Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 10 Volume 24 October 2018

Mechanical and Energy Engineering

The Response of Some Properties of (Al-Si-Mg) Alloy to Nano-Ceramic Materials' Addition

Dr.Sarmad Imad Ibrahim*
Assistant Professor
Materials Eng. Dept.-University of Technology
Email: srmade@yahoo.com

Dr.Arwa Faraj Tawfeeq
Lecturer
Materials Eng. Dept.-University of Technology
Email: arwatawfeeq@yahoo.com

ABSTRACT

Al-Si alloys which are widely used in engineering applications due to their outstanding properties can be modified for more enhancements in their properties. Current work investigated the ability of these alloys to be modified by casting them through the addition of nanoparticles. So, Multi-wall carbon nanotubes (CNT) and titanium carbide ceramic particles (TIC) with size of (20 nm) were added with different amounts started from (0.5 up to 3%) weight to cast alloy A356 that was considered to be the base metal matrix, then stirred with different speeds of (270, 800, 1500, 2150) rpm at 520 °C for one minute. The results showed change in microstructure' shape of the casted alloys from the dendritic to spherical grains with increasing stirring speed. Also, EDX analysis confirmed the existence of CNT and TIC additions over inter-dendritic locations related to the affected area. However, the enhancement in the mechanical properties for both types of castings was gained at a weight of 2.5% and a stirring speed of 1500 rpm.

Key Words: nanoparticles, aluminum alloys, stirring speed, casting.

استجابة بعض الخواص لسبيكة (Al-Si-Mg) المدعمة بمواد سيراميكية نانوية

سرمد عماد ابراهيم
أستاذ مساعد
قسم هندسة المواد-الجامعة التكنولوجية

أروى فرج توفيق
مدرس
قسم هندسة المواد-الجامعة التكنولوجية

الخلاصة

سبائك (Al-Si) لها استخدامات واسعة في التطبيقات الهندسية بسبب خواصها الرائعة والتي ممكن ان تتطور لاجل تعزيز خواصها.العمل الحالي يحقق قابلية هذه السبائك لتطويرها بعملية السباكة من خلال الاضافة للدقائق النانوية.أنابيب الكاربون النانوية وكاربيد التيتانيوم ذات حجم حبيبي (20nm) أضيفت بكميات مختلفة وبنسب تتراوح بين (0.5-3%) لسبيكة الاساس (A356) ، بعدها تم الخلط بسرع مختلفة (270،800،1500،2150 rpm)عند درجة حرارة (520°C) ولمدة دقيقة واحدة.النتائج بينت تغير في شكل البنية المجهرية للسبيكة من الشكل الشجيري الى الشكل الكروي مع الزيادة في سرعة المزج. أيضاً فحص (EDX) أكد وجود المضافات النانوية من أنابيب الكاربون النانوية وكاربيد التيتانيوم داخل المواقع الشجيرية، على اي حال تعزيز الخواص الميكانيكية للسبيكة الاساس المدعمة بالدقائق النانوية من (TiC,CNT) كانت عند نسبة اضافة (2.5%) وعند سرعة خلط (1500rpm).

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2018.10.01
2520-3339 © 2018 University of Baghdad. Production and hosting by Journal of Engineering.
This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-cc-nc/4.0/).
Article accepted: 6/12/2017

الكلمات الرئيسية: الدقائق النانوية، سبائك الالمنيوم، سرعة الخلط، الصب

1. INTRODUCTION

Al-Si alloys are characterized by their multifunctional capabilities like high castability, abrasion resistance, and lightweight, strong and stiff. Therefore, they have widely been used in engineering applications such as automotive, aircraft, and aerospace industries **Gruzleski and Closset, 1990**. However, the modification of this kind of alloys has still been under research. To understand it, comprehensive studies have been achieved on these alloys, some of them represented by adding P, Na, Sr or Sb **Rooy,1992** while others added (Ca) with (Na), (Sr), and (Sb), to AL-Si alloys. The first study showed changes in both coarse and unmodified eutectic Si to hyper-eutectic Al-Si alloys through adding (P) to the melt of the mentioned alloys, these changes were represented by surrounding the refined primary Si of the unmodified eutectic Si alloys by (P). In addition, **Gruzleski** found that both (Na) and (Sr) addition could refine the eutectic Si in the same unmodified alloy, however, it was noticed that this refinement was not effective in case of achieving this study by adding P, Na, and Sr at the same time, this is related to phosphors' chemical properties itself, as it is described as an incompatible element with the (Sr) and (Na) elements, leading to formation either (Sr) or Na phosphides once adding (Sr) or (Na) to (P) pre-refined alloys. The latter study provided structures with thin layers of fibers arranged evenly in an interconnected system of eutectic, **Rooy, 1992**. Similar findings were obtained from adding rare earth elements to Al-Si alloys **Chen, 2007 and Cruz, 2010.** Also, adding ceramic particles to cast Al alloys to improve their stiffness and strength attracted many researchers **Rohatgi, 1986, Singh and Alpas, 1995, Reihani, 2006, Amirkhanlou and Niroumand, 2011**. Similarly, in researches about adding Al_2O_3 particles to the melt of Al-Si alloys, it was seen that change dendritic grains to finer spherical during solidification raises the viscosity of Al_2O_3 leading to better dispersion and elongation, **El-Mahallawi, 2012, Shash, 2014** and **Choi, 2012**.

Rohatgi noticed that fabrication Al-Si alloys enhanced by ceramic materials which are worthy to be used in manufacturing engineering products and tools could help to reduce consumed energy. However, lots of studies were made before to develop these alloys and strengthen their mechanical properties by adding Al_2O_3 and SiC, the ceramic micro-sized particles. Few of these alloy's products were marketed; despite no improvement in casting modification was recognized, **Haizhi, 2003**.

In regard to improving the mechanical properties of the hypo- and hyper-eutectic Al-Si alloys, it was found that controlling the size, distribution, and the morphology of primary Si particles and eutectic Si, as well as refinement the dendritic structure of the Al should be taken into consideration, **Chen, 2007**. **Cruz, 2010,** revealed same results on a study involved the mechanical behavior of the A356 alloy as a function of dendritic structures, size, and morphologies of the eutectic Si particles. They attributed their findings to the formation of coarse primary Si particles which could harm the mechanical properties of the alloy especially the ductility, showing some irregular shapes, during solidification under normal casting conditions. **Cruz, 2010,** showed that the grains' structure and its orientation in the Al-Si alloys are the main reason behind occurrence the failure either by fatigue or wear in engine parts through delamination the surface.

