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Influence of Stirring Speed on Mechanical Properties for Cast Nano-Particulate AA7075-Al_2O_3 Composites

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Abstract

Aluminum metal matrix composites are widely employed for improving the mechanical properties. Various fabrication routes like liquid state, solid state and liquid-solid state are currently available for producing these materials. The objective of the present work is the fabrication of nano particulate composites AA7075-Al2O3 with different amount of nano particles (20-30 nm) reinforced material Al2O3 (2, 4 and 6 wt%) using stir casting technique at three stirring speeds (300, 850 and 1500 rpm). Tensile tests of these composites were carried-out to obtain the mechanical properties (ultimate strength and ductility). Vickers hardness tests were also performed to obtain the hardness number (VHN) of these materials. All tests were performed at room temperature. The microstructures of the best mechanical properties' composites were examined for the three stirring speeds. It was revealed that the ultimate strength (6u) and Vickers hardness (VHN) for the composite containing 6 wt% Al2O3 fabricated at 850 rpm show the best properties compared to the other composites fabricated at 300 and 1500 rpm and the matrix. The 6u and VHN were increased by about (36.6 %) and (24.5 %) respectively. Ductility of the strongest composite (6 wt% Al2O3 at 850 rpm speed), however, was the least when compared to other composites and the matrix. With increasing the amount of Al2O3, 6u and VHN, an increasing trend was noticed while the ductility shows a reduction trend. The maximum reduction in ductility occurred for the composite containing 6 wt% Al2O3 obtained at 850 rpm. The ductility of the developed composite was reduced by (23 %). The optical microstructures of unreinforced, as-cast Aluminum alloy AA7075 and 6 wt% Al2O3 composites for all stirring speeds show dendrite microstructure resulting from the casting process, but the composite at the stirring speed of 850 rpm shows a more refined microstructure.

Keywords: stirring speed, cast Aluminum nano particulate composites, mechanical properties.

تأثيرسرعة التحريك على الخواص الميكانيكية لمسبوكات متراكب الألمنيوم ذو الجسيمات النانوية AA7075-Al_2O_3

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الخلاصة:

تمتلك المتراكبات التي اساسها معدن الألمنيوم استخدامات واسعة نتيجةً لتحسين المواصفات الميكانيكية لها وتتوفر حالياً طرق تصنيع مختلفة لتصنيع هذه المواد مثل الحالة السائلة والحالة الصلبة والحالة السائلة-الصلبة . ان هدف البحث الحالي هو تصنيع متراكبات نانوية (AA7075-Al2O3 Nano composites) بكميات مختلفة للمادة النانوية (Al2O3) المقواة ذات الحجم الحبيبي (nm 30-20) وبنسبة وزنية (wt% Al2O3 6, 4, 2) بأستخدام تقنية السباكة بالتحريك عند ثلاث سرع وهي (300، 850، 1500) دورة بالدقيقة . ولقد اجريت فحوصات لهذه المتراكبات (المقاومة العظمى والمطيلية) وكذلك تم اختبار الصلادة للحصول على عدد فيكرز (VHN). أن جميع الاختبارات

