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Influence of Tio_2 Particles Reinforcement on Microstructure and Mechanical Properties of Al-Zn-Mg Alloy

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Abstract: This research aims to study the influence of TiO_2 particulate reinforcement addition by different weight percent (0.5, 1.5, 2.5%) on the microstructural and mechanical properties of Al-Zn-Mg alloy. The base alloy and composite were prepared by stir casting process. The mechanical properties of base alloy and composite were measured by using tensile test and hardness. The scanning electron microscope and energy dispersive spectroscopy (EDS) were utilized to study the fracture surface topography. The results represent that the hardness, yield strength and ultimate tensile strength increased with increasing the weight percentage of TiO_2 up to 2.5 wt% m while the elongation decreased. The microstructure inspection by optical microscope which show the distribution of particles in the matrix without any voids. The X-Ray phases and intermetallic compound.

Keywords: Vortex method, single composite, hybrid composite, mechanical properties

Introduction

Aluminum matrix composites (AMCs) have been widely studied and are now is utilized in electronic packaging, sporting goods and automotive industries. The aluminum alloys are so attractive because of their good corrosion resistance, low density, high thermal and electrical conductivity, capability to be strengthened by precipitation and their high damping capacity [1]. AMCs contain a non-metallic reinforcement (SiC, AlN, B_4C ,TiC, Si_3N_4, TiB_2, TiO_2) integrated to aluminum matrix which provide beneficial properties more than base metal Al-alloys. These include enhancement creep resistance, abrasion resistance, exceptionally good strength-to-weight and stiffness-to-weight ratios, dimensional stability and best high temperature performance [2]. Aluminum matrix composites exposure higher wear resistance and good mechanical properties compared with the alloy regardless of sliding speed and applied load. This is mainly because of the fact that the hard particles such Al_2O_3, WC , ZrO_2, TiO_2 and SiC etc., when dispersion in matrix make it plastically restricted and enhancing the rise temperature strength of the base alloy [3]. Most of composite materials reinforced with particle by liquid metallurgy method (or so called vortex method) has the advantage over the traditional methods as its simple, inexpensive, good binding to matrix, easier to control the composition of the mixture, flexibility and its application for larger production quantities. A numerous studies and research have been published in this field. M. Yellappa et.al. 2014[4]studied the Al-7075 alloy reinforced with E-glass and Fly ash particulates of several weight proportions (2:1, 4:1, 6:1, 2:3, 4:3, 6:3, 2:5, 4:5, 6:5) wt%. using liquid metallurgy technique of stir casting. The particle size of fly ash 200µm. The result is found to have the improved tensile strength and hardness compared to Al-7075 alloy.

Experimental work

In this research we used TiO_2 particles with particle size (50-75µm) as reinforcement phase embedded in Al-Zn-Mg as matrix phase, the table (1) show the chemical composition of the Al-Zn-Mg alloy. The Al-Zn-Mg alloy was melted in alumina crucible at temperature 700 ^{o}C in the electric furnace(local industry) and then pouring in the preheated steel mold at 300 ^{o}C for one hour to prepared base alloy. The composites have been prepared by stir casting method where it was melting the base alloy in electric furnace at 750^{o}C which is above the liquidus temperature. The melt was held at this temperature for approximately 15 min for homogenization chemical composition, then added flux(1%wt.). The reinforcing materials (titanium oxide) gradually added to melting alloy along with mechanical stirrer, particulates added with 0.5 ,1.5, 2.5 wt % were utilized, where they were wrapped by aluminum foil and preheated to 550^{o} C for 1 hour to remove moisture and to help improve wettability with the Al-Zn-Mg alloy melt after making vortex within melting by electric stirrer rotational speed (750 r.p.m) so as to obtain good dispersion of the reinforcing within the melt. Magnesium has been added (1wt%) to improve the wettability between the base metal and reinforcement. Then, pouring the melting in the preheated mold to get a composite material reinforcing by TiO_2 particles, and the process is repeated for all additions. After the preparation of all samples of the base alloy and composites it has been done a machining process (turning) for castings according to the standard dimensions required for each test.

Table (1): Chemical composition of Al-Zn-Mg alloy (wt %).

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Casting alloy	0.0949	0.221	1.38	0.0261	2.31	0.191	5.88	0.0278	Bal.
Stander alloy(7075)	Max 0.4	Max 0.5	1.5-2.0	Max 0.3	2.1-2.9	0.18-0.28	5.1-6.1	Max 0.2	Bal.