On the contrary, these alloys have superior mechanical properties namely the strength and stiffness compared to the traditional engineering materials. So, understanding the way how the size and shape factors are controlled is desirable. To maximize the mechanical performance of the alloys, distribution the particles evenly in the matrix was also investigated by considering the main parameters of stir casting method, which are stirring speed and time.

Only two studies investigated stirring speed, one of them **Prabu, 2006** selected different stirring speeds beginning from500 rpm up to 700 rpm at a different time. The second **Shash, 2007** used higher stirring speeds in the range between (1000–1500 rpm). Thus, selecting the appropriate stirring speeds are still debatable in the literature. The limited studies about understanding the effect of stirring speeds on the mechanical behavior of the alloys have encouraged current study. So, stirring speeds will be one of the candidate parameters in this study.

This work aimed to understand the relationship between casting routes' parameters and improvement of production cast A356 alloys reinforced by Nano ceramic material additions via changing stirring speed, kind of Nano ceramic material additions and their weight percent in the cast A356 alloys.

2. EXPERIMENTAL WORK

2.1 Material Preparation

Al cast A356 alloy was used as a base metal to form the reinforced cast. Measured mechanical properties of aluminum cast A356 alloy shown in **Table 1. Table 2** and **Fig.2** show the measured chemical composition (in weight %) of the material and an optical microstructure image of the base metal in as-cast condition respectively. Two types of Nano ceramic material, which are multi-wall carbon nanotubes (CNT) and titanium carbide ceramic (TIC) nanoparticles, with the size of (20nm) were selected to be mixed with the melt of cast A356 alloy to form the reinforced cast alloy.

One kilogram of AL alloy (graded with A356) was heated in a furnace to 700°C. However, to get homogenous melting environment, pre-heating for the furnace was necessarily done in temperatures' range between (640-710) °C. Then, the (CNT) and (TIC) nanoparticles were added to the melt cast A356 alloy at 700°C through a mechanical stirring at different speeds starts from 270, 800, 1500 rpm and ends with 2150 rpm at a constant time of one minute.

Adding (CNT) and (TIC) nanoparticles were conducted in the way of wrapping small packages of them in Al foil, and immersion them directly to the liquid metal cast A356 alloy. The reason for wrapping was to provide the homogeneous environment, hence, even distribution for the (CNT) and (TIC) nanoparticles in the liquid of the cast. Nanoparticles of (CNT) and (TIC) were added at different weights% of (0.5, 1, 1.5, 2, 2.5, and 3). After that, the mixture was poured into a preheated steel mold and air cooled. Mold' preheating was at 300 °C, to avoid cracks or other defects. The final step was made by achieving solution treatment for the final cast at 520°C to avoid entering the sintering stage. The above technologic route for preparing the material was already relied on by many previous works, **El-Mahallawi, 2012**. The final reinforced cast A356 alloy then was cut and machined depending on test type.

2.2 Mechanical Testing

It included three tests, which were tensile, hardness, and wear, using samples with three specimens per each. The tensile test was conducted using a universal testing machine/DIN 50125 and an around tensile sample with the dimensions as shown in **Fig.1**.

Hardness test was conducted using Vickers microhardness testing machine. And Wear test was conducted using Plant Te 79 Multi-Axis Tribometer Machine and a standard sample with diameter and length of (10 and 20) mm respectively, at a velocity of 0.8 m/s, and time about ~20 minutes. During running the test, the sample was loaded longitudinally at a load of 10 N in the direction perpendicular to the disc related to the wear machine. Estimation wear resistance was based on calculation weights' inequality.

Tensile with hardness tests were conducted at room temperature, in order to select the better stirring speed and best weight% for best addition. After that, the wear test was conducted at constant stirring speed and different weights to select the best weight% that it resists friction. The results are shown in section (3.2).

2.3 Microstructure and SEM/EDX Examination

It included microstructure and (SEM) examinations. The equipment used for microstructure examination was (OLYMPUS DP12), which was already provided by advanced camera system with high resolution, in order to observe dispersion's manner for (CNT) and (TIC) nanoparticle on the microstructure behavior of the new matrix of cast A356 alloy.

SEM equipment of (JSM-5400 SEM, JEOL Company) was used for the purpose of examination surface topography and materials' orientations that draw a clear picture about the relation between surface's fracture characteristics and wear mechanism.

However, best locations for nanoparticles incorporation that was satisfied with modifications and caused changes in the material's orientation were detected by using (SEM) equipment in this work.

Two microstructure examinations were achieved; the first was for the base metal A356 in as-cast condition **Fig.2**. The second was for the cast A356 alloy reinforced by TIC and SiC nanoparticles at 2.5 weight% with different stirring speed **Fig.5**.

SEM examination was run for sample of cast A356 alloy reinforced by CNT and TIC nanoparticles at 2.5weight%, which was prepared at conditions of constant stirring speed to examine best weight% for best morphology **Fig.6**, also another examination for cast A356 alloy reinforced by different weights% of CNT and TIC nanoparticles which was produced at constant stirring speed. The images were taken after the samples were subjected to wear test, in order to examine wear surface **Fig.7**. Microstructure and SEM Analysis discussed in sections (3.1, 3.3) respectively.

3. RESULTS AND DISCUSSION

3.1 Base Metal Material

According to **Fig.2**, which presents the microstructure of the base metal in the as-cast condition without nanoparticles. It seems that the structure consists of two phases, the primary which is Al matrix (white phase) and the secondary which is Al-Si eutectic (dark lamellar structure). These phases are uniformly distributed in a dendritic structure.

3.2 Mechanical Testing Results

3.2.1 Effect of Stirring Speed

Fig.3 presents tensile and hardness behavior at 25°C for the casting reinforced with TIC and CNT at weight% from (0.5-3) with increasing stirring speed from (270- 2150) rpm.

Tensile results, **Fig.3 (A and B)** revealed that the highest value of tensile strength and the lowest for elongation were noticed about (2.5% TiC) at 1500 rpm speed. However, with increasing stirring speed to 2150 rpm, the decline in the tensile strength and raise in elongation values were seen. This was attributed to formation inclusions such as porosity in the cast at 2150 rpm stirring speed causing increasing elongation, **El-Mahallawi, 2012**.