أجريت في درجة حرارة الغرفة. تم فحص البنية المجهرية لأفضل خواص ميكانيكية للمتراكبات لثلاث سرع تحريك. أظهرت النتائج أن المقاومة العظمى(6u) وصلادة فيكرز (VHN) للمتراكب المصنع الذي يحتوي (6 wt% Al2O3) و بسرعة (850) دورة بالدقيقة كانت هي الأفضل نسبة" للمتراكبات الاخرى المصنعة بسرع (300، 1500) دورة بالدقيقة وكذلك أفضل من سبيكة الألمنيوم الأساسية (بدون تقوية) وكانت الزيادة في المقاومة العظمى (6u) والصلادة (VHN) بنسبة (36.6%) و(24.5%(على التوالي، وكانت اوطأ مطيلية هي للمتراكب الذي يحتوي على (6 wt% Al2O3) وبسرعة (850) دورة بالدقيقة بالمقارنة مع المتراكبات الاخرى و سبيكة الألمنيوم الأساسية. وبزيادة النسب الوزنية (wt%) للمركب Al2O3 فأن المقاومة العظمى وقيمة الصلادة (VHN) سوف تظهر اتجاها" متزايدا" في حين ان المطيلية سوف تظهر اتجاها" تناقصيا" الى الحد الأدنى الذي يحدث للمتراكب (6 wt% Al2O3) و بسرعة تحريك للمنصهر مقدارها 850 دورة بالدقيقة. تم تقليل مطيلية المتراكب المطور (6 wt% Al2O3) بنسبة (23%). وقد اظهرت البنية الدقيقة بإستخدام المجهر الضوئي لسبيكة الألمنيوم الأساسية (AA7075) والغير مقواة بجسيمات الألومينا وللمتراكبات التي تحتوي (6 wt% Al2O3) ولجميع سرع التحريك بنية شجيرية (dendrites) نتيجة عملية السباكة ولكن المتراكب (6 wt% Al2O3) عند سرعة تحريك مقدارها (850) دورة بالدقيقة أظهر تنعماً أكثر لحبيبات البنية المجهرية.

الكلمات المفتاحية : سرعة التحريك، مسبوكات متراكب الألمنيوم ذو الجسيمات النانوية، الخواص الميكانيكية.

1- Introduction

Aluminum-based metal matrix composite (AMMC) has been studied for the last five decades, where micro-sized reinforcements have usually been used. Research work that incorporates nano-sized particle reinforcement is rather scarce [1]. AMMC reinforced with nano-sized ceramic particles have attracted researchers' interest due to their improved mechanical and tribological properties, like a high specific modulus, long fatigue life, good strength, superior wear resistance, and improved thermal stability. These properties permit these composites to have broad applications in the aerospace, marine and automobile industries [2-7].

The main reinforcement particles commonly in use are ceramics, such as Alumina (aluminum oxide Al_2O_3) and silicon carbide (SiC). Other reinforcements include titanium carbide (TiC), boron carbide (B_4C), zirconium oxide (ZrO_2), silicon nitride (Si_3N_4), aluminum nitride (AlN), titanium boride (TiB_2) and titanium dioxide (TiO_2) [8, 9].

AMMCs are made using different techniques. These can be categorized as (a) liquid state processes (casting), such as stir casting, squeeze casting, ultrasonic-assisted casting, vacuum infiltration, pressure-less infiltration, and dispersion methods; (b) solid-state processes, such as powder metallurgy (PM) techniques with variations in the processing steps, that's, use of hot or cold iso-static pressing, hot die pressing and dynamic compaction and (c) liquid-solid processing, such as compo-casting and semi-solid forming [8].

Powder metallurgy is the most common way to the produce the AMMCs, since it has the ability to generate near net shapes with the minimal material loss concerning production. A uniform reinforcement distribution is possible in powder metallurgy; and then powder metallurgy technique has better control on microstructure comparing with casting [10]. Stir casting, however, is a simple and flexible low-cost processing method for producing AMMCs. It can be applied in mass production for near net shaped components. In stir casting, better matrix-reinforcement particles bonding happens because of the stirring action of the particles into the molten metal matrix. Previous research studies showed that the homogenous mixing and good wetting could be acquired by choosing suitable processing parameters such as stirring time, stirring speed, preheating temperature of the mold, temperature of molten metal, and uniform feed rate of particles [10, 11].

Very little researches have been carried out on stirring speed and stirring time needed for uniform distribution of particles in the matrix. Hashim et al. [12-14] conducted some researches about stir casting technique. Naher et al. [15] studied the impact of stirring speed on the uniform distribution of particles by simulation. They carried out experimental tests on fluids with similar properties of the liquid and semi-solid aluminum. SiC reinforcement particulate similar to that employed in AMMCs had been employed in the simulation fluid mixtures. Prabu et al. [16] studied the effect of stirring speed and time on the hardness and the distribution of SiC particles in AMMC containing 10 wt% of SiC particles and produced by the stir casting method. The results showed that the uniform hardness values were achieved at 600 rpm stirring speed with 10 minutes of stirring. Above a certain stirring speed, however, the hardness of the composite deteriorated. Microstructure analysis also showed that at lower stirring speed with lower stirring time, the particle clustering was more. Increase in stirring speed from 300 to 850 rpm and stirring time from 4 to 10 minutes resulted in a better distribution of particles.

