) planes. The peak corresponding to aluminum and silicon phases might make obviously seen in the structure. Which have higher intensity, but the carbon peaks of composition which corresponds to (220) and (400) planes appears in figure (2b) , and several Al and Si peaks would formed, meanwhile the peaks of Al phase period ended up generally become stronger over that of mixed CNT powders.

Microhardness results:

The microhardness technique comprises of stitches and indenting the surface for a diamond indenter, a manifestation of a correct pyramid for a square base and an angle of 136 degrees between inverse countenances to a load. The Microhardness of a material may be a paramount mechanical property on account of it relates what amount of the material will have inelastic misshape when An surface load will be connected during applied Abou Bakr Elshalakany,(2014) The Microhardness of the all prepared specimen might have been measured utilizing n advanced Microhardness tester. Fig. (3) indicates the microhardness value of specimens with different percentages of CNT powders (0.25, 0.5, and 1%) for as received alloy compared with reinforcement alloy with nano-powders after heat treatment at 520 ^{o}C and artificially aged at 185 C^{o} for (2-8 hr.) . The Microhardness of the composite specimens might have been expanded with increasing of nano-powders proportion. It is noted starting with the figure that was as about carbon nanotubes doesn't influence in the phases stages of ageing, as those values of the hardness of all the alloys incensement with expanding the duration of ageing, its greatest qualities in a time at an age of ageing (6hr). The rate expansion in hardness increases with the increment of the weighted fraction of the additive. The strength of the composites were showed significantly or increment, that CNTs could strengthen the alloy matrix regard of the heat treatment conditions, and no abnormal precipitate distribution was revealed. The significant strengthening effect of CNTs under the treatment condition of CNT/Al-Si composites This is because the addition of CNT and its distribution in the ground of the base alloy leads to the hardness of the alloy.

Wear Test results

Adhesion wear machine kind (pin looking into disk) will be utilized to measuring wear rate specimens were cut cylindrical shape specimen 10 mm in diameter and 15 mm in length. Those specimens were machined ahead a lathe, and the two wind surface of each specimen were ground with (120,320,600,1000) grade silicon carbide paper, polished with (5 μm and 0.03 μm) alumina slurry respectively. A carbon steel disc might have been utilized as a counter face with a hardness values of 428 Hv. The disc rotational velocity might have been 420 rpm, with a linear or straight sliding of (1.14,2.73,3.08). The linear speed was calculated as follows Haitham R.(2010)

$$V = \pi Ds\ N / 1000 \times 60 \quad (1)$$

where *V* is a linear sliding speed (m/sec), *Ds* is sliding circle diameter (mm), and *N* is disc rotational speed. Loading was carried out normally by putting suitable weight on the specimen holder weighting (5, 10, and 15 N) and wear rate calculated from weight loss into rate is Haitham R.(2010)

$$\text{Wear rate (weight loss)} = \Delta W/S \quad (2)$$

where ΔW: W1 – W2 weight loss of the sample (gm), W1 : sample weight before the wear test, and W2: sample weight after the wear test.

Figures (4 and 5) indicates the wear rate value of specimens with different percentages of CNT powders (0.25, 0.5, and 1%) for as received alloy compared with reinforcement alloy with nanopowders after heat treatment during variation of wear parameters from sliding speed and loading. The wear rate of the composite specimens was increased with increasing of nanopowders ratio. Results show that the wear property of the composite specimens with CNT is lower than the pure Al-4%Si alloys, it is clear those the hardness of specimens increases with increasing materials content, apparently because of the decreasing in density. Fig. (4) shows the applied loads effect of increasing on the wear resistance for composite specimens compared with (Al-4%Si) as received alloy. The increasing of applied loads leads to an increase in the rate of wear because of plastic deformation of the protrusions which present in the touching surfaces and then lead to removing the particular top of protrusions. The wear loss decreased linearly with the increasing content of CNTs additive and, in case of (0.5%) CNT/Al-Si composites, the wear loss is reduced to 1/2 compared to that of the(Al–4% Si) matrix. Whereas, figure(5) shows the decreases the rate of wear as sliding speed increase, the wear resistance decrease until it reaches a speed at which the time for contact surface is very short that lead to increase the wear resistance also high sliding speeds may cause the elimination of surface roughness because friction may take off the drips between the contact surfaces. The samples of CNT/Al-Si give higher resistance to wear. The decrease in wear properties are thought to be due to the increase of hardness and the decrease of friction coefficient. This dramatic improve of wear resistance has not been reported yet in CNT reinforced Al matrix composites demonstrate the excellence of the fabrication process of the aluminum matrix by the homogenously dispersed CNTs, thus enhancing mechanical properties. Thence, wear rate values are exceedingly associated for relative form of pores, something like that lessening in a composite is a more line of enhancement wear may be the higher pressing effectiveness of nanoparticle for materials this is lead to that increasing the content of nanomaterials is more effective in improve wear is due to the improvement of structure with disappear of defect ,cracks and porosity which leads to more contact of the nanoparticles bonding as shown in figure (6) .