Hardness finding, **Fig.3-C** agreed with tensile strength results as it reached its maximum value at 1500 rpm, while it went down at 2150 rpm reaching to the minimum for the same reason referred by **El-Mahallawi, 2012** and his co-workers about inclusion's formation.
To conclude, stirring speed of 1500 rpm provided the best improvement in the mechanical properties for both types of nanoparticles. In addition, the casting A356 reinforced by TIC nanoparticles had lower elongation and higher tensile strength and hardness than that of CNT at the same value of speed.

3.2.2 Effect of Nanoparticles Additions.
Fig. 4 (A, B, C, and D) illustrates tensile, elongation, hardness and wear behavior respectively at 25°C for the casting with CNT and TIC nanoparticles produced at 700°C with weights from (0.5-3)% at a constant stirring speed of 1500 rpm.
According to **Fig.4**, for both CNT and TIC reinforcements, the weight 2.5% recorded highest values of tensile strength and hardness, and the lowest for the elongation, while the weight 3% recorded lowest values of tensile strength and hardness and highest values of elongation. However, it was noticed that the tensile strength and hardness for TIC particles are higher than that of CNT, whereas the elongation for CNT particles is higher than its counterpart of TIC particles.
In conclusion, increasing tensile strength and hardness were gained at a weight% of 2.5%, while elongation's increase was gained at a weight% of 3%. This indicates that adding nanoparticles supports the mechanical properties.
The conclusion was supported by previous studies such as **Shackelford and Alexander, 2001, Koch, 2002**. They explained the improvement for many reasons, e.g. the increase in tensile strength and hardness was due to occurrence constriction in the plastic flow of the matrix with increasing the additions up to 2.5%weight, resulted from narrowing the spaces between nanoparticles distributed in the matrix, forcing the plastic deformation movement of the matrix to be consistent with that of the nanoparticles leading to constraint matrix's movement in the shape either to be paralleled or over the particles during plastic deformation, **Shackelford and Alexander, 2001**.
Also, the inconsistency in the lattice parameter for the phases formed in the matrix, which is induced by the changes in the cooling rates during solidification helped to improve, this phenomenon came from the differences in the thermal expansion coefficients for the matrix which cause formation different phases in the matrix, that are the primary represented by (Al or Si), and the secondary related to the nanoparticles.
Nanoparticles' existence in the matrix encourages generation dislocations and minimizes the size of sub-grains, so leading to increasing hardness which is supported by increasing strength, **Shackelford and Alexander, 2001**.
Another study confirmed that getting different phases during rapid quenching from the reactions of liquid and solid state in the reinforced cast through technologic route for the casting process, one of the ways that help increase the hardness, **Koch, 2002**.
Finally, a study on A356 alloys reinforced by nanoparticles mentioned that during stirring, the nanoparticles tend to be gathered vertically around the grain boundaries of the matrix in a uniform manner along the structure, leading to improving the mechanical properties, **Kim, 2010**.

3.2.3 Effect of Wear Properties
The curves in **Fig.4-D** present wear behavior as a function of weight fraction% of nanoparticles at 25°C for the machined A356 castings reinforced by CNT and TIC

nanoparticles that were produced at a constant stirring speed of 1500 rpm and temperature of 700°C.
The curve shows a reverse relationship between wear rate and weight% of nanoparticles. The overall curve indicates a decline in wear rate with increasing the amount of weight till 2.5%, and then starts to rise up at a weight of 3%, recording the highest value over the whole curve, which indicates to deterioration in wear rate. However, TIC nanoparticles gained lowest wear rate, the matter made it has less effect of failure than that of CNT nanoparticles.
It was concluded that 2.5% weight fraction of TIC nanoparticles recorded the best number to avoid deterioration. This conclusion supports the findings in regard to tensile strength and hardness as explained in **Fig.4 (A and C)**.

3.3 Microstructure and (SEM) / (EDX) Analysis

3.3.1 Effect of Stirring Speed

Fig.5 (A, B, and C) presents the microstructure of the casting A356 alloy enhanced with a weight of 2.5% TIC particles at speeds of 270, 800, and 1500 rpm.
The three images show gradual changes in the shape and direction of the primary (α-Al) grains by converting the coarse grains at 270rpm speed to finer and finer with an increase in the speed of to1500 rpm. The microstructure images here support the results in section (3.2.1). Comparing Figures 4 and 1, it was clearly seen the conversion of AL and Si spots in the base matrix from the dendritic to the spheroidal structure.
The factor that encouraged this phenomenon related to containing the structure enough amount of eutectic phases which helped provide an improvement in the mechanical properties with increase stirring.
Some studies related that to the relationship between stirring speed and plastic deformation of the materials, as increasing stirring speed leads to reduction plastic strains in the fragmented dendritic grains which are always formed at low speeds causing coarsening. Coarsening is produced from the interfacial energy leading to minimizing the surface area for the grains and formation globular structure **Reihani, 2006**.
It was suggested that under a specified mixture system, coarse grains are possible to operate in Nano-crystalline materials or alloys as well **Choi, 2012**.
Also, it was proved that increase stirring speeds help dissolve the secondary dendritic structure leading to grain growth as they homogenize matrix's temperature by creating slight gradients of temperature on the surface, which reduces from nucleation barrier in the liquid, **Amirkhanlou and Niroumand, 2011**.
A study about Si eutectic refinement process also developed nucleation Si nanoparticles from Si element with increase in the stirring speed leading to strengthen the mechanical behavior of the alloys, explaining that to nanoparticles' ability of Si to be incorporated within the interface formed during solidification of the alloy and become the dominant factor of hardening as long as the sizes get finer, **Choi, 2012**.

3.3.2 Effect of Nano-Particles Additions

Fig.5 (C and D) shows the microstructure evolution of the alloys reinforced by CNT and TIC nanoparticles at 2.5% weight in the condition of as cast.
Both images showed clear morphological changes and even arrangements for the grains in the microstructure.
Comparing **Fig.5** and **Fig.2** confirmed the results in section (3.2.2), as both shape and sizes of grains were modified at 2.5% weight addition, improving the structure of the matrix for the better. This result supported by Figure 6, which included SEM and EDX images for the

matrix reinforced by 2.5 weight % TIC and CNT nanoparticles produced at stirring speed of 1500 rpm, showing dispersion's presence of TIC and CNT nanoparticles in the matrix.