Results and Discussion

Examination of the microstructure

The cast of Al-Zn-Mg alloy and composites samples have been cut in the dimensions (15x10). The samples were prepared using grinding of specimens with SiC paper of (220, 320, 400, 600, 800, 1000, 1500 and 2000) grit. Then the specimens are polished by utilizing polishing alumina (5µm). After complete grinding and polishing the specimens are cleaning with water and alcohol, the surfaces are immersing in etching solution (1%HF and 99%H_2O) for (10 sec) then washing by water and alcohol and dried in hot air. The prepared specimens have been examined utilizing metallurgical microscope assisted with optical digital camera. The results show that important factor for obtaining a homogeneous property of composite material with intermittent reinforced is the uniform dispersion of the reinforcement particles. Fig.(1,2) show the observation of which the microstructure approximately have a spherical shape and that its distribution is uniform rationally organized throughout the matrix in a particulate matter with particles coalescence that company at many location. The contact between the Al-melt and the particles of reinforcement is expected to lead to an interactive layer that enhances wetting between the particles and the matrix. The interaction of interfacial between the metal matrix and reinforcement on the MMCs is very important due to the strong bonding which permits the distribution and transferring the load from the composite matrix to the reinforcement particles, as mentioned in [5,6].

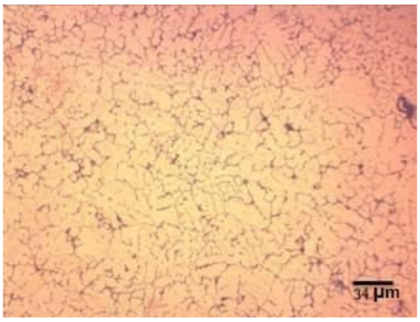
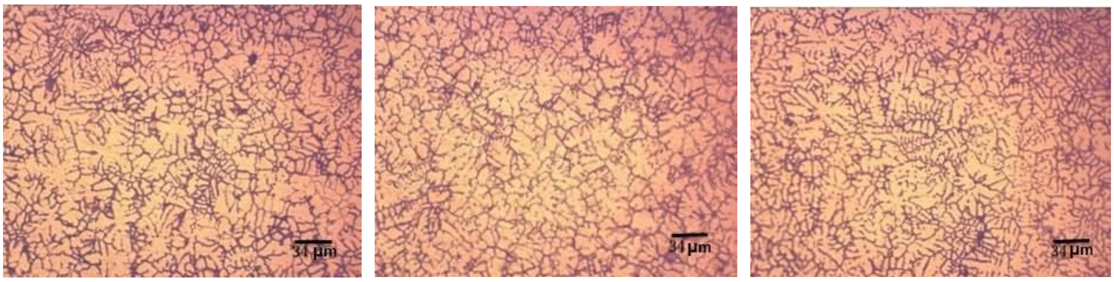


Fig. (1) The microstructure of base alloy.



(a) **(b)** **(c)**

Fig. (2) Microstructure of TiO_2 for (a-0.5 wt%, b-1.5 wt%, c-2.5 wt%).

Tensile test

The tensile test has been proceeded for the samples after prepared using (ASTM E8) standard, as shown in fig. (3). The tensile test has been done by using Instron Machine (DWD-200E). The tensile strength test of both the composites and the base alloy in the fixed strain was performed. Evidences that have been gotten from the table show that the yield strength and tensile strength values were higher than those of the base alloy value (unreinforced) because of the nature of the hardened ceramic particles that were added to the composite and strong bond between the matrix and particles. Also grain refining increases the strength of composite materials according to Hall-petch equation [7,8,9]. The addition of the particles of ceramic are mainly improving the composite tensile strength and effective fracture by transferring stress from the aluminum matrix(ductile) to the particles of reinforcing (brittle). This is due to the mechanism of orowan by which a dislocation by passes to heavy obstacles when the restricted is dislocated around a reinforced particle [10]. It could be seen that elongation decrease, due to ceramic particles increase brittleness [8].

