Mechanical Properties of Aluminum-Magnesium Alloy Prepared by Slope Plate Casting Process

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ABSTRACT

The present work encompasses the development of microstructure by using cooling plate casting process. This process consists in pouring the molten metal at temperature close to the liquidus line in an inclined cooling plate. The mould and the slope plate unit were manufactured by researcher. Pouring temperature and inclination angles have effect on microstructure, tensile strength, and on macro hardness for both Al-1.6%Mg, Al-0.46%Mg.

The following variables have been used in this work: pouring temperatures of (750,800,850°C), tilt angles of (30°, 40°, 50°and 60°), and Mg additive of (1.6%, 0.46%) with constant cooling length (380mm). Tensile results reveal that (750,800 and 850°C) especially for (30°, 40°, 50°) for 1.6%-Mg, and 0.46%Mg have a high value. Vickers macro hardness has a gradual increasing value for Al-0.46%Mg, but for Al-1.6%Mg rheocast alloy it has a fluctuated value, the higher value is for small angles (30°, 40°, and 50°) and small value for high angle (60°).

Key Words: Aluminum alloy,Al-Mg alloy, Rheocasting process.

الخصائص الميكانيكية لسبيكة ألمنيوم – مغنيسيوم محضرة بطرقة الصب بالصفيحة المائلة

الخلاصة

ويشمل هذا العمل على تطوير الخصائص الميكانيكية بواسطة عملية الصب باستخدام صفيحة التبريد المائلة. تتكون هذه العملية بصب المعدن المنصهر في درجة حرارة قريبة من خط السائل على صفيحة التبريد المائلة. وتم تصنيع القالب ووحدة الصفيحة المائلة من قبل الباحث. وقد استخدمت المتغيرات التالية في هذا العمل: الصب في درجات الحرارة (750800850 °C)، وكانت زوايا الميل من (30°، 40°، 50° و 60°)، ونسب المغنيسيوم المضافة (1.6٪، 0.46٪) وكانت مسافة التبريد المستخدمة (380mm). بعد جريان المنصهر أسفل صفيحة التبريد المائلة ، ويصبح المعدن المصهور شبه صلبا في نهاية الصفيحة. ثم يتم تقطيع هذه السبائك وفقا للاختبار المطلوب.
اظهرت نتائج الشد بانه عند درجة حرارة (750,800,850 م°) وخصوصا عند (30°,40°,50°) لكل من المنيوم-1.6%مغنيسيوم ، المنيوم-0.46% مغنيسيوم لها قيم عالية. الصلادة الماكروية لها قيم تزداد تدريجيا" لسبيكة المنيوم-

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0.46%مغنيسيوم ولكن لسبيكة المنيوم-1.6%مغنيسيوم لها قيم متذبذبة ، حيث كانت القيم العالية للزوايا الصغيرة (30˚,40˚,50˚) ، بينما القيم الصغيرة كانت للزوايا الكبيرة (60˚).

INTRODUCTION

Aluminum is the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. It was to become a metal of its time. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of aluminum and its alloys, greatly benefit growth in the production and use of the new metal. The properties of aluminum that make this metal and its alloys the most economical and attractive for a wide variety of uses are appearance, light weight, fabric ability, physical properties, mechanical properties, and corrosion resistance[1].

Semisolid metal (SSM) processing has been a promising technique for the rheocasting or thixocasting of aluminum alloys for more than 30 years. Extensive effort has been expended to take SSM based casting of aluminum alloys to full scale commercial exploitation with very limited success. In order to develop the new rheocasting process for aluminum it was realized that the key step to provide ideal semi-solid slurry was to subject the alloy melt to extreme conditions of shear and turbulence [2].

Experimental Work

Raw Materials

Aluminum Alloy

The chemical composion of the basic alloy 6063Al that was used in this work is given in Table (1), the atomic absorption done at Iraqi geological Survey.

Table (1) Chemical composion of the 6063 Al alloys.

alloy		Composions %						
Al%	Mg%	Si%	Fe%	Cu%	Cr%	Mn%	Zn%	Ti%
97.5	0.4-0.9	0.2-0.6	0.35	0.1	0.1	0.1	0.1	0.1

Magnesium Powder:

The Magnesium (metal) powder which was used in cooling slope casting techniques has At.w. 24.31 And 500gm, the source is THOMAS BAKER (chemicals) PVT. Limited 4/86, BHARAT MAHAL, Mumbai-CAS NO.7439-95-4, UN.869, the composition is shown in Table (2):

Table (2) the composition of Mg powder:

Powder Compositions%	
Mg (powder) maximum assay	98.5%
HCL Insoluble matter	0.05%
Iron(Fe)	0.05%

Cooling Slope Plate:

It represents the basic element of cooling slope method. According to this technique, the molten alloy is poured on upper plate (was 20mm Wide, 550mm long), while lower plate was (20mm wide, 450 mm long) for circulation the water. The thickness of each one was 5.5mm the lower plate had two holes, one for water in and second for water out Each plate was joined by seam welding process, The active cooling slope plate length was set at (380mm) as shows in fig.(1).