3.3.3 Effect of Wear Surface

Fig.7 presents SEM images after performance wear test for AL cast A356 alloy reinforced by 2.5% weight of CNT and TIC nanoparticles which was produced at a constant stirring speed of 1500rpm.

The Figure shows accumulating TIC and CNT nanoparticles along the morphology for the tested samples at a weight fraction of 2.5%.

In comparison between the two images, it was seen that the surface with accumulated TIC nanoparticles is smoother than that of the CNT. Similar work confirms this result, which pointed out the dominant wear mechanism for hyper-eutectic Al-Si alloy A390, as a combination of adhesion and delamination, **Shash, 2014**. The findings here support the results obtained by **Fig.4-D**.

4. CONCLUSIONS

1- Stirring speed of 1500rpm helped to improve the mechanical properties for the cast with both types of nanoparticles through increase tensile strength and hardness values, and decrease friction, also change in the microstructure constituent of the reinforced cast to the better.

2- Both additions caused a modification in the alloy through increase tensile strength, hardness, and decrease wear rate. However, (TIC) addition is more worthy to be applied as it gained higher values in tensile strength, hardness, and wear resistance, also caused modification in the constituent of the reinforced cast A356 alloy.

3- A 2.5% weight fraction modified the microstructure's grains to the finer state for the cast compared with that of the base metal recording best weight to select for applications where high strength, hardness, and wear resistance are demanded. While a 3% weight is suggested the best for applications require ductility.

REFERENCES

- Amirkhanlou, S. and Niroumand, B., 2011, *Development of Al356/SiC particles cast composites by injection of SiCp containing composite powders*, Mater Des, Vol.32, pp.1895–1902.
- Chen, C. Z. Liu, B. Ren, M. Wang, and Liu, Y., 2007, *Influences of complex modification of P and RE on microstructure and mechanical properties of hypereutectic Al-20Si alloy*, Trans. Nonferrous Met. Soc. China, Vol. 17, pp.301–306.
- Cruz, S. Meza, S. Fernandes, P. Quaresma, V. Casteletti, C. and Garcia, A., 2010, *Dendritic arm spacing affecting mechanical properties and wear behavior of Al–Sn and Al–Si alloys directionally solidified under unsteady-state conditions*, Metall. Mater. Trans, Vol. 41, pp.972–984.
- Choi, H. Konishi, H. and Li, X., 2012, *Al_2O_3 nanoparticles induced simultaneous refinement and modification of primary and eutectic Si particles in hypereutectic Al–Si alloy*," Mater. Sci. Eng, Vol. 541, pp.159–165.

- El-Mahallawi, I. Abdelkader, H. Yousef, L. Amer, A. and Mayer, J., 2012, *Influence of Al_2O_3 nano dispersions on microstructure features and mechanical properties of cast and T6 heat-treated Al Si hypoeutectic alloys*," Mater. Sci. Eng, Vol. 556, PP.76–87.
- Gruzleski, G. and Closset, J., 1990, *The Treatment of Liquid AL-Si Alloys*, AFS, Des Plaines, IL, USA, Vol.97, pp.107–126.
- Haizhi, Y., 2003, *An overview of the development of Al-Si-alloy based material for engine applications*, J. Mater. Eng. Perform. JMEPEG, Vol. 12, pp. 288–297.
- Koch, C.,2002, *Nanostructured Materials, Processing Properties, and Potential Applications*, CRC Press, Boca Raton, FL, USA, Vol.16, pp.423–526.
- Kim, G. Hong, S. Lee, M. Kim, S. Ioka, I. and Kim, B., 2010, *Effect of oxide dispersion on dendritic grain growth characteristics of cast AL alloy*, Mater. Trans, Vol.51, pp.1951–1957.
- Prabu, B., 2006, *Influence of stirring speed and stirring time on distribution of particles in cast MMC*, J. Mater. Process. Technol, Vol. 171, pp.268–273.
- Rohatgi, K. Asthana, R. and Das, S., 1986, *Solidification, Structure and Properties of Cast Metal-Ceramic Particle Composites*," Int. Met. Rev, Vol.31, pp.115–139.
- Rooy, L., 1992, *AL and AL alloys, In ASM Metals Handbook, Aluminum Company of America*, New York, NY, USA, Vol. 15, pp.221-243.
- Reihani, S., 2006, *Processing of squeeze cast Al6061–30 vol% SiC composites and their characterization*, Mater Des, Vol.27, pp.216–222.
- Singh, J. and Alpas, T., 1995, *Elevated temperature wears of Al6061 and Al6061 20% Al_2O_3*, Scr. Metall. Mater, Vol.32, pp.1099–1105.
- Shash, Y. Rashad, M. Abdelaziz, H. Mayer, J. and Schwedt, A., 2014, *Hardness and Wear Behavior of Semi-Solid Cast A390 Alloy Reinforced with Al_2O_3 and TiO_2 Nanoparticles*, Arab. J. Sci. Eng, Vol. 39, pp.5171–5184.
- Shash, Y., 2007, *Effect of Processing Parameters on the Mechanical Characteristics of A356/(Al_2O_3)particles Cast Metal Matrix Nano-Composites (MMNCs)*, Master's Thesis, Cairo University, Cairo, Egypt.
- Shackelford, F. and Alexander, W., 2001, *Front matter*, Materials Science and Engineering Handbook, Shackelford, CRC Press LLC, Boca Raton, FL, USA.

Table 1. Measured mechanical properties of Aluminum cast A356 alloy (Al-Si).

Proof Stress (N/mm^2)	Tensile Stress(N/mm^2)	Elongation (%)	Brinell Hardness(HB)	Endurance Limit	Modulus of Elasticity (MPa)	Shear Strength (MPa)
185	230	2	75	56	71	120

Table 2. Measured chemical composition (in weight %) of Aluminum cast A356 alloy (Al-Si).