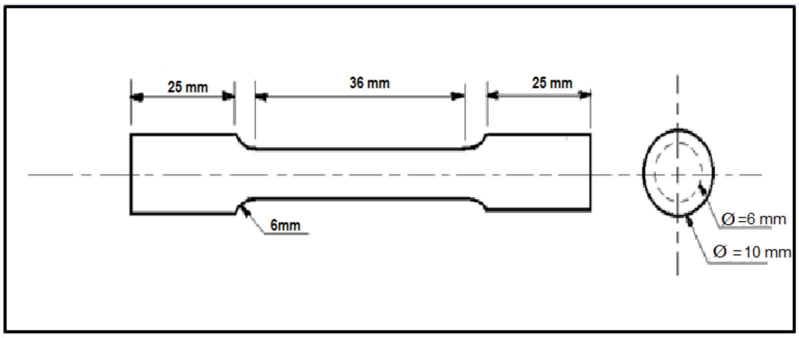
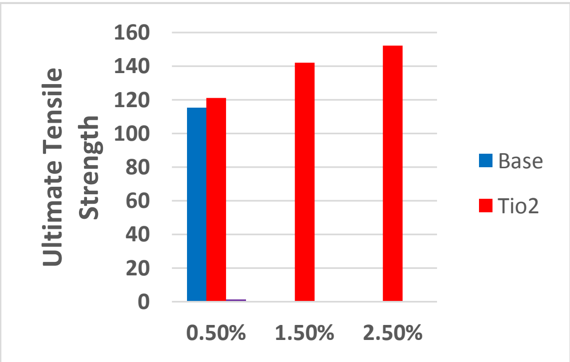
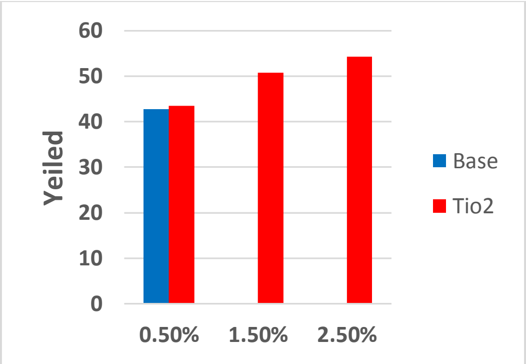


Fig. (3) Standard tensile test specimen[11]

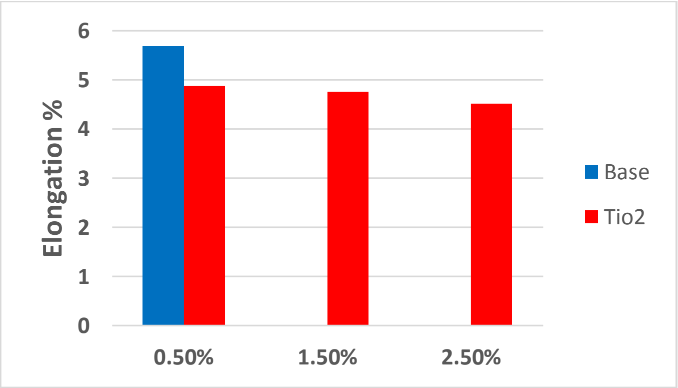
Fig.(4) show the relationship between the yield strength ultimate tensile strength and elongation of the reinforcement percentage for the base alloy. These particles deposition that are distributed in the base alloy, and the coefficient of thermal expansion between the matrix and the particles of ceramic caused an increasing in the dissociation density in the matrix. So that the dislocation passes through the . particles that are distributed in the phase of matrix. The particles were acting as barriers to deform the base alloy that results from the effective coherence between the particles of reinforcement and the base alloy. The high resistance form in the interfacial bond, allows the load to transmit between the particles of TiO_2 and the base alloy. This could represent a decreasing in elongation as a result of increasing the brittleness that is caused by the particles of ceramic [8].



(a)



(b)



(c)

Fig. (4) The relationship between (a- Ultimate tensile strength, b- Yield strength, c- Elongation of the reinforcement percentage for the base alloy

The surface of fracture for the deformed fracture under tensile loading test samples were examined by using scanning electronic microscope to determine the fracture to fractography, as shown in fig. (5 to 9). The fracture surface examination represents the fracture behavior which is influenced by two essential mismatch between the particles of reinforcement and the matrix alloy. The first mismatch is the variation in the strain ability of carrying between the matrix alloy and the brittle reinforcement particles TiO_2. The second mismatch is due to variation in the thermal expansion coefficient between the matrix alloy and the particles of TiO_2. The first mismatch enhances the concentration stress near the particles of reinforcement TiO_2. The local plastic constraints are particularly of larger particles size and particle coalescence during composite fracture. The second thermal mismatch induces dislocations at the reinforcement /interface of matrix. The presence of reinforcement particles TiO_2 will act reduce composite average distance by providing strong barriers to the dislocation movement. The dislocations interaction is between the particles of TiO2 and other dislocations. The results of dislocations movement are in the dimple structure. The void nucleation is occurring in the matrix interface for aluminum particles, which could be related either by particles cracking and de-cohesion of interface. Constraints caused by the existence of hard and brittle oxides of the particles of TiO_2. Then, the voids are grown under the effect of the applying load and the effect of the plastic local constraint until the mechanism of condensation is activated and that could be followed by the total sample failure. The void coalesecncence occurs when the void elongates to the initial inter void spacing. This is leading to the appearance of dimple of a surface fracture[12].