The distance between the input and output of water holes was about 350mm. This instrument was fixed by holder which has (450 mm length, 26.3mm width) and was made from mild steel, while the base was made from cast iron.

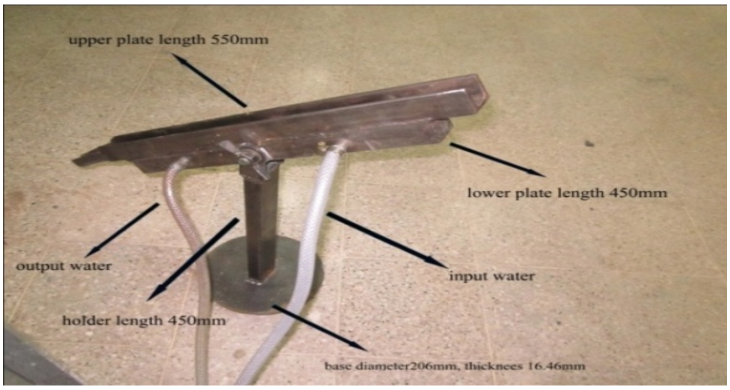


Figure (1) The instrument of cooling slope.

Permanent Mould

The casting mould was made from mild steel with dimensions 200mm length 100mm width, 50mm thickness for producing rheocasting alloy, The mould had two cavities with different dimensions ,the first was (130mm in length) and (22mm ϕ) narrowing by of (5mm) with(18mm ϕ) narrowing with distance (24mm) with (13mm ϕ) down with (110mm). The second cavity was (80mm in length) with (17 ϕ) then narrowed by (10mm) and (13ϕ) then narrowing by of (20mm) and (10 ϕ) down with distance (45mm). See Figures (2).

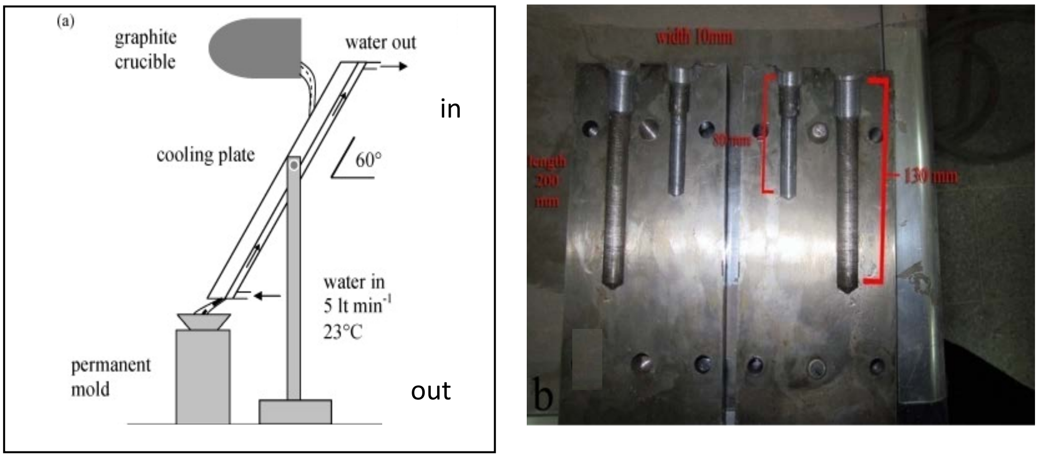


Figure (2) The mould and cooling slope unit

Procedure

This process can be divided to three steps After reaching the specific temperature of (750,800,850)°C, the first step is taking the crucible out from furnace followed by adding the pure magnesium, then stirring device is used for (30sec)to ensure that the alloying elements are completely melted. Figure (3) shows the stirring device, this step is done for 1.4% of Mg. The process is repeated again for0.46% weight percentage of Mg added to molten Al alloy, the second step is the molten alloy returned back to furnace in order to reach the desired temperature mentioned above, step three, the molten alloy is poured on the cooling plate which is fixed by the holder, taking in to consideration the mould before the casting is reheated in electric oven of about (200) °C for (10-15) min.

(a)

(b)

Figure (3) The electric furnace and the string device

The above process is done at different angles (30°, 40°, 50°, 60°) degree with respect to the horizontal plate cooled by water circulation underneath.

Tests and Measurements

Macrohardness Test

Vickers macrohardness tests were carried out on the cross-section of the rheocasting alloy Al-1.6%Mg, Al-0.46%Mg by using Digital Vickers macro hardness tester type (HBRVS-187.5, P/NO.11053592). This test was done by using load (294) gm for dwell time (10 sec).Three reading was taken for each rheocast alloy Al-Mg. The indenter of Vickers macrohardness is diamond indenter which was pressed on to a prepared metal surface to cause a square-based pyramid indentation.

Tensile Test:

The tensile tests were carried out on rheocast alloy specimens cut according to ASTM (E8M) which is the standard method for tensile testing of metallic materials (gage length45mm, diameter 9mm, length of reduced section 54mm), these rheocast alloys were tested by using tensile device type Instron (WDW-200E) which has Max. Capacity of 200KN, serial number-0492, class 1,China, the dimensions were in (mm).