This paper is primarily aimed to show the impact of stirring speed on the mechanical properties of cast

AMMC reinforced with various amount of nano-sized ceramic particles (Al_2O_3).

2- Experimental Work

(A) Materials

Aluminum oxide (Al_2O_3) ceramic particles with particle size of (20-30 nm) were selected as the reinforcement material. It is widely used in the production of metal matrix nano-composites. The Al_2O_3 nano-particles were added to the base unreinforced Aluminum alloy AA7075. The chemical composition of AA7075 is illustrated in Table (1). Chemical analysis has been implemented atomic fluorescence spectrometer (AFS) device at Tarbiat Modares University in Tehran/ Iran.

Table (1): Chemical analysis of AA7075 (in wt%)

Composition	Al	Zn	Mg	Cu	Mn & Cr
Standard	87.1-91.4	5.1-6.1	2.1-2.9	1.2-2.0	<0.5
Experimental	Balance	5.4	2.62	1.64	0.36

Various amounts of Al_2O_3 (2, 4 and 6) in wt% were used in this study to fabricate different cast composites.

(B) Production of cast composites

Stir casting was the method of production of the cast AMMC. The procedure of production of the composites included the following steps:

1. Melting the required weight of Aluminum alloy AA7075 in an electric furnace at (800 °C).
2. Preheating the required weight of the Al_2O_3 nano-particles to (200 °C) and adding them to the molten aluminum alloy.
3. Mechanically stirring the mixture at specific speed (three speeds of 300, 850 and 1500 rpm were chosen in this investigation) and for a constant stirring time of four minutes.
4. Pouring the molten composite into steel molds which are already preheated to (400 °C).

Table (2) shows the percentage amount of reinforced material added to the alloy (rule of mixture) and the speed of stirring. Table (3) shows the tensile strength, hardness and ductility (% elongation) of the unreinforced, as-cast alloy. The tensile properties are determined from stress-strain curve using computerized WDW-200E tensile test rig. These as-cast alloy properties are actually similar to the as-cast properties of AA7075 alloy reported in the literature [17, 18].

Table (2): Amount, stirring speed and constituents of the composites

Al_2O_3 Wt%	Stirring speed (rpm)	AA7075 (gm)	Total weight (gm)	Al_2O_3 (gm)
2	300	980	1000	20
4	=	960	=	40
6	=	940	=	60
2	850	980	=	20
4	=	960	=	40
6	=	940	=	60
2	1500	980	=	20
4	=	960	=	40
6	=	940	=	60

Table (3): Tensile strength, hardness and ductility of the unreinforced, as-cast alloy

σu (MPa)	VHN	Ductility (% elongation)
142	57	15.6

(C) Mechanical properties testing

Tensile strength (σu), hardness (VHN) and ductility (expressed as % total elongation during the tensile test) were obtained for the composites fabricated with three weight percentages (wt %) of Al_2O_3 (2, 4 and 6) for each speed of stirring.

The tensile testing machine that has been used in this investigation is a computerized (WDW-200E) machine with a capacity of 200 KN as shown in Fig. 1. Stress-Strain diagrams can be obtained from the machine and the required tensile properties can be determined. Round tensile specimens of the shape and dimensions shown in Fig.2 were used in tensile testing. Three tests were conducted for each combination of wt% Al_2O_3 reinforcement and stirring speed and the main value of each tensile property was recorded. The cross-head speed for all tensile tests was 1 mm/min.