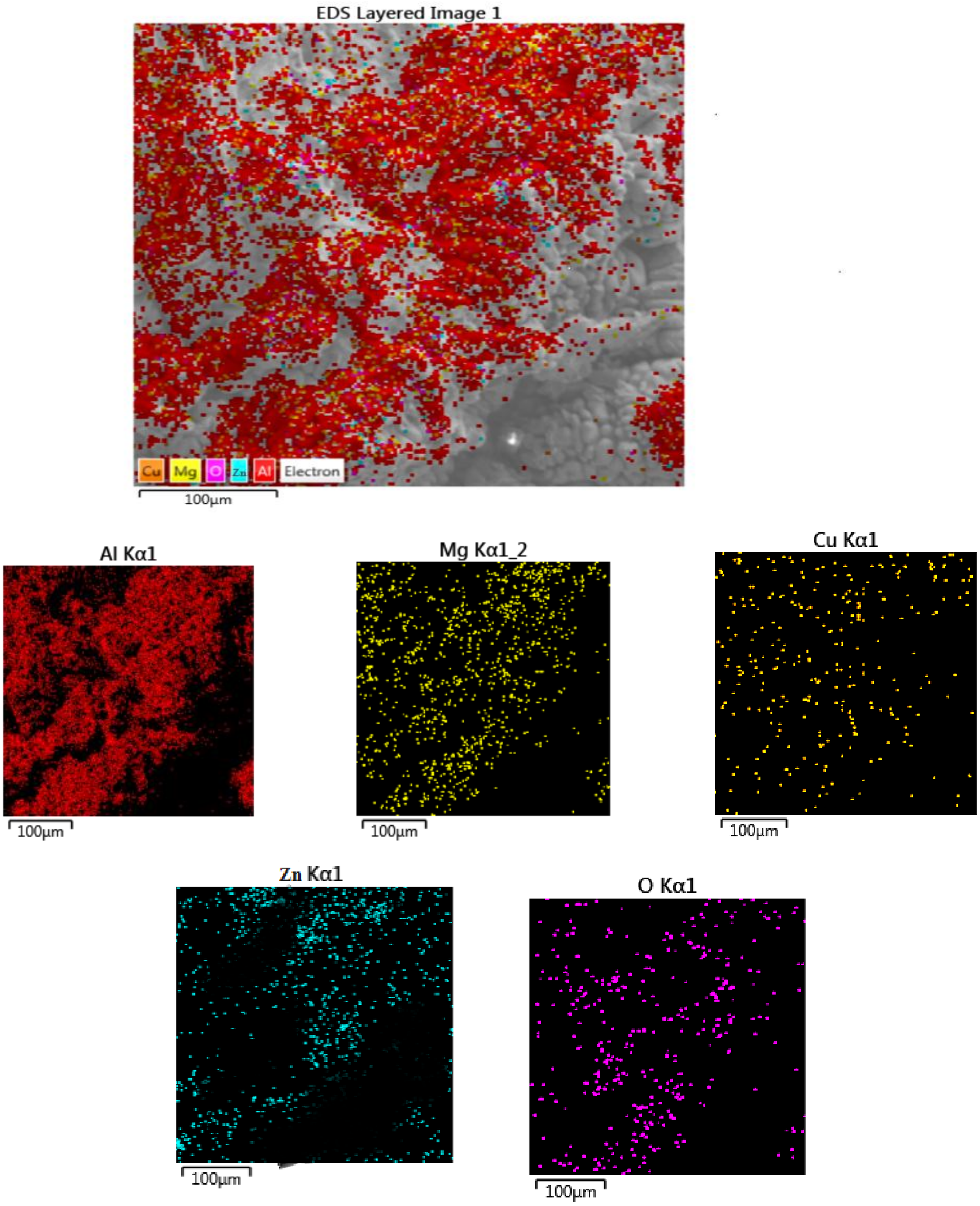


Fig. (5) The elemental mapping of Al-Zn-Mg alloy by using SEM