Results and Discussion

Tensile Test Results

Tables (3) and (4) show the tensile testing results for both rheocast alloys, Al-1.6%Mg and Al-0.46%Mg.the cooling slope casting parameters were; pouring temperature (750,800,850)°C, and the inclination angles were (30°,40°,50°,60°). Figures (4) through (6) in this research show the relationship between pouring temperatures and ultimate tensile strength. The results of Al-0.46%Mg rheocast alloy are illustrated in Table (3), while Table (4) illustrates the tensile strength results of Al-1.6%Mg rheocast alloy shown:

Table (3)Tensile strength for Al-0.46%Mg rheocast alloy

Tilt angle /degree	Pouring temperature/°C	Ultimate tensile strength / M pa
30°	750	110.4
40°	=	111.5
50°	=	/
60°	=	/
30°	800	102.2
40°	=	60.9
50°	=	111
60°	=	68.4
30°	850	126.7
40°	=	56.1
50°	=	87.4
60°	=	92.3

Note (1): For Al-1%Mg -750 °C -50° and 60° rheocast alloy failed in casting by theway cooling slope plate technique.
Note (2): The cooling slope technique was done at room temperature of 21°C.

The results of tensile strength for Al-1.6%Mg rheocast alloy are shown in Table (4) below:

Table (4) The tensile strength results for Al-1.6%Mg rheocast alloy:

Tilt angle/degree	Pouring temperature/C°	Ultimate tensile strength /M pa
30°	750	120
40°	=	81.6
50°	=	81.15
60°	=	72.16
30°	800	91.2
40°	=	69.4
50°	=	126.5
60°	=	87.6
30°	850	65.3
40°	=	78.2
50°	=	101.6
60°	=	53.4

Figures (4) through ( ) show the relationship between the pouring temperature and the ultimate tensile strength for both Al-1.6%Mg and Al-0.46%Mg rheocast alloys:

The observation of the tensile strength figures shows, the relationship between the tilt angles of (30°, 40°, 50°, 60°)at specific pouring temperature of (750,800,850) °C and ultimate tensile strength are illustrated. Moreover the tensile strength has a higher value especially for Al-1.6%Mg rheocast at certain tilt angles and pouring temperature of (850C°-5%Mg-30°-40°-50°),(800C°-5%Mg-30°-50°),and at(750C°- 5%Mg-30°-40°-50°)..
For 850 °C –Al-1.6%Mg rheocast alloy , the ultimate tensile strength at (30° ,40°,50°)tilt angle, gradually increases in values(65.3,78.2,101.6Mpa) while at(60°) it decreases in value to (53.4Mpa).

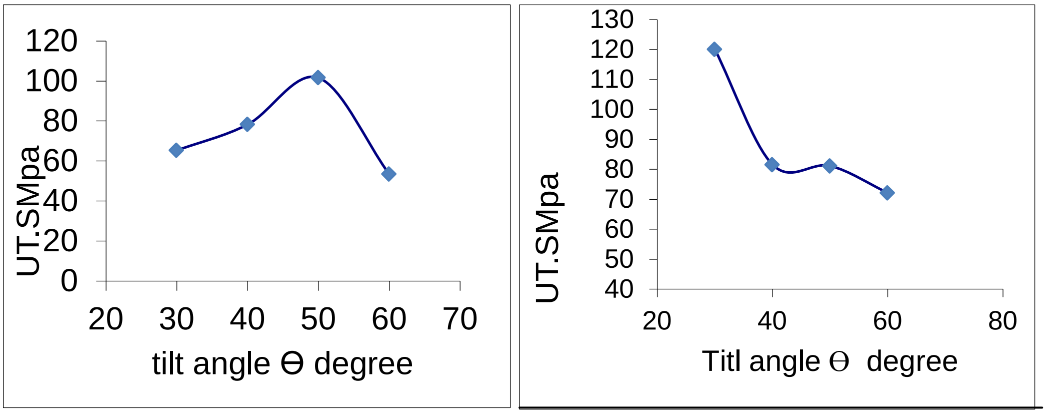


Figure (4) The relationship between UT.S and Tilt angle for rheocast alloyAl-1.6%Mg 850°C pouring temperature at right , Al-1.6%Mg at 750°Cat left .

For 750°C-Al-1.6%Mg rheocast alloy, the ultimate tensile strength at (30° ,40°,50°) has a higher value of (120,81.6,81.15Mpa) while at the high tilt angle (60°)the ultimate tensile strength reaches which is lowest value than that of other tilt angles(72.16Mpa).
For 800°C-Al-1.6%Mg rheocast alloy, the ultimate tensile strength at (30°, 50°) tilt angle has a higher value of (91.2, 126.5Mpa) while other tilt angle (40°, 60°) has a lower strength tensile value of (69.4, 87.6Mpa).