CONCLUSIONS

The discussion of the main obtained results leads to the following conclusions:

1. Effect of the CNT in the aluminum composite reflected variations in top of peak intensities of the phases matrix (aluminum) and carbide (Al_4C_3), which generating because of the reaction with strong bonding between the matrix and CNT. This bonding force is largely dependent on the wettability between the aluminum matrix and CNT.
2. The strength of the composites were showed significantly or increment, that CNTs could strengthen the alloy matrix regard of the heat treatment conditions, and no abnormal precipitate distribution was revealed.
3. CNT/Al-Si composites have been exhibited to increase hardness and strength compared to the Al-Si alloy under casting and solution treatment conditions. However, the insignificant strengthening effect was observed for the composites.
4. CNT/Al-Si composite gives higher resistance to wear. The decrease of wear properties is thought to be due to the increase of hardness and the decrease of friction coefficient improve of wear resistance with CNT reinforced Al matrix composites and demonstrates the excellence of fabrication process of the Aluminum matrix by the homogenously dispersed CNT.

Table (1) composition contents of as received alloy

sample	Si%	Fe%	Cr%	Mn%	Zn%	Cu%	Mg%	Ni%	V%	Al%
Piece metal	3.87	0.271	0.002	0.002	0.004	0.005	0.0035	0.005	0.005	Bal.

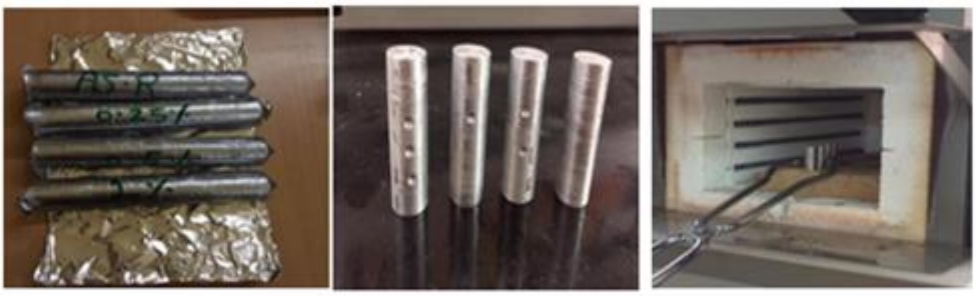

Fig. (1) The alloy specimens with difference weight percentage after preparation and heat treatment in RWF rapid wire chamber furnaces.