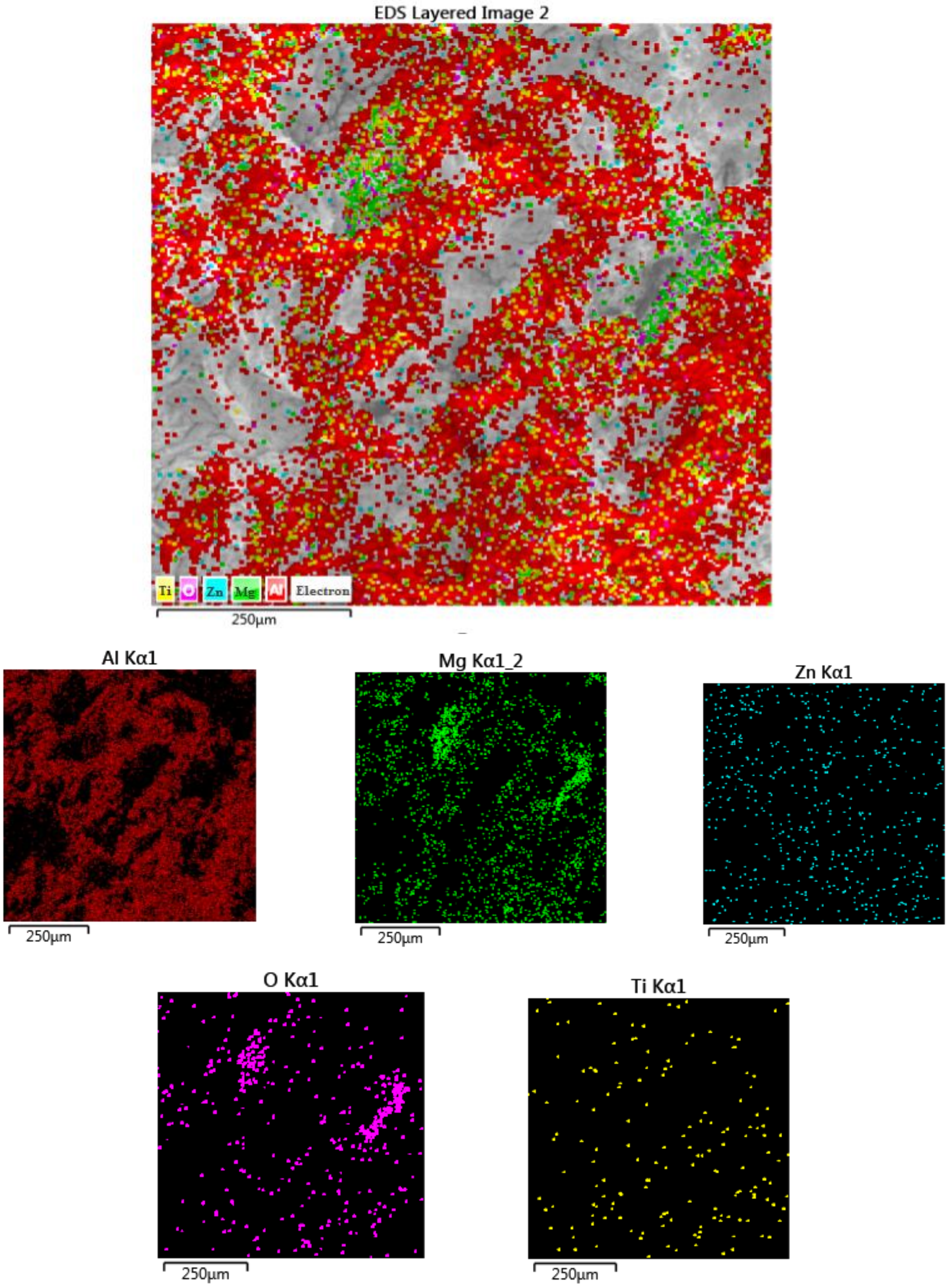
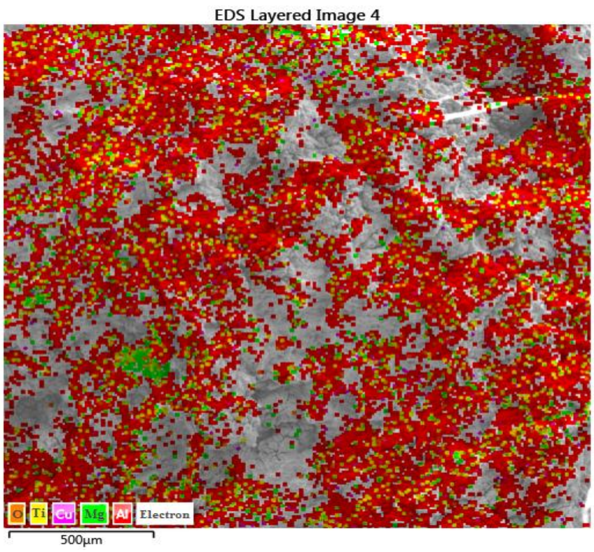