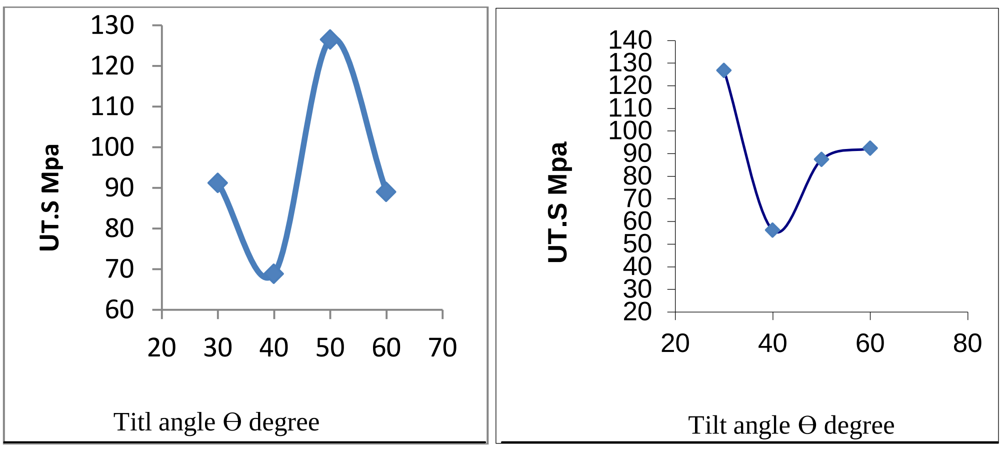


Figure (5) The relationship between UT.S and Tilt angle for rheocast alloy Al-1.6%Mg at 800°C at right,
Al-0.46%Mg at 850°C at left pouring temperature.

For 850°C-Al-0.46%Mg rheocast alloy the ultimate tensile strength at (30°, 50°, 60°) has a higher value of (126.7,87.4,92.3Mpa) while at (40°)it has lowest value of (56.1Mpa) as can be shown in Fig. (5). For 800°C-Al-0.46%Mg rheocast alloy the ultimate tensile strength at (30°,50°) has a higher value of(102.2, 111Mpa) while at (40°,60°),it has the lowest value of (60.9,68.4Mpa) as shown in fig. (6).

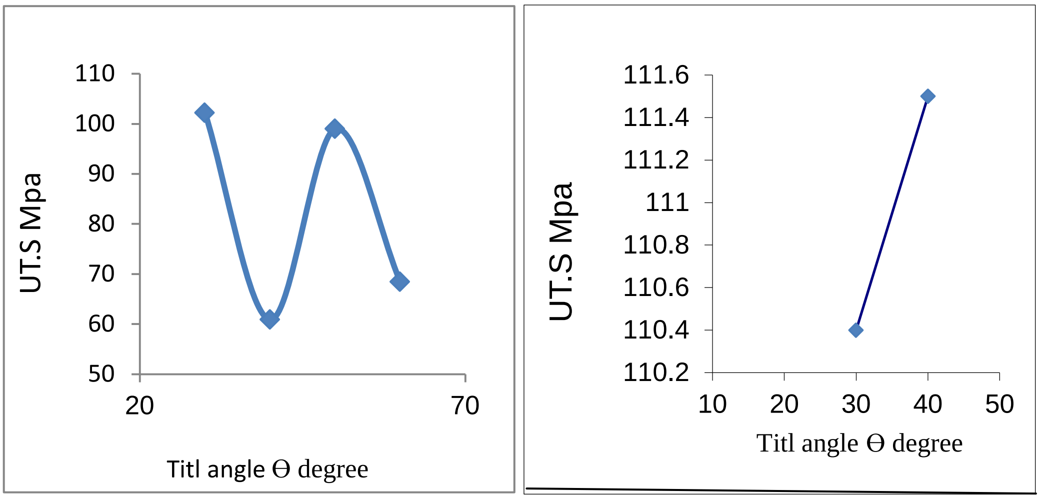


Figure (6) The relationship between UT.S and tilt angle for rheocast alloyAl-0.46%Mg at 800°C at right , alloy Al-0.46%Mg at 750 °C pouring temperature at left.

For750 °C- Al-0.46%Mg, the ultimate tensile strength at (30°, 40°) has a higher value (110.4, 111.5Mpa), where only two rheocast alloy can be performed by using cooling slope technique as shown in fig (6)at left .The Al-0.46%Mg rheocast alloy has higher value at (750C°-30°-40°), (800C°-30°-50°), and (850C°-30°-50°) these higher value appear due to adding Mg atoms to molten aluminum alloy affecting on their mechanical properties by increasing the strength for Al alloy in solid solution strengthen**.** The tensile strength did not go up straight with the rise of tilt angles of cooling slope technique but they fluctuated a bit under the same parameters like pouring temperature, inclination angles, and the amount of adding magnesium This can be seen also in Fig(7) below ,which shows the relationship between the pouring temperature and ultimate tensile strength:

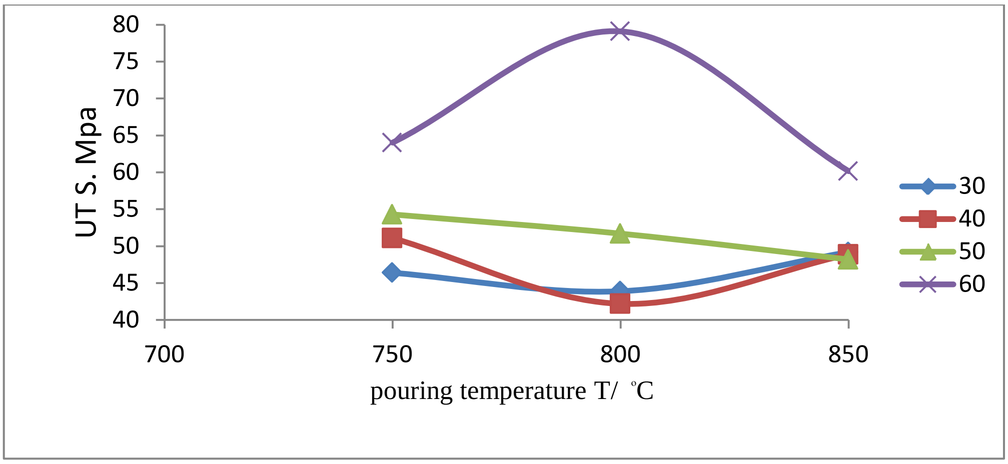


Figure (7) The relationship between the pouring temperature and ultimate tensile strength for Al-1.4%Mg rheocast alloy.

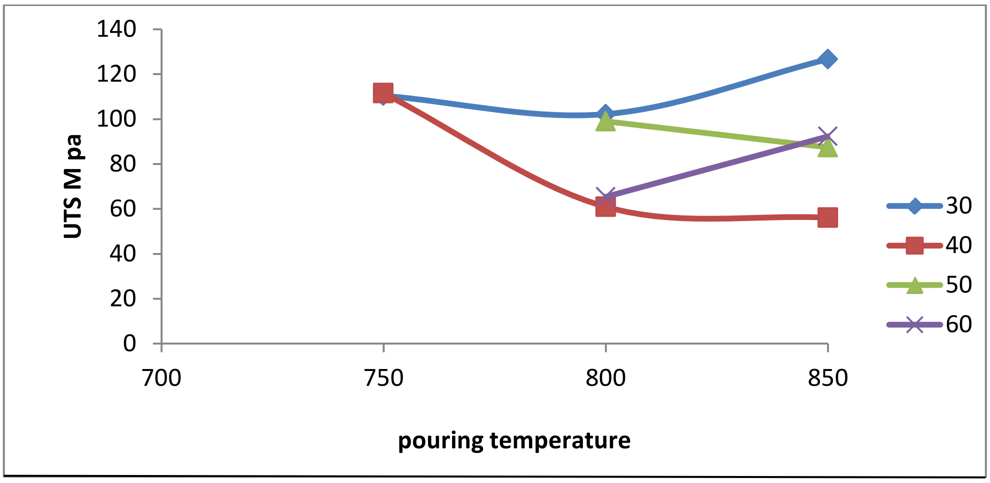


Figure (8) The relationship between the pouring temperature and ultimate tensile strength for Al-0.46%Mg rheocast alloy

The increasing value in tensile strength is the result of elimination of micro gas holes and shrinkage cavities. The tensile strength does not change too much with the change of tilt angles but fluctuates.at the adding Magnesium to Aluminum alloy many reasercher studied that like Girishia [4], studied the increasing amount of magnesium in rheocast alloy from 0.5%-1%-2%, and found the average value of grain size will slightly decrease, consequently she found that this results in a fine uniform grain structure especially when Mg content approaches 1% beyond which it increases .

Many parameters that affect mechanical results by applying inclined plate at high heat transfer as a result of contacting the melt with inclined plate, consequently exerted shear stress on the layers of the melt as a result of gravity force [5].

Therefore, by increasing the angle up to 40°, the rate of metal flow will be higher as the tilt angle increases, and lower number of primary solid phases is formed into the melt flowing over the surface of the inclined plate. Finally, these formed solid particles accompanied to remained melt were poured into the mold, and finer and globular microstructure is produced[5].

On the other hand, duration time of exerted shear stress and heat transfer between the melt and surface of inclined plate decreases by further increase in the angle from 40° to 60°. Therefore, a small number of solid particles and a fraction of solid phase are formed in the flowing melt over the surface of the inclined plate due to decrease in the duration time of heat transfer and exerted shear stress, a majority of the remaining melt is poured into the mold and solidifies in the mould environment.

Because the rate of heat transfer in the mold is lower than that of the inclined plate, the exerted shear stress is eliminated, solidification starts under lower nucleation and growth rates conditions [5].

Finally, the microstructures containing coarser solid phase with lower shape factor as a result of decrease in the rate of heat transfer occur between the melt and the surface of the inclined plate. Therefore, by increasing the angle up to 40°, the rate of heat transfer between the melt and the surface of the inclined plate increases as a result of decrease in the thickness of the bottom layer and lower number of primary solid phases are formed into the melt with high flowing over the surface of the inclined plate. Finally, these formed solid particles accompanied by remained melt are poured in the mould, and finer and globular microstructure is produced[5].