Figure (1): Photograph of the tensile testing machine

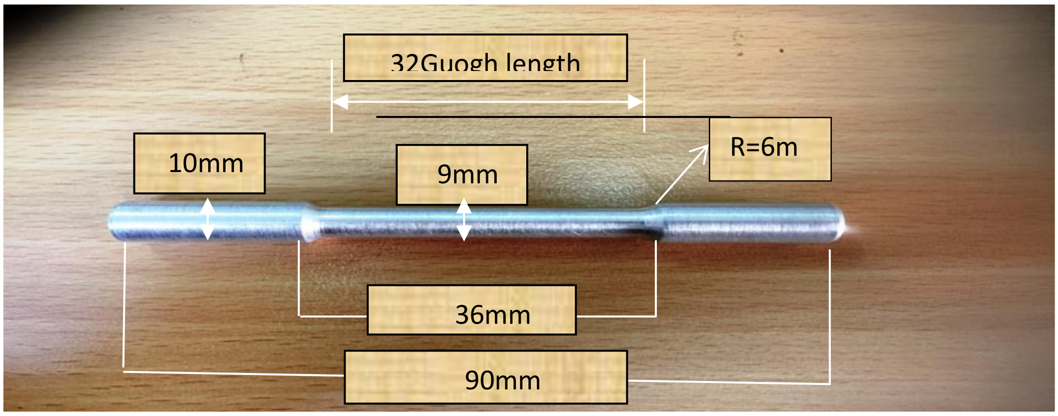


Figure (2): Photograph of the tension specimen according to ASTM (E8/E8M-09) [19]

The standard Vickers hardness number (VHN) was measured on polished samples with a load of 20 N and the value reported as a mean of 5 readings taken at different locations. The hardness device used is type (TH714) available in the Department of Production Engineering and Metallurgy/ University of Technology, Baghdad-Iraq.

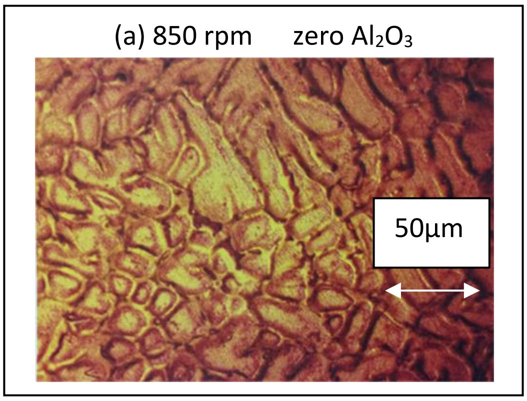
3- Results and Discussion

(A) Microstructure

Figure (3) shows the optical un-etched microstructures of the as-cast alloy AA7075 and the composites fabricated with 6 wt% Al_2O_3 at different stirring speeds. It can be observed that the microstructure of the as-cast aluminum base alloy AA7075 (without reinforcement) consists of the typical dendrite structure of castings with small dendrite arms. It is also clear that the optical micrographs of 6 wt% Al_2O_3 composites at 300, 850 and 1500 rpm speed resulting from stir casting method show fairly a more refined microstructure.

The Al_2O_3 particles had been separated at inter-dendrite regions. According to the microstructure examination, Fig (3), it is concluded that the nano Al_2O_3 particles can be successfully introduced into the base metal and the best fairly uniform distribution of Al_2O_3 is observed at 850 rpm stirring speed.

El-Mahallawi et al. [20] have concluded that the best distribution of nano-particles occurs at 1500 rpm using alumina particles Al_2O_3 added to A356 aluminum alloy. They used stirring speeds of 270, 800, 1500 and 2150 rpm and the composites were produced by semi–solid state technique.