Element	Si %	Fe %	Cu %	Mn %	Mg %	Zn %	Ti%	Cr %	Ni%	Pb %	Sn %	Sb %	Al %
Percentage (%)	7.3	0.42	0.17	0.06	0.47	0.023	0.008	0.02	0.005	0.03	0.007	0.025	Rem

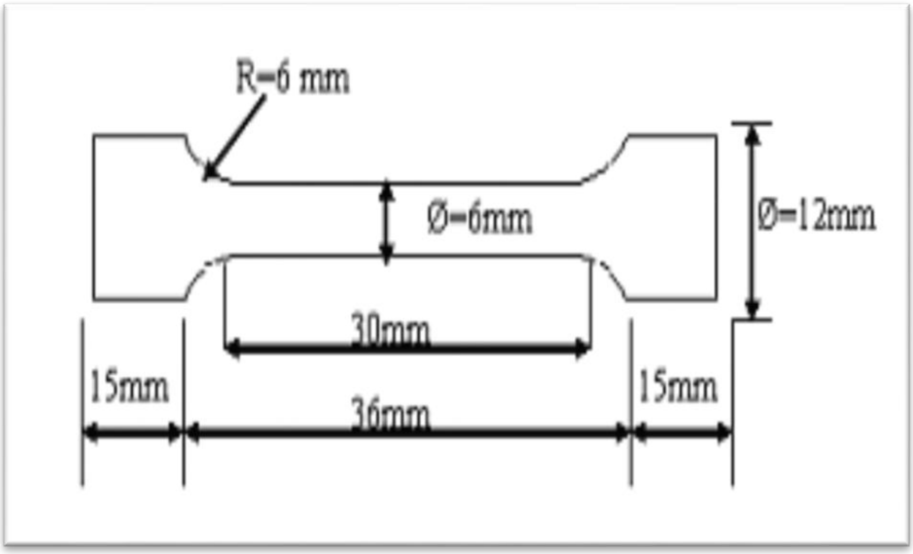


Figure 1. Dimensions of tensile test sample.

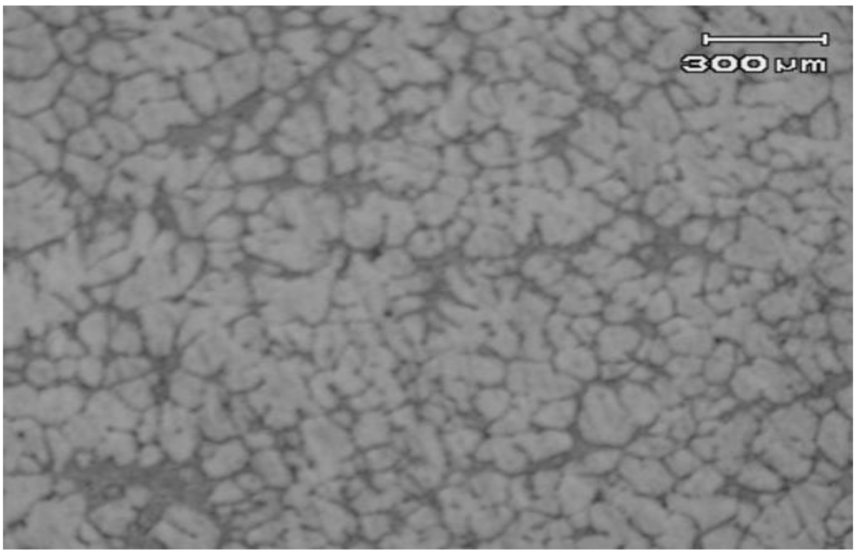


Figure 2. The microstructure of cast A356 alloy without nanoparticles.

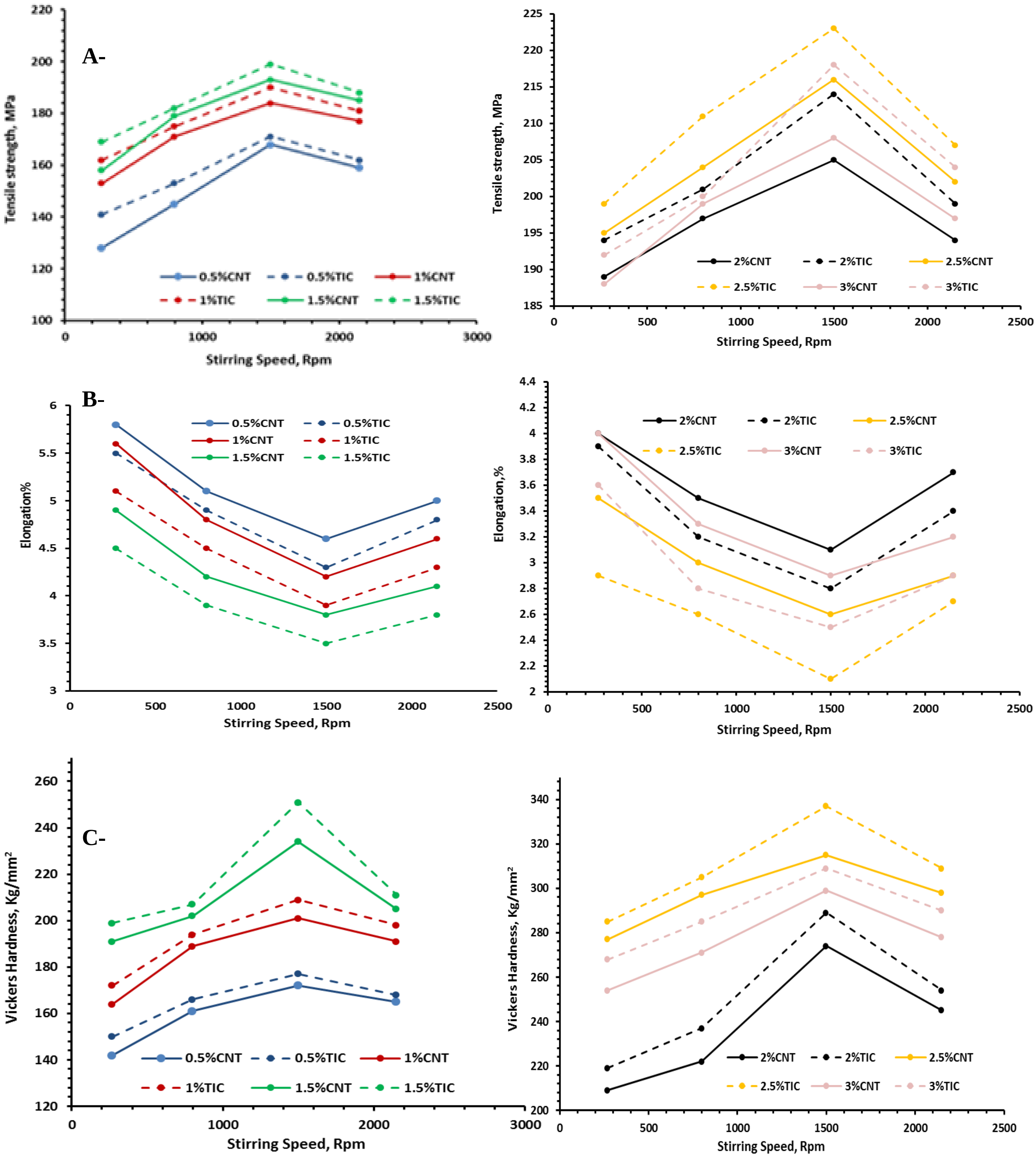


Figure 3. Stirring speed as a function of **a**: Tensile strength; **b**: Elongation; **c**: Vickers hardness at 25°C for the machined enhanced cast A356 alloy' samples that were prepared at 700°C with different stirring speeds and weights% of nanoparticles.