Vickers Macrohardness

Tables (5) and (6) show the Vickers macrohardness results for Al-1.6% Mg, Al – 0.46% Mg rheocast alloys , which were studied under parameters; pouring temperature (750, 800 ,850)°C, by using inclination angles of (30°,40°,50°,60°) . This shown in Table (5) and (6):

Table (5) The Vickers Macrohardness for Al-0.46%Mg rheocast alloy

Tilt angle /degree	Pouring temperature /C°	Vickers macro hardness/HV
30°	750	46.4
40°	=	51.1
50°	=	54.3
60°	=	64.0
30°	800	43.9
40°	=	42.2
50°	=	51.7
60°	=	79.1
30°	850	49.2
40°	=	48.9
50°	=	48.2
60°	=	60.1

Table (6) is for Al-1.6% Mg rheocast alloys:

Table (6)Vickers Macrohardness for Al-1.6%Mg rheocast alloy

Tilt angle /degree	Pouring temperature/C°	Vickers macro hardness/HV
30°	750	52.9
40°	=	59.9
50°	=	72.1
60°	=	47
30°	800	59.9
40°	=	65.6
50°	=	54.3
60°	=	72.5
30°	850	47.5
40°	=	58
50°	=	44.3
60°	=	44.2

Note (3): this test was done at 21°C room temperature.

750°C Al-1.6%Mg rheocast alloy shows Vickers hardness at higher value of inclination angle of (30°,40°,50°) Vickers hardness are(52.9,59.9,72.1), while at (60°)it has a lower value of (47) as shown in fig (9) , all the figures are between the pouring temperature and Vickers macro hardness value at different tilt angles for rheocast alloy Al-1.6%Mg for examples (750C°-1.6%Mg-30°-40°-50°), (800C°-30°-40°), and (850C°-30°-40°) refer to adding magnesium which increases the strength of aluminum alloy and their effect on the grain size according to L.F .Mondolfo [6]. The other factors which can causes addition lower value in the oxidation process and which affect magnesium amount [3]. The increase in some value of mechanical results of rheocast alloy is due to the effect of tilt angle, according to Haga [7] in angles (30°, 40°) and a little rheocast alloy at (50°) that effect on the metal which means in small tilt angles leads to a slower metal flow. The formation of high number of fine grains is the result of slower cooling rate.

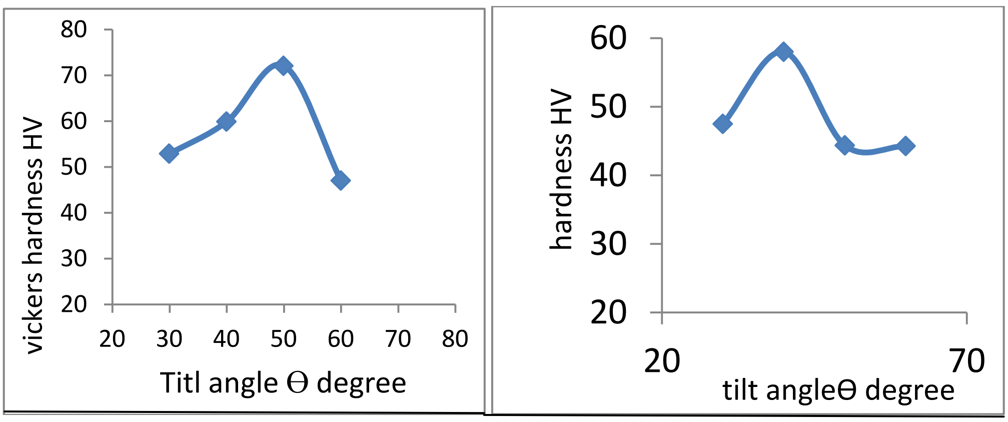


Figure (9) The relationship between the Vickers hardness and tilt angles for rheocast alloy Al -5%Mg at 750°C at right, Al-5%Mg at 850°C pouring temperature at left.

For 850 °C Al-1.6%Mg rheocast alloy the Vickers hardness shows higher values at (30°,40°,50°) they are (47.5,58,44.3Mpa) while at(60°) it has a lower value of(44.2Mpa) as shown in Fig (9). Some researches [8] found that the effect of tilt angles on cooling slope technique governs the flow rate of molten metal and in contact time between the molten metal and the cooling plate, where if high angle is responsible for the faster flows and a fewer crystals will be formed than when using low angles.

Haga [7] found that the tilt angle of the cooling slope affects the spread of the metal on the cooling slope. It is clear that the spread of the melt becomes wider as the tilt angle of the cooling slope becomes smaller. The adhesion of the solidified metal increases as the tilt angle becomes smaller. The effect of the tilt angle of the cooling slope on the adhesion of the solidified metal is the greatest in the conditions investigated in the present study.

The temperature of the metal decreases as the tilt angle decreases. The vertical force of the melt against the cooling slope becomes larger as the tilt angle of the cooling slope becomes smaller. Therefore, the contact condition between the melt and cooling slope becomes better, and the heat transfer between the melt and the cooling slope becomes larger. The speed of the melt on the cooling slope becomes slower as the tilt angle becomes smaller.