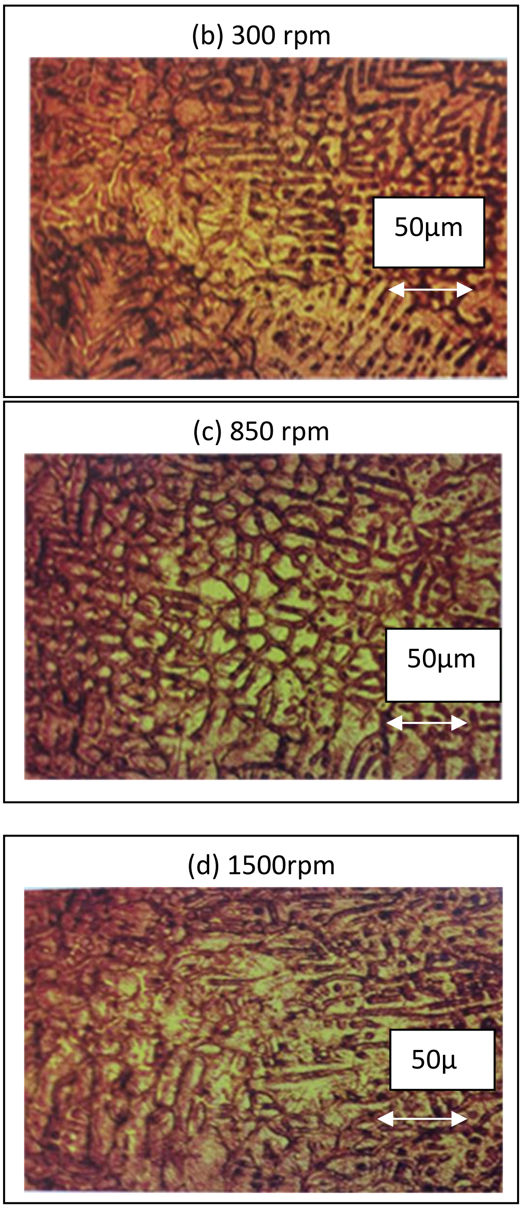


Figure (3): Optical micrographs of (a) as-cast alloy and (b, c, d) 6 wt% Al_2O_3 composite at three different stirring speeds (Magnification X50)

(B) Mechanical Properties

For analyzing the mechanical properties (tensile strength 6u, hardness VHN and ductility), twenty

seven experiments with three replications (nine experiments for each speed) were examined at constant strain rate of 1 mm/min. The average of three specimens' results are tabulated in Table (4).
Table (4) demonstrates all the experimental results of mechanical properties at the three stirring speeds used in this investigation (300, 850 and 1500 rpm).

It is clear from Table (4) that the σu and VHN for the most of the resulting composites at the three speeds investigated are greater than the unreinforced, as-cast AA7075. The ductility, however, of all composites are lower than that of the as-cast alloy. It was found that both σu and VHN were improved as the wt% of Al_2O_3 increased from 2% to 6% for all speeds, while the ductility was reduced. The highest improvement in σu and VHN and the highest reduction in ductility were observed at 6% Al_2O_3 and for the 850 rpm stirring speed as shown in Fig. (4).

As shown in this figure, tensile strength and hardness increase and ductility decrease as the weight percentage of Al_2O_3 reinforcement increases for all stirring speeds used in this investigation. This could be attributed to the presence of Al_2O_3 reinforcement particles which possess high hardness. The presence of Al_2O_3 particles imposes more constraint to the localized matrix deformation during a tensile test or hardness test; which act as barriers to the motion of dislocations and resist the deformation of the matrix. The rise in the residual stresses induced due to the mismatch of thermal expansion between the matrix and reinforcement resulted in higher dislocation density and effective load transfer from matrix to better bonded and uniformly distributed reinforcements [16, 21-23]. All these lead to higher tensile strength and hardness of the composite.

The effect of stirring speed on tensile strength, hardness and ductility are shown in Figs. (5), (6) and (7). The effect is similar to the effect of Al_2O_3 reinforcement, but there is a critical stirring speed where the strength and hardness of the composite are at their maximum and the ductility is at the minimum. This critical stirring speed in this investigation is (850 rpm). Above this speed, both tensile strength and hardness decrease and ductility increases for all the weight percentage of Al_2O_3 reinforcement used in this investigation, but still better than that of the as-cast aluminum alloy.