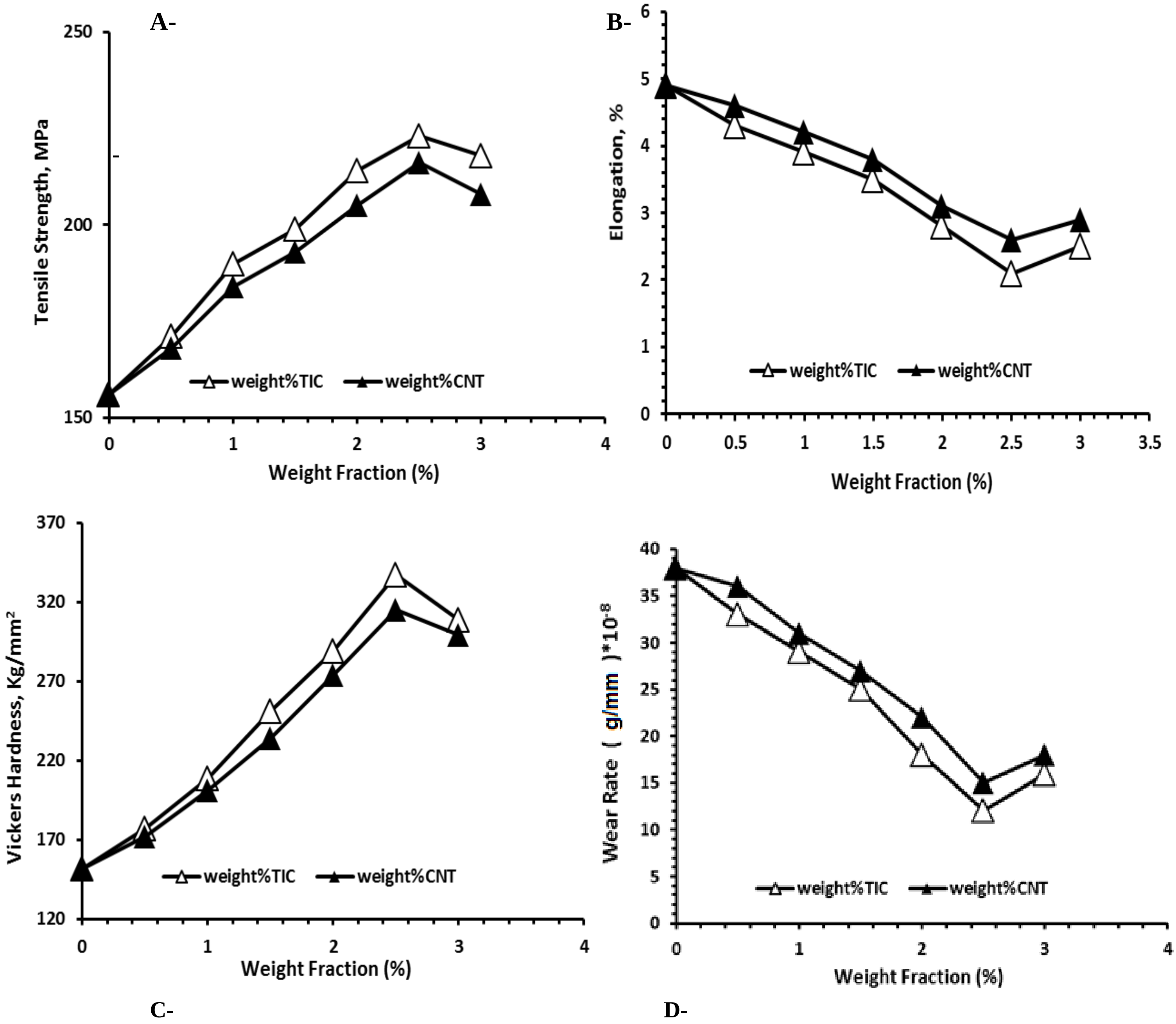


Figure 4. Weight fraction % of nanoparticles as a function of A: tensile strength; B: elongation; C: Vickers hardness; D: wear rate at 25°C for the machined enhanced cast A356 alloy' samples that were prepared at 700°C with a constant stirring speed of 1500 rpm.