For 800 °C-Al-1.6%Mg rheocast alloy the Vickers hardness has a higher value at ((30°, 40°, 60°) are (59.9, 65.6, 72.5Hv) while at (50°) it has a lower value (54.3Hv) as shown in fig (10)..

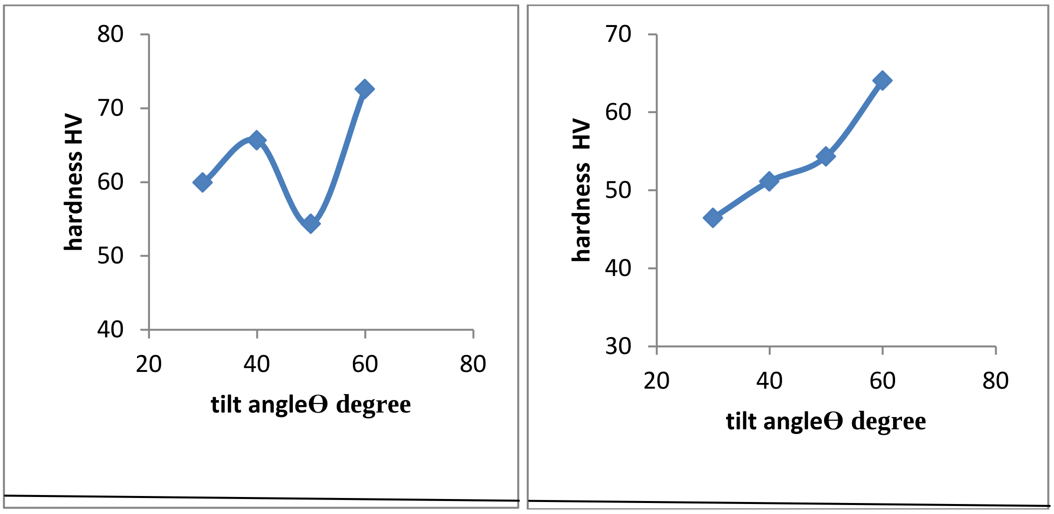
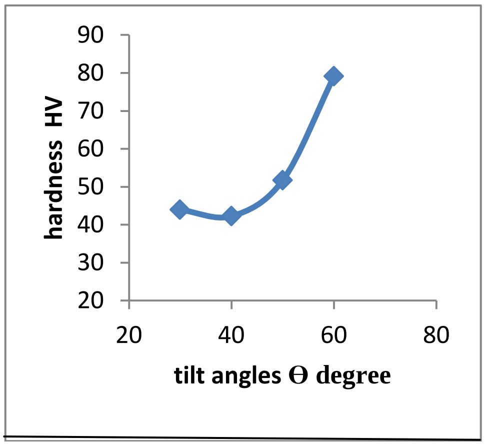


Figure (10)The relationship between tilt angle and Vickers hardness for rheocast alloy Al-1.6%Mg at 800 °C Al-0.46%Mg,and rheocast alloy at 750 °C pouring temperature.

For 750 °C Al-0.46%Mg rheocast alloy the Vickers hardness has the gradual increase with increasing tilt angle (30°, 40°, 50°, 60°)they are (46.4,51.1, 54.3, 64Hv).For 800°C-Al-0.46%Mg rheocast alloy the Vickers hardness has a gradual increasing value (43.9, 42.2, 51.7, 79.1Hv) with increasing tilt angle (30°, 40°, 50°, 60°) as shown in fig (11) below:



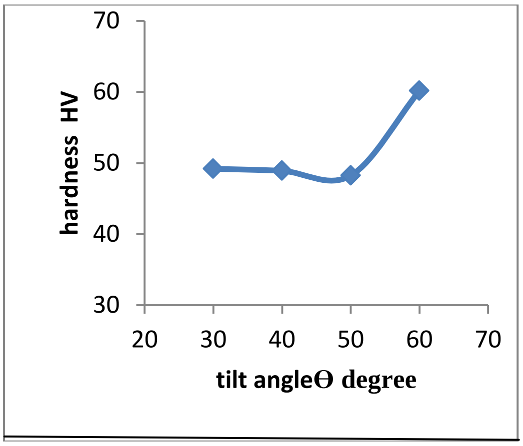
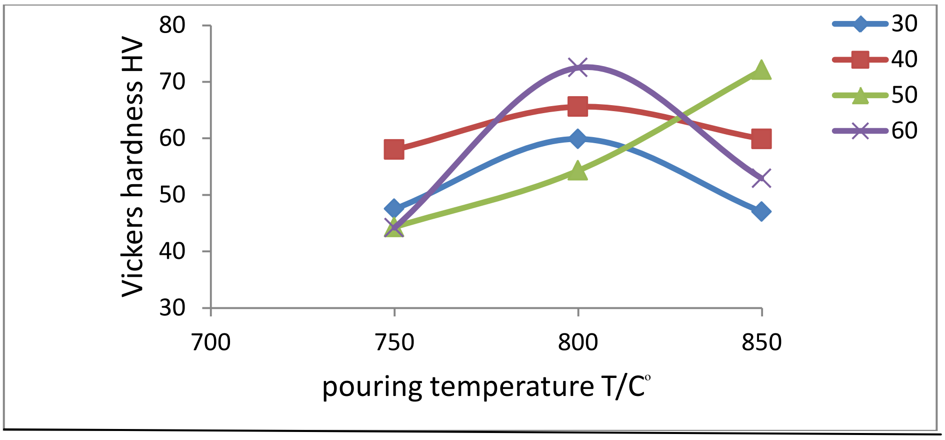