Table (4): Experimental results of mechanical properties at various stirring speeds

	300 rpm			850 rpm			1500 rpm			850 rpm
Al_2O_3 content	2w%	4wt%	6wt%	2wt%	4wt%	6wt%	2wt%	4wt%	6wt%	Zero% (as-cast)
σu (MPa)	141	166	182	146	171	194	138	156	177	142
VHN	59	62	68	63	66	71	59	60	66	57
Ductility (%)	15	13.8	12.2	14.2	13.8	12	15.2	14	12.8	15.6

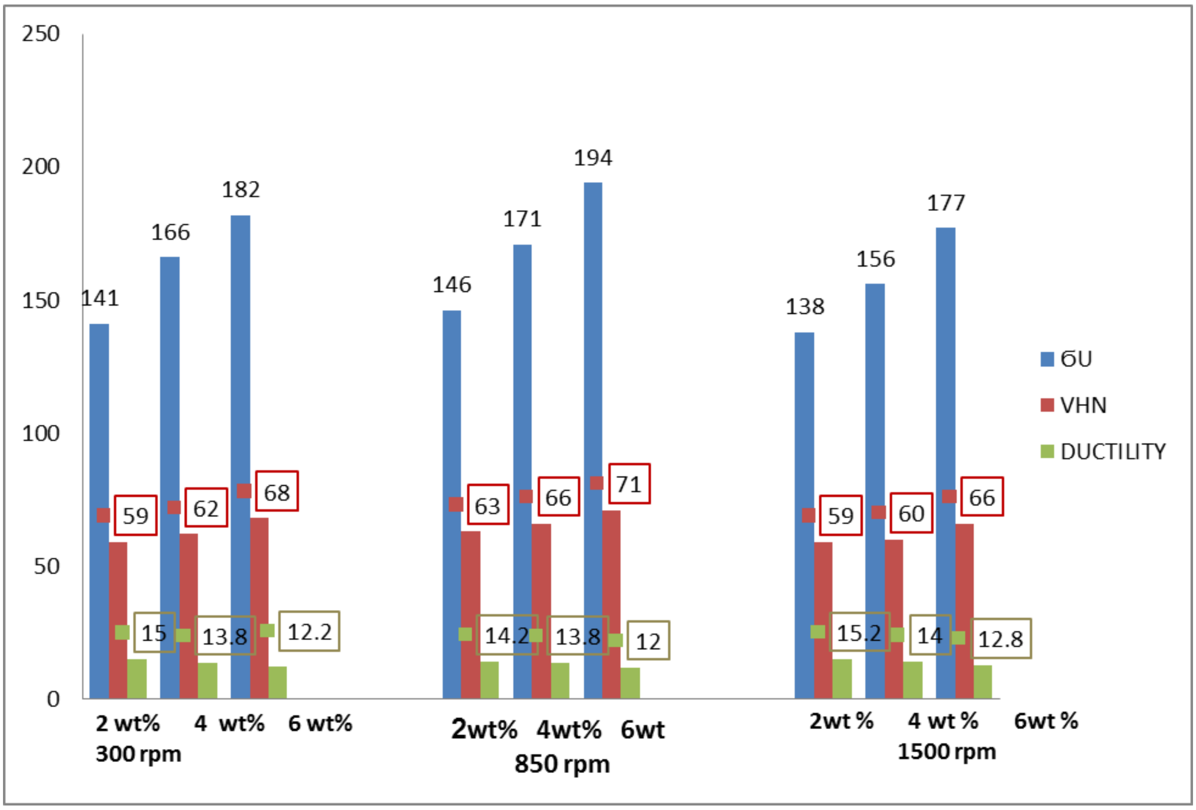


Figure (4): Mechanical properties as a function of Al_2O_3 content and stirring speed.