Fig. (6) The elemental mapping of composite 0.5%TiO_2 by using SEM



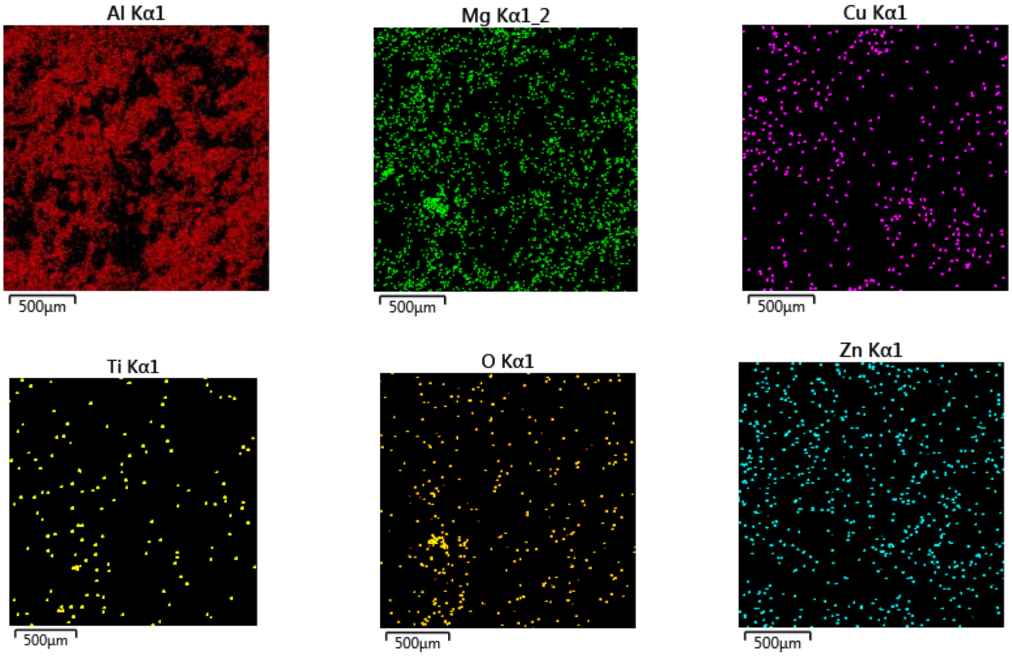


Fig. (7) The elemental mapping of composite 1.5%TiO_2 by using SEM

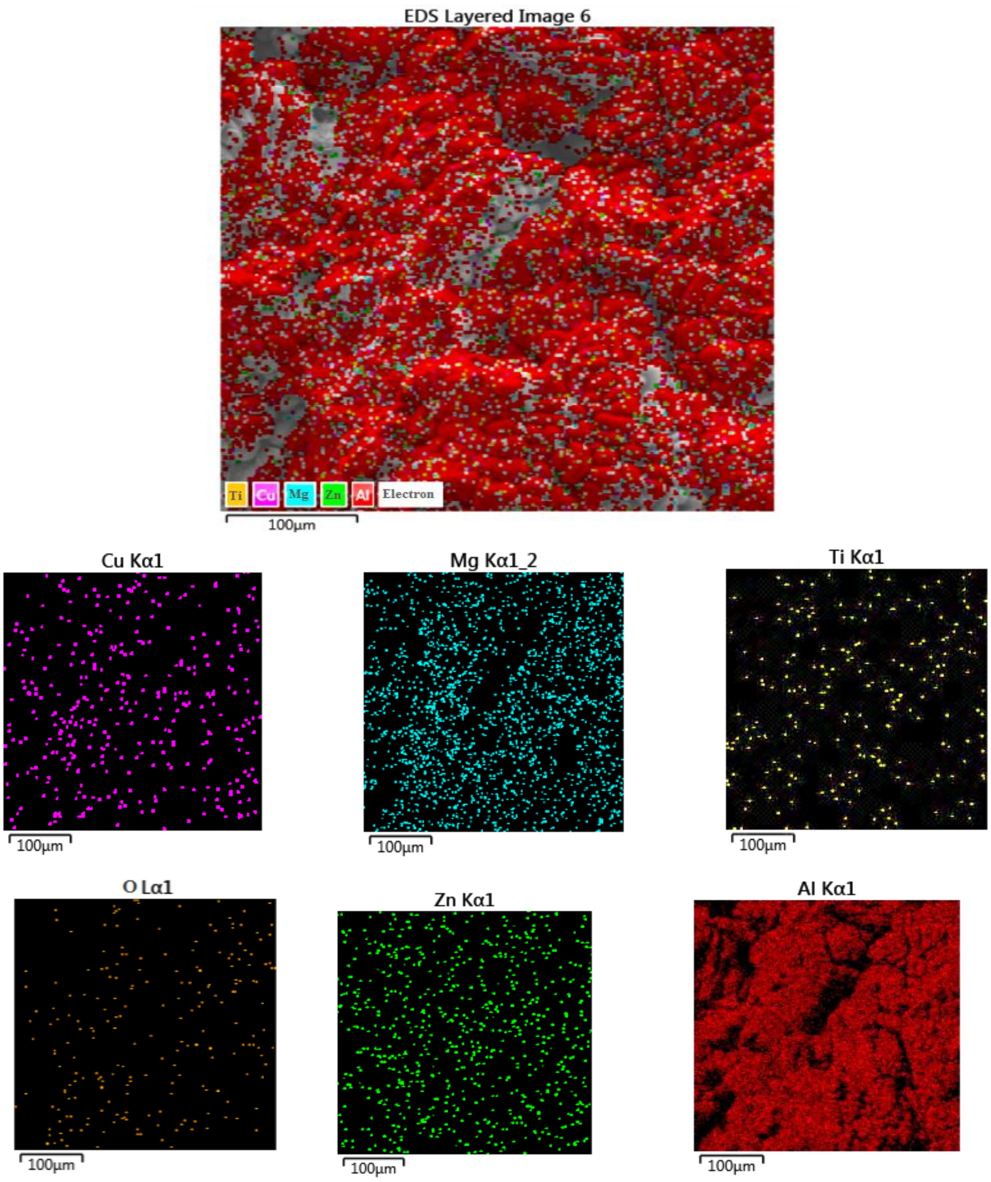