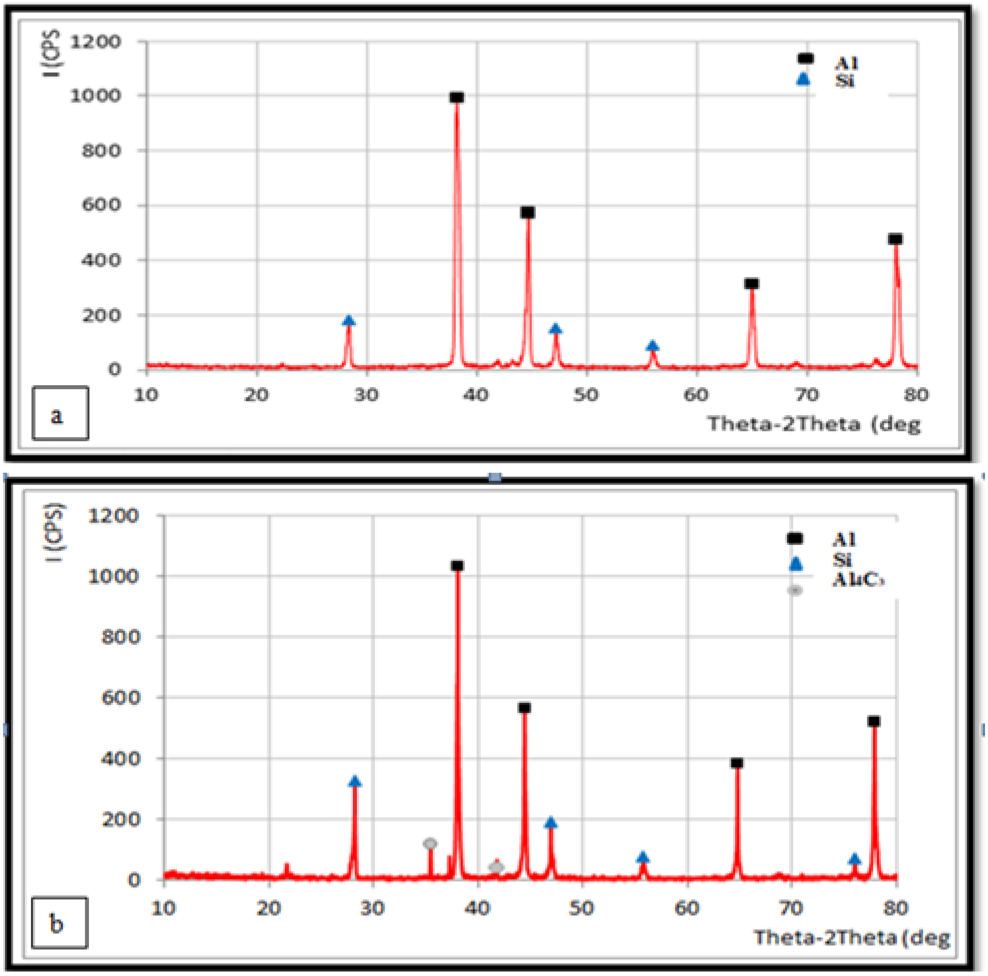

Fig. (2) XRD spectra of the specimen for (a) pure of Al-Si alloy and (b) composite metal matrix by reinforcement of (Al-4%Si) alloy with CNT.

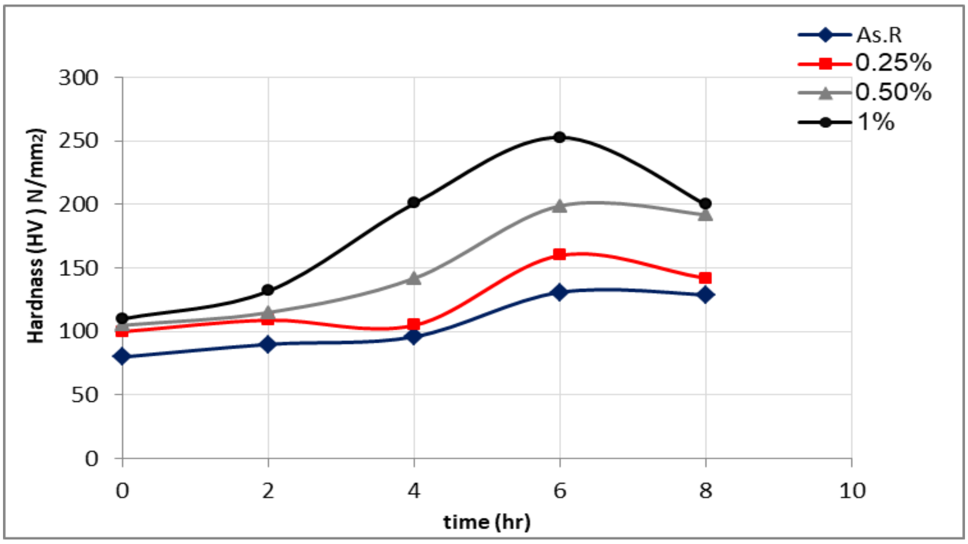

Fig. (3) Effect of artificial aging time of the base alloy reinforced by carbon nanotubes on hardness values.