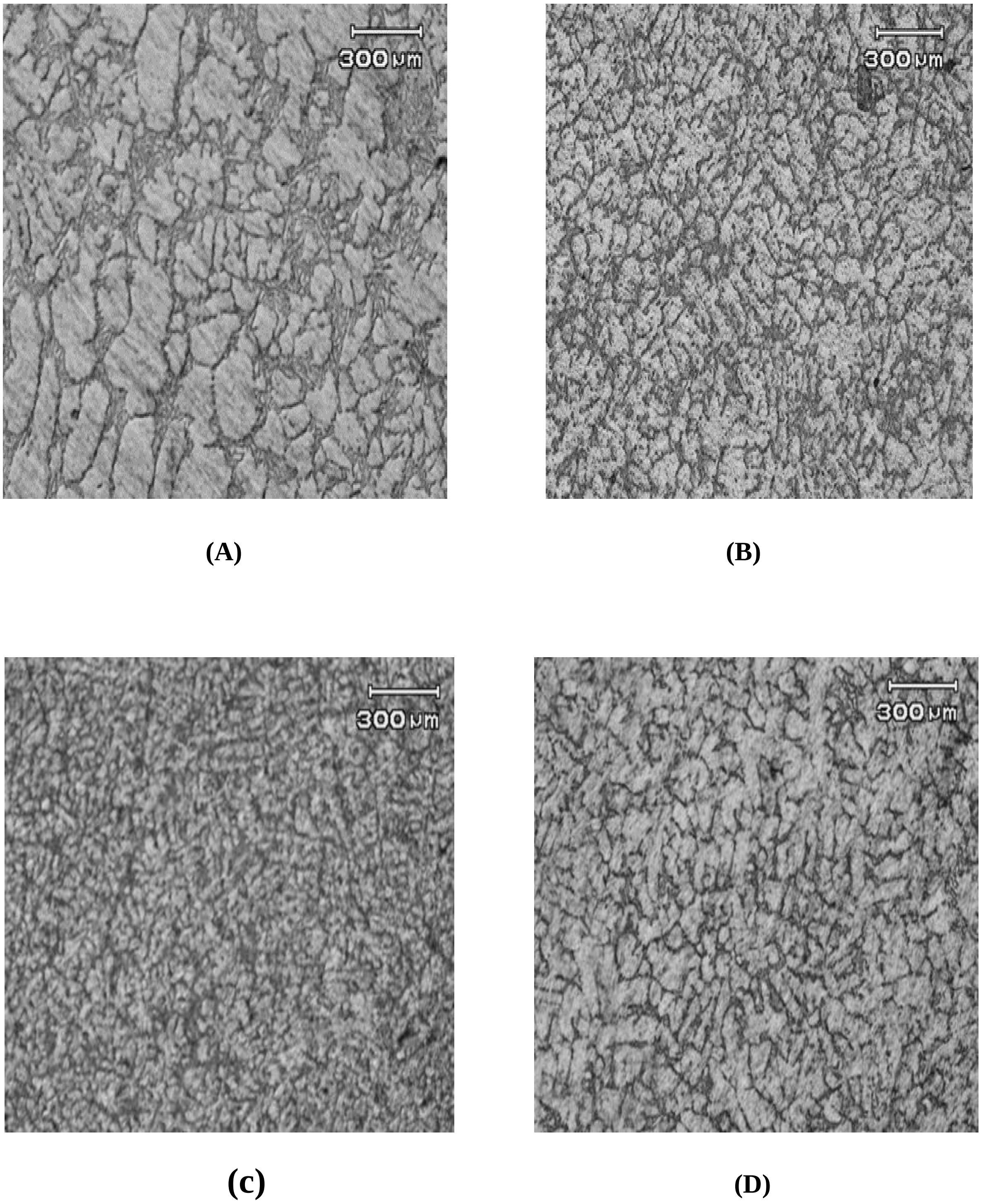
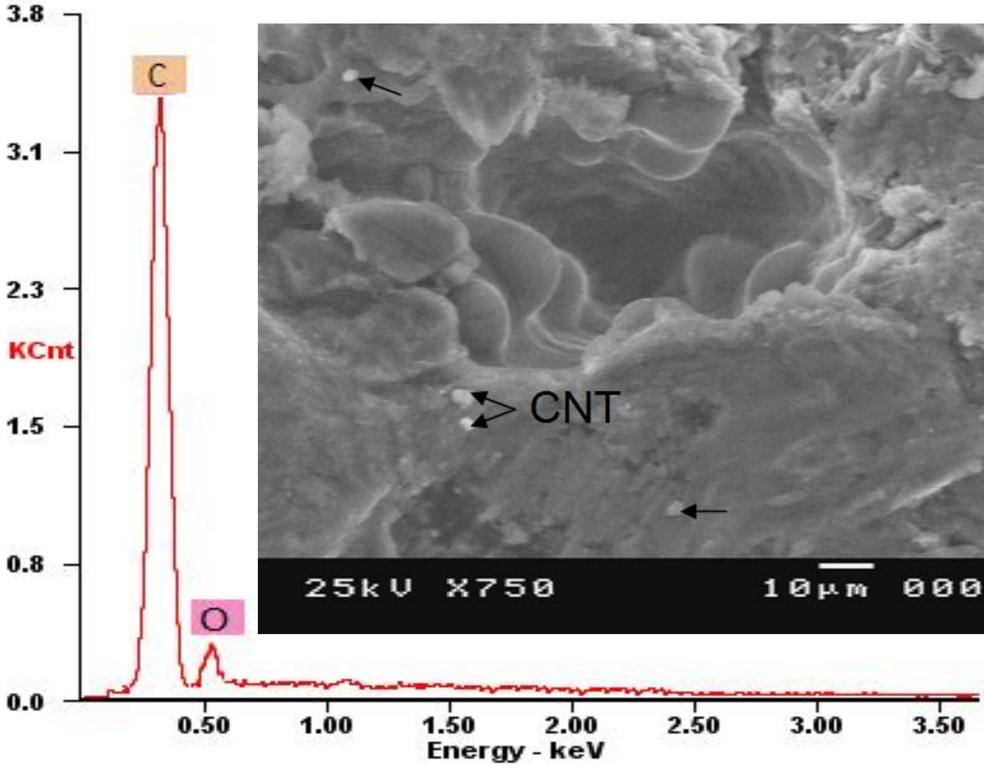


Figure 5. Microstructure of casting reinforced with nanoparticles, **A :**(2.5%TiC at stirring speed 270r.p.m), **B**: (2.5%TiC at stirring speed 800r.p.m), **C**: (2.5%TiC at stirring speed 1500r.p.m), and **D**: (2.5%CNT at stirring speed 1500r.p.m).

(A)



(B)