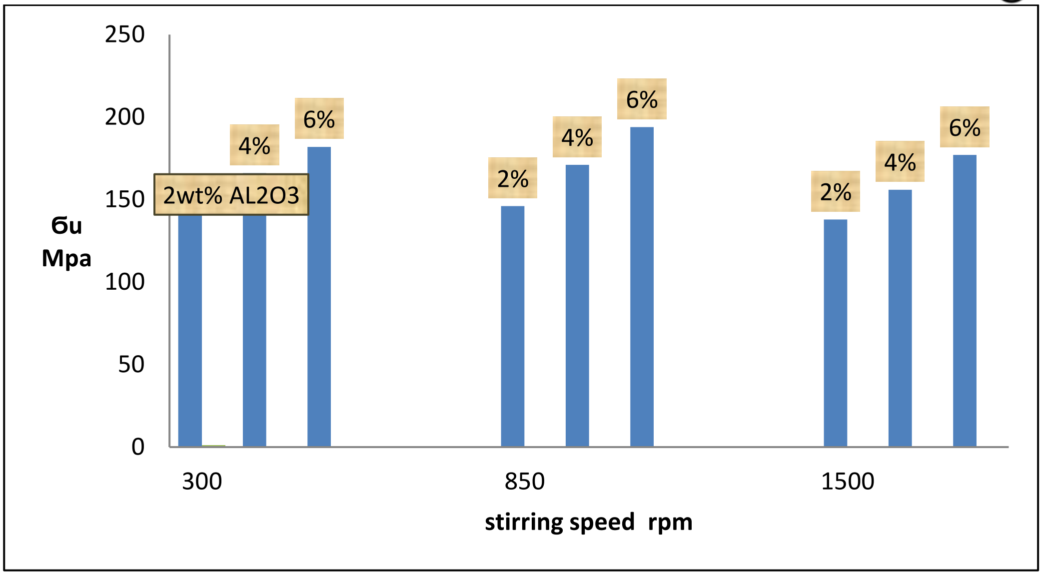


Figure (5): Variation of tensile strength (бu) with wt% Al_2O_3 and stirring speed

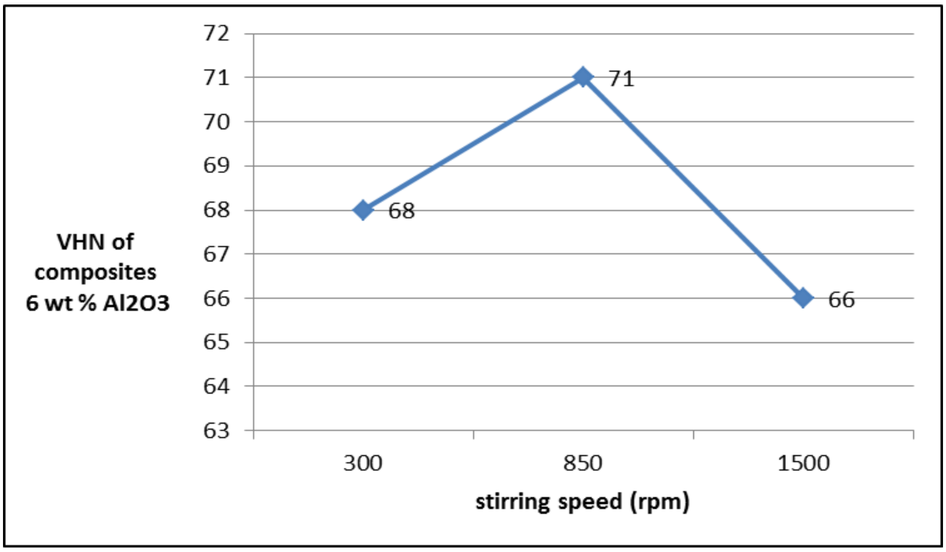


Figure (6): Variation of hardness (VHN) with stirring speed for the 6 wt% Al_2O_3 composites