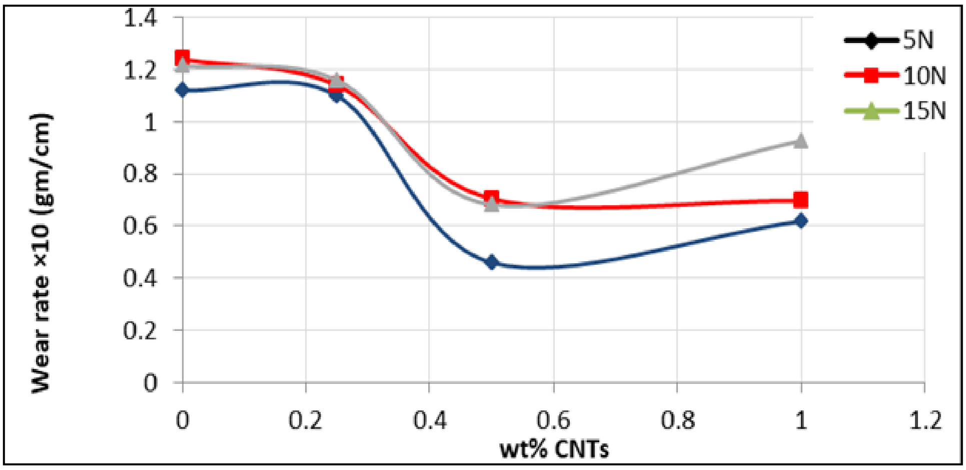

Fig. (4): Effect of applied load on wear rate of Al-4%Si base alloy reinforced by carbon nanotubes.

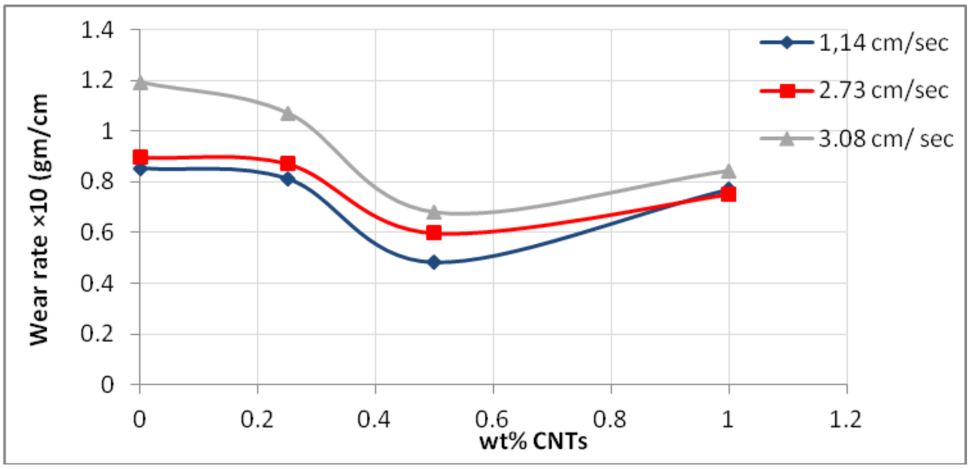

Fig. (5) Effect of sliding speed on wear rate of Al-4%Si base alloy reinforced by carbon nanotubes