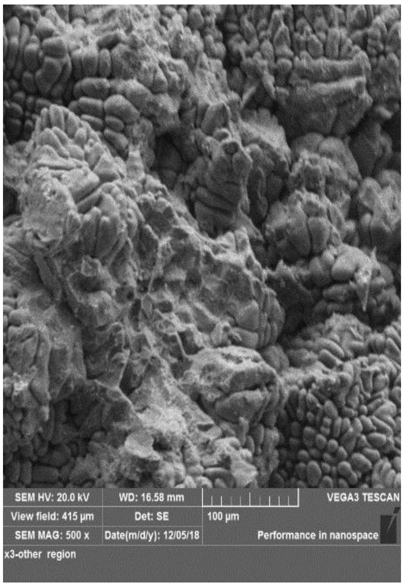
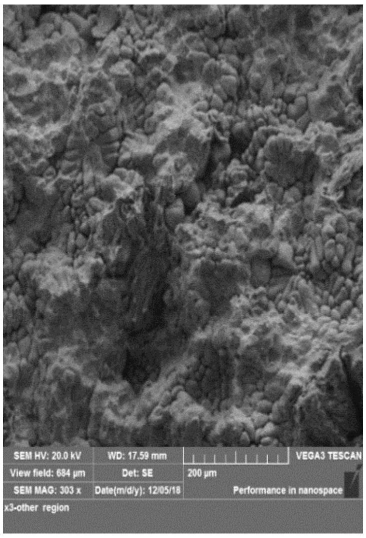
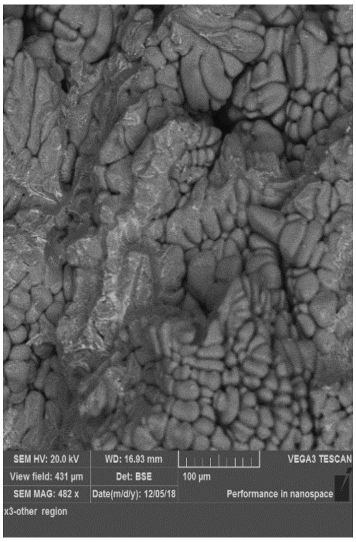


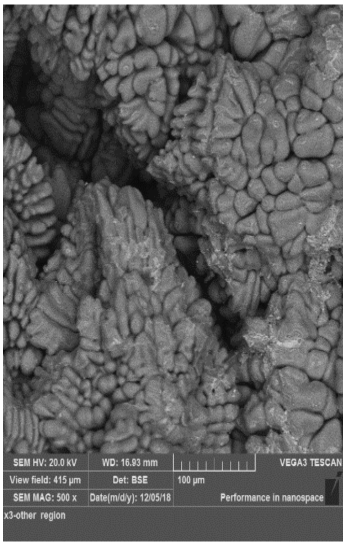
Fig. (8) The elemental mapping of composite 2.5%TiO_2 by using SEM