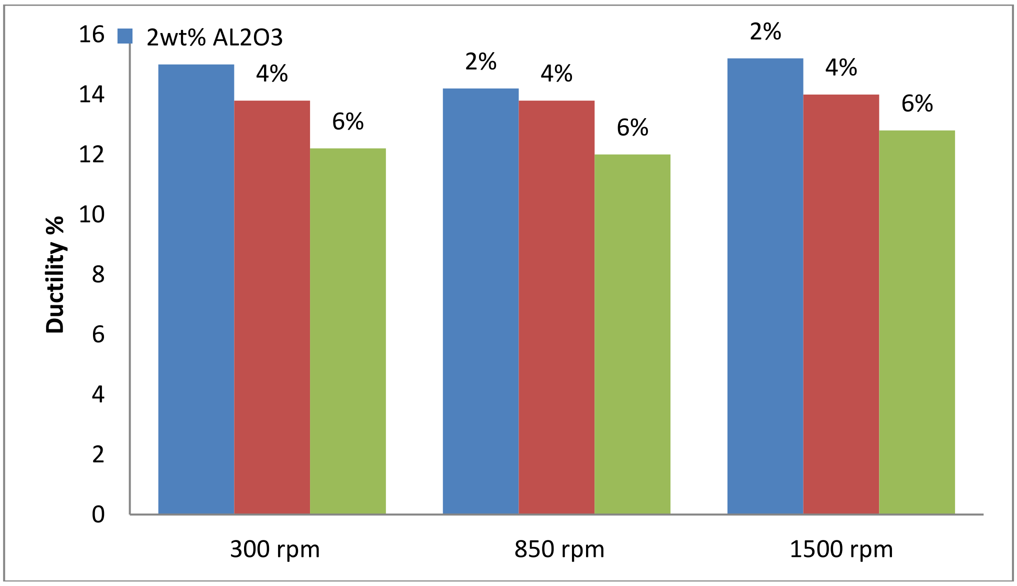


Figure (7): Variation of ductility with wt% Al_2O_3 and stirring speed

The highest value of σu and VHN is in the resulting composite containing 6 wt% of Al_2O_3 processed at a stirring speed of 850 rpm, showing an improvement of 36.6% and 24.5% respectively, as compared to the as-cast aluminum alloy. Prabu et al [16] reported an improvement in VHN of 38% in a composite containing 10 wt% SiCp and aluminum alloy AA6061 produced by the stir casting method.

All the resulting composites containing Al_2O_3 nano-particles exhibited lower ductility as compared to the as-cast metal matrix. The lowest ductility is in the composite containing 6 wt% Al_2O_3 at a stirring speed of 850 rpm, showing a reduction of 23% as compared to the as cast alloy. Bharath et al [24] tested AA6061 before and after addition of 6, 9 and 12 wt% Al_2O_3 and they explained the increase in strength and hardness and the drop-in ductility in terms of the incorporation of hard Al_2O_3 particles in AA6061 alloy.

4- Conclusions

Several methods were used in strengthening the mechanical properties of engineering materials such as powder metallurgy, stir casting method, and semisolid method. In this study, composite materials fabricated by stir casting route using AA7075 base metal and 2, 4 and 6 wt% of Al_2O_3 (20-30 nm particle size) were successfully synthesized for three stirring speeds of 300, 850 and 1500 rpm. The main conclusions obtained are as follow:

1. The optical micrographs of unreinforced, as-cast Aluminum alloy AA7075 and 6 wt% Al_2O_3 composites for all stirring speeds show dendrite microstructure resulting from the casting process, but the composite at the stirring speed of 850 rpm shows a more refined microstructure.
2. The hardness of composites increases when increasing the amount of Al_2O_3 for all stirring speeds used. Maximum hardness was observed at 6 wt % Al_2O_3 with 850 rpm. The hardness increases by 24.5% in case of 6 wt% Al_2O_3 with 850 rpm compared with the as-cast alloy.
3. The increase in the amount of reinforcement significantly improves the tensile strength and the highest tensile strength was recorded at 850 rpm stirring speed and the improvement percentage was 36.6 % as compared to the matrix alloy.
4. The increase in wt% of Al_2O_3 decreases the ductility of the composite and the maximum reduction was observed with 6 wt% Al_2O_3 and at 850 rpm stirring speed showing a reduction of 23 % as compared to the as-cast alloy.

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