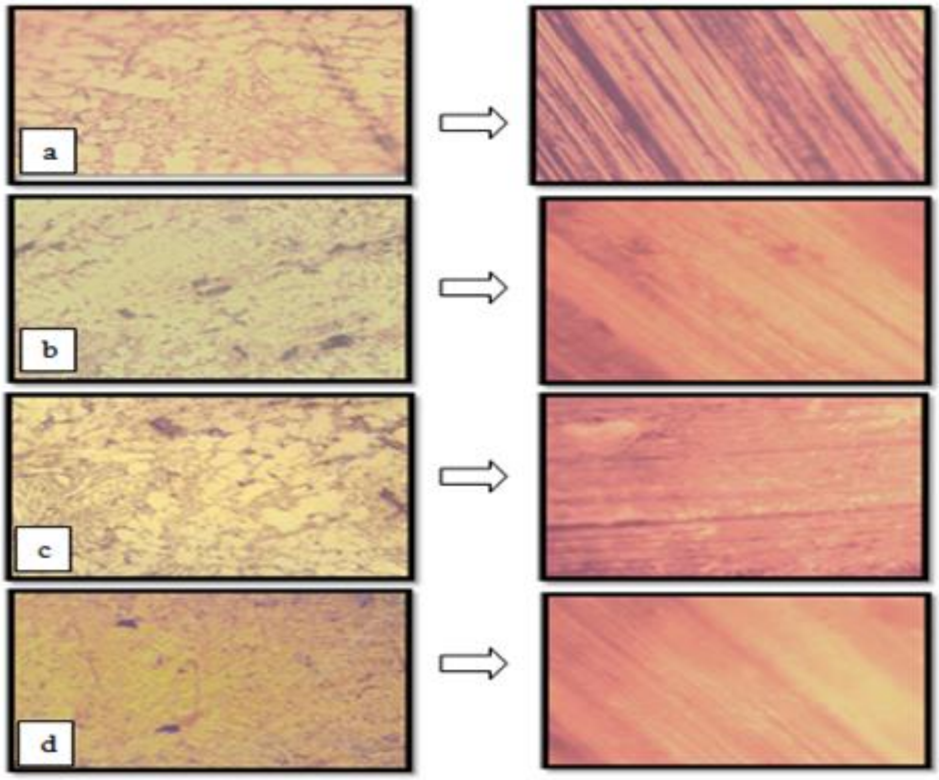

Fig. (6): Microstructure of Al-4%Si base alloy reinforced by carbon nanotubes with different weight percent before and after wear test. (a): Al -4%Si alloy (b): Al-Si reinforced by 0.25% CNT, (c): Al-Si reinforced by 0. 5%CNT, (d): Al-Si reinforced by 1%CNT reinforced.

References:

Abou Bakr Elshalakany, T. A. Osman, A. Khattab, B. Azzam, and M. Zaki, Microstructure and Mechanical Properties of MWCNTs Reinforced A356 Aluminum Alloys Cast Nanocomposites Fabricated by Using a Combination of Rheocasting and Squeeze Casting Techniques", ,Journal of Nanomaterials ,Volume 20 ,2014.

Bienas, J., Surowska, B., & Walezak, M, The Corrosion Characteristics of Aluminium Matrix Composite Reinforced with SiC Particles, 12^{th} Conference Proceedings of Achievement in Mechanical and Materials Engineering, Lublin University of Technology , Poland. 99-102 ,2003.

D.M. Stefanescu, Science and Engineering of Casting Solidification, Kluwer Academic/Plenum Publishers, New York, 2002.

Farzan B., Mojtaba L., Ehsan M.far, Mohammad H. M. and Abdollah S.," Novel AM60-SiO_2 Nanocomposite Produced via Ultrasound-Assisted Casting; Production and Characterization", Materials, 12, 3976, pp.2-11, 2019.

Hadi Ebrahim Fathabadi, “Investigation into the industrial use of nanocomposite coatings”, Petroleum University of Technology, Faculty of Petroleum Engineering, Abadan-Iran, pp.1-10, 2007.

H. Fredriksson, U. Åkerlind, "Solidification and Crystallization Processing in Metals and Alloys", John Wiley & Sons Ltd., Chichester, 2012.

Haitham R. Saleh," Mechanical Properties of The Modified Al-12%Si Alloy Reinforced by Ceramic Particles", Engineering &Technology journal,Vol.28,No.2, , p.289-300.

Huang, D., Wang, Y.L.,Wang, Y., Cui, H.B., Guo, X.F. "In situ Mg2Si reinforced Mg alloy synthesized in Mg-SiO2 system", . Adv. Mater. Res. 2011, 147, 1775–1779, 2010

Jean-Paul Salvetat-Delmottea,b. Angel Rubioc ―Mechanical properties of carbon nanotubes: a fiber digest for Beginners",Carbon 40 ,1729–1734, 2002.

R. Gadow, F. Kern and A. Kiplinger, "Manufacturing of Nanocomposite Structural Ceramic Materials and Coatings", Universität Stuttgart, Institut für Fertigungs technic keramischer Bauteile, D-70569 Stuttgart, 2007.

Suneel D. NageswaraRao D. SatyanarayanaChPawan Kumar Jain," Estimation of Cavitation Pressure to Disperse Carbon Nanotubes in Aluminium Metal Matrix Nanocomposites, AIJSTPME 2(1):53-60, 2009.

Xiaomin Y. , Haonan Z., Huiling Ji , and Yiwei Z.," Effect of CNT Contents on the Microstructure and Properties of CNT/TiMg Composites", Materials, 12, 1620, pp.2-9, 2019.