(a)







(b) **(c)** **(d)**

Fig. (9) SEM of fracture surface, (a) as cast, (b) 0.5% TiO_2 , (b) 1.5% TiO_2, , (c) 2.5% TiO_2

Hardness test

Vickers hardness tests were carried out on base alloy and composites after prepared as microstructural test without etching process using digital device micro hardness vickers tester TH714. The load was used (200 g) for dwell time (15 sec). Three readings were taken for each sample to obtain the average hardness value. The equation used to estimate Vickers hardness as the following is:-

$$HV=1.8544\,\frac{P}{d_{avg}^{2}} \qquad \text{...................(1)}$$

Where:

HV: Vickers hardness (MPa)

P: applied load (N)

d_{av}: diagonal length (mm)

Fig. (10) shown the relationship between the values of hardness for TiO_2 composites and base alloy. It has been observed that the composites' hardness is increased with the increasing of the weight percentage for the particles of reinforcement because the reinforcement particles are working as refining grains and therefore increasing strength such as equation of Hall-petch and the dislocations motion resistance, Fig.(11) shows the relationship between grain size and hardness. And this causes a big obstruction to the dislocations movement, and the result shows the exhibiting TiO_2 composite at 2.5% which has a greater hardness than that of the 0.5,1.5 and base alloy [7,8,13]. The increasing in the composite hardness is caused by the particles of reinforcement that have a high hardness. In addition the resistance to the plastic localized deformation is increased as a result of these particles which impede the movement of dislocations [10,14]. One of the greatest benefits for this strengthening dispersion influence is that it retains even for long periods of time and at elevated temperatures.

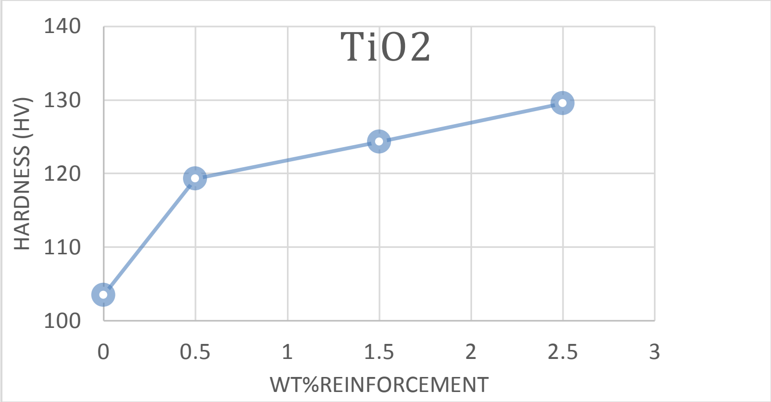


Fig. (10) The relationship between hardness and reinforcements

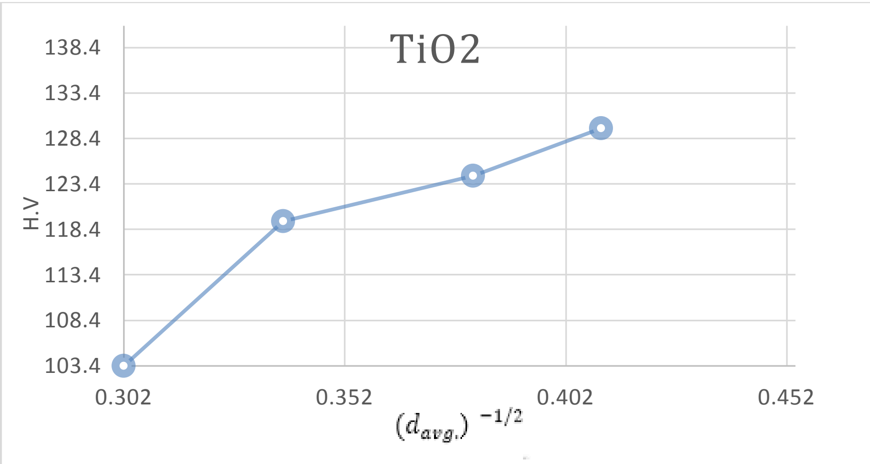


Fig. (11) The relationship between hardness and grain size

Conclusion

It may be mentioned the most important conclusions reached in this paper, as follows:

1- Improve the microstructure of the base alloy after the addition of titanium oxide particles where the change from dendritic structure to roughly equal axes structure.

2-The hardness increased with increasing the weight percent of TiO_2 additions.

3- The ultimate strength and yield strength increased with increasing the weight percent of particles additions.

4- The elongation decreases with increasing the weight percent of TiO_2.

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