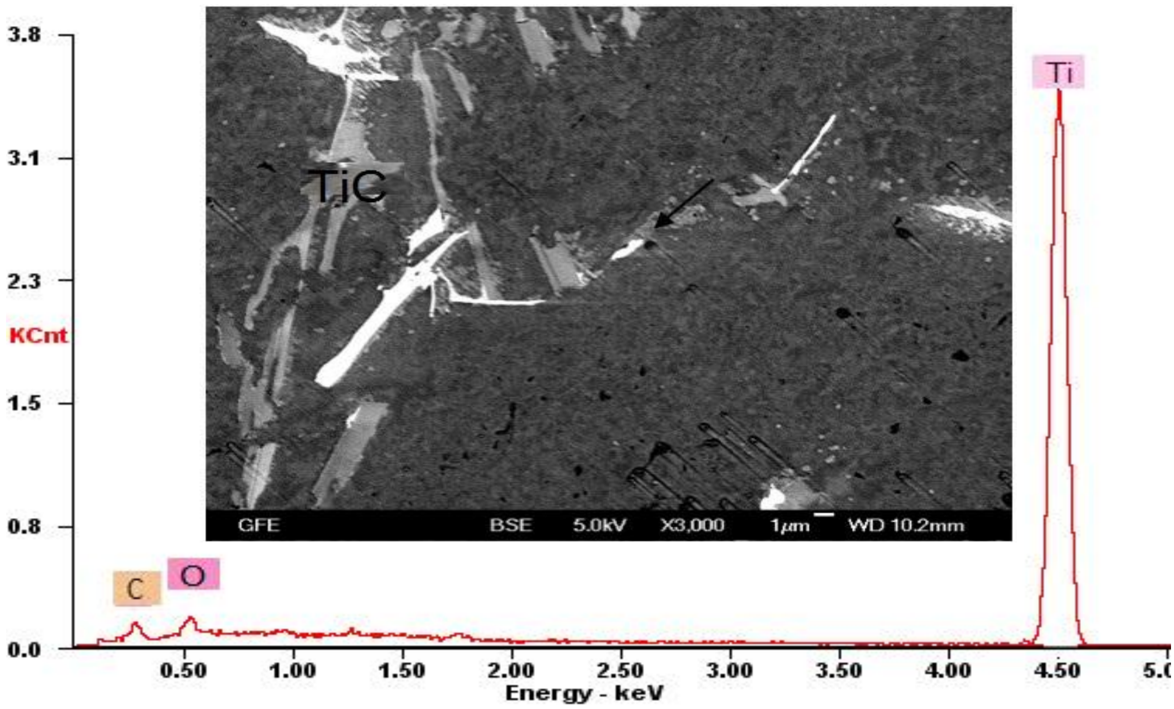
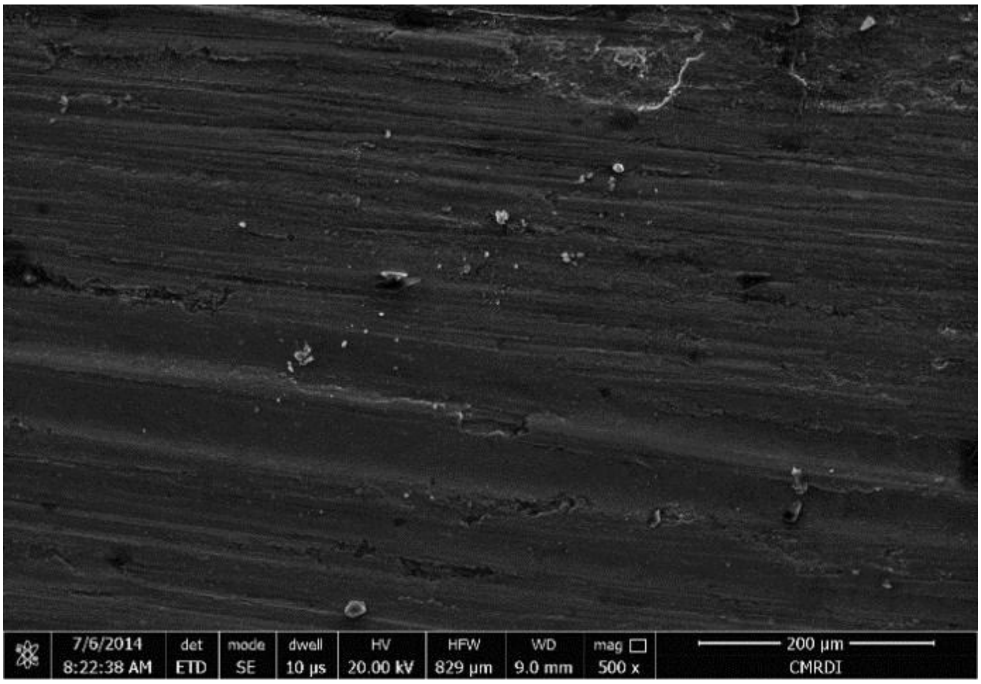
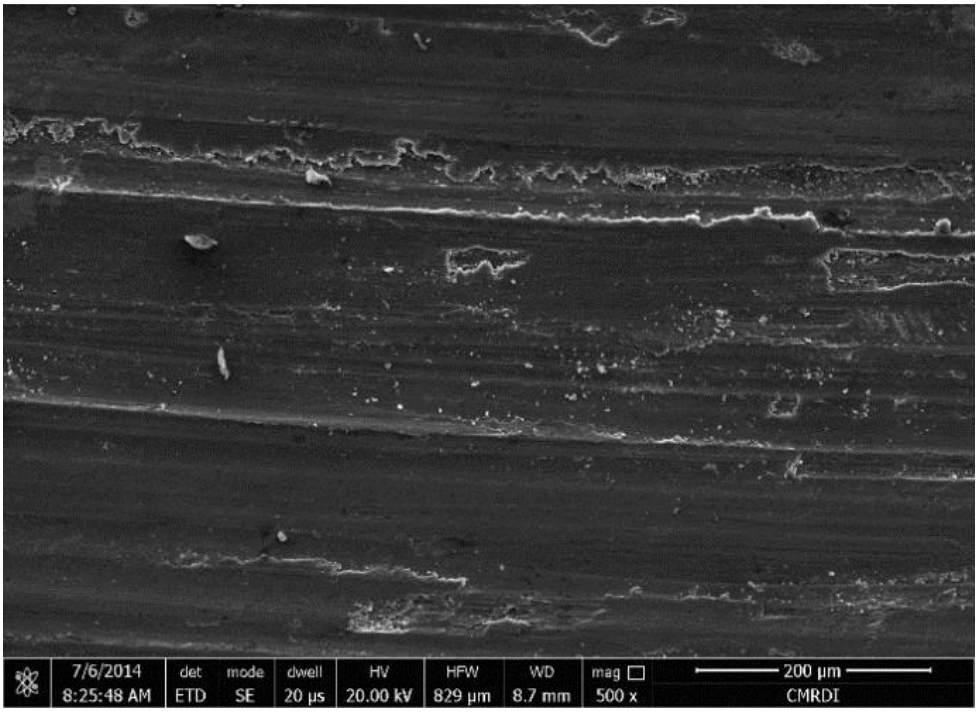


Figure 6. EDX and SEM for the casting reinforced nanoparticles of (A) CNT and (B) TiC.



(A)



(B)

Figure 7. SEM images of wear surface with 2.5 weight% nanoparticles of (**A**): CNT and (**B**): TIC at 25°C for the machined enhanced cast A356 alloys that were prepared at the constant stirring speed of 1500 rpm and 700°C.