Figure (11)The relationship between tilt angle and Vickers macro hardness value for rheocast alloy Al-0.46%Mg at800°C Al -0.46%Mg at850°C, pouring temperature.

For 850°C Al-0.46%Mg rheocast alloy the Vickers hardness has a gradual increasing value (49.2, 48.9, 48.2, 60.1Hv) with tilt angle increasing (30°, 40°, 50°, 60°),also the rheocast alloy of Al-0.46%Mg which has gradual increasing in their Vickers macro hardness value may refer to adding magnesium which enhances their mechanical properties [6].Fig (12) and (13) show the relationship between the pouring temperature and Vickers hardness for Al-0.46%Mg,and Al-1.6%Mg rheocast alloy, as shown below:



Figure(12) The relationship between the pouring temperature and Vickers hardness for rheocast alloy Al-1.6%Mg.

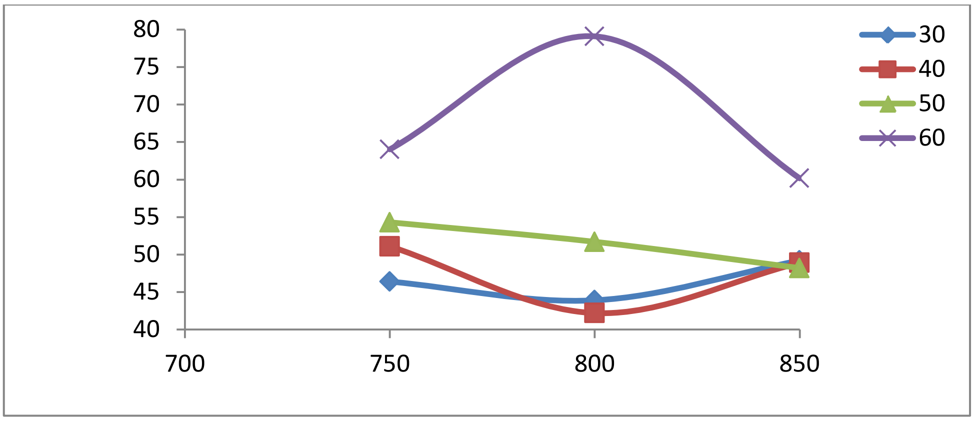


Figure (13) The relationship between the pouring temperatures and Vickers hardness for rheocast alloyAl-0.46%Mg.

T. Surczyn [8] realized that the evolution of the effect of Mg content on the mechanical properties of cold – rolled 5251 Aluminum strip alloy, there is a slight change of magnesium content in Al-Mg alloy result in significant increase in hardness and strength of material ,but the microstructure examination performed confirms the fact that magnesium content has a little or no influence on the grain size

For Al-0.46%Mg rheocast alloy the Vickers macro hardness results show a higher value than that found in Al-1.6%Mg which agrees with Girisha[4] who investigated the influence of Mg on microstructure change and the mechanical properties. Adding Mg in (0.5%-1%-2%) to Aluminum alloy shows that in the range of Mg addition of 0.46% is seems to be the most favorable alloy in terms of tensile strength and hardness test due to the influence of Mg on the grain size as well as the mechanical properties.

CONCLUSIONS

From this work the following conclusions are drawn:

1) It is preferable in pouring to tilt the slope by angles (30°, 40°, 50°) which is much more than (60°) and these angles have more semi globular grains than in (60°)..

2) In tensile test each rheocast alloy of 1.6% Mg and 0.46% Mg show high value at (30°, 40°, 50°) but a small value at (60°).

3) Vickers macro hardness, shows a fluctuated value, for Al-0.46%Mg. Appear a gradual increase in value , on the other hand for Al-1.6%Mg is shown a high values at (30°, 40°, 50°) for (750,800,850 °C).

4) It is preferable in pouring to tilt the slope by angles (30°, 40°, 50°) which is much more than (60°) and these angles have more spherical grains than in (60°).

5) In tensile test each rheocast alloy of 0.46%Mg, and1.6%Mg shows a high value of (30°, 40°, 50°) but a small value at (60°).

6) Vickers macro hardness ,shows a fluctuated value of both pouring temperature , tilt angles ,and percent of magnesium for Al-0.46%Mg. Appear a gradual increase in value , on the other hand of Al-1.6%Mg is shown at a high values (30°, 40°, 50°) for (750,800,850 °C).

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