# Characterization of Rheocast Al-Mg Alloy

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**ABSTRACT:**
The present work encompasses the development of a new method of cooling plate casting process by changing the inlet and outlet of water flow which is different from the conventional cooling plate casting process. This process consists in pouring the molten metal at temperature close to the liquid line in an inclined cooling plate. Pouring temperature and inclination angles have effect on microstructure. The following variables have been used in this work: pouring temperatures of (750, 800. and 850°C), tilt angles of (30°, 40°, 50°, and 60°), and Mg additive of (1%, 5%) with constant cooling length (380mm). After the melt flow down cooling plate, the melt becomes a semi-solid slurry at the end of the plate. Optical microstructure test shows that, the pouring temperature and tilt angle affect the size. Grains shape decreases with decreasing of tilt angles and with decrease pouring temperature as well as Mg addition also has the same effect on Al-Mg microstructure. X-Ray diffractography for Al-Mg alloys shows the appearance of peaks of intermetalic compound and different phases of ($Al_3Mg_2$, Al, $\delta Al_2O_3$)and for Al-1%Mg has a phases (Al Mg , ,MgO ),while SEM picture shows , $Al_3Mg_2$ phase as dark region and α-Al as light region for Al-5%Mg, and Al Mg phase for Al-1%Mg.
**Keywords:** AlMg alloy, Rheocast processes.

## مميزات سبيكة ألمنيوم – مغنيسيوم

**الخلاصة**
يشمل العمل الحالي على تطوير طريقة جديدة لعملية الصب بالتبريد المائل بتغيير مداخل ومخارج الماء والتي تختلف بدورها عن عملية الصب بالتبريد المائل التقليدية .تتضمن هده العملية صب المنصهر المعدني بدرجة حرارة مقاربة من درجة حرارة خط السيولة على صفيحة مبردة مائلة. درس تاثير كل من درجة حرارة الصب و درجة ميلان الصفيحة على التركيب المجهري، درجات حرارة الصب (٧٥٠,٨٠٠,٨٥٠ م°) ،ودرجة الميلان(٣٠°،٤٠°،٥٠°،٦٠°) واضافات المغنيسيوم (١%،٥%) مع ثبات مسافة التبريد (٣٨٠ملم). بعد جريان المنصهر المعدني اسفل صفيحة التبريد ،يصبح المنصهر عالق شبه- صلب عند نهاية الصفيحة.اظهر الفحص المجهري بان نقصان حجم وشكل الحبيبة تزامن مع نقصان زاوية الميلان ودرجة حرارة الصب ، وان اضافة المغنيسيوم كان له تاثيرا" مشابها"على التركيب المجهري لسبيكة المنيوم –مغنيسيوم .
يظهرنقصان الحجم الحبيبي عند درجة ميلان صغيرة (٣٠°،٤٠°،٥٠°) كما لوحظ نفس التصرف مع زيادة درجة حرارة الصب . اظهرت نتيجة الفحص المجهري بان التركيب الشجيري سيتغير الى التركيب الدائري مع وجود اشكال غير منتظمة عند مختلف درجات الحرارة (٧٥٠,٨٠٠,٨٥٠ م°) وعند درجات ميلان مختلفة (٣٠°،٤٠°،٥٠°) هي اكثر من (٦٠°) لكل من المنيوم-١% مغنيسيوم، المنيوم-٥% مغنيسيوم. اظهرت الأشعة السينية لكل من سبائك الالمنيوم-المغنيسيوم بظهوركل من المركبات الوسطية واطوار اخرى مختلفة من ( $AL_3$


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$Mg_2$ ، α AL، $\delta Al_2O_3$، و$MgO$)، في حين يظهر في الصورة SEM التركيب الشبه كروي في مختلف درجات الحرارة.

**INTRODUCTION:**

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. Unlike all conventional casting processes high shear rheocasting ensures a high survival rate of nuclei and the generation of fine grained uniform as cast microstructures with no entrapped gas to cause porosity or macroscopic oxide film defects to devalue mechanical properties. This means that aluminum alloys can be produced with fine uniform microstructures from the cast state and that subsequent thermo mechanical processing can be minimized to provide cost effective high performance semi-fabricated forms and components [2].

**Materials and Methods:**

The experimental work of rheocasting process is done by using the cooling obique plate casting techniques for casting Al Mg alloys. The main experimental variables which are ; pouring temperature, percentage weight of magnesium and pouring angle, Fig (1) shows the charts of the experimental work.

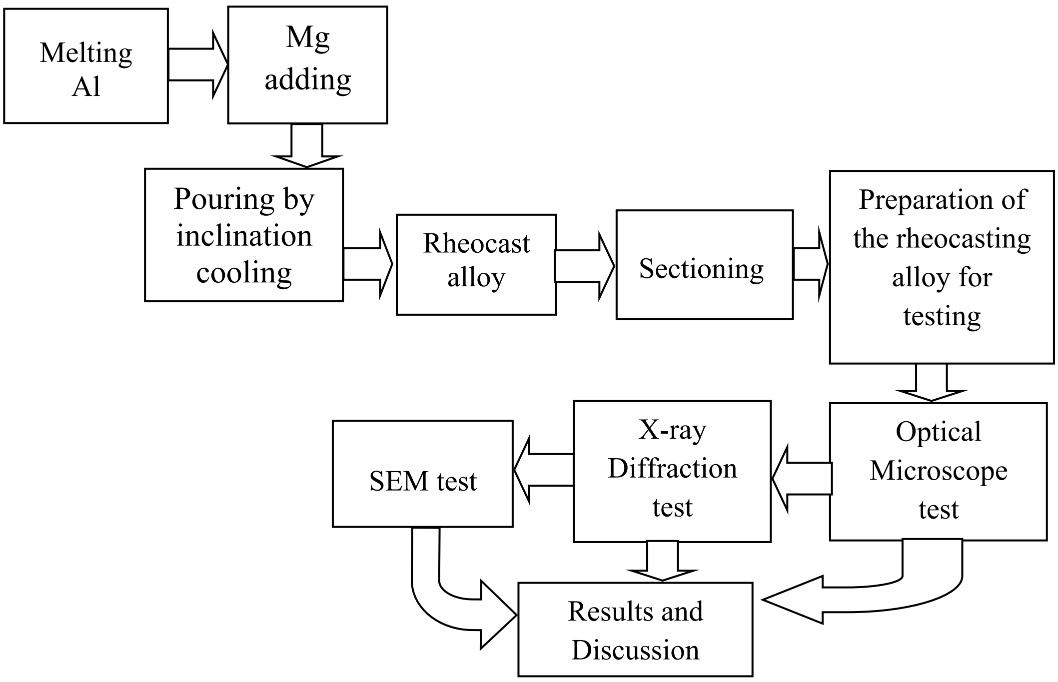



**Figure (1) Flow chart of experimental work**

**Raw Materials:**

**Aluminum Alloy:**

The chemical composition of the basic alloy Al that was used in this work is given in Table (1).

**Table (1) Chemical composition of the Al alloys.**

| **element** | | **Composites %** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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, composition is shown in Table (2)

**Table (2) the composition of Mg powder:**

| Powder Compositions wt% | |
|---|---|
| Mg (powder) maximum assay | |
| HCL Insoluble matter | 0.05% |
| Iron(Fe) | 0.05% |

**Construction of Slope Plate Casting Unit:**
The experiments were performed in designed unit. The slope plate casting unit was made by the researcher. The figure (2) shows the unit; it consists of continuous flat slope which is cooled with circulation underneath. The whole unit was made from mild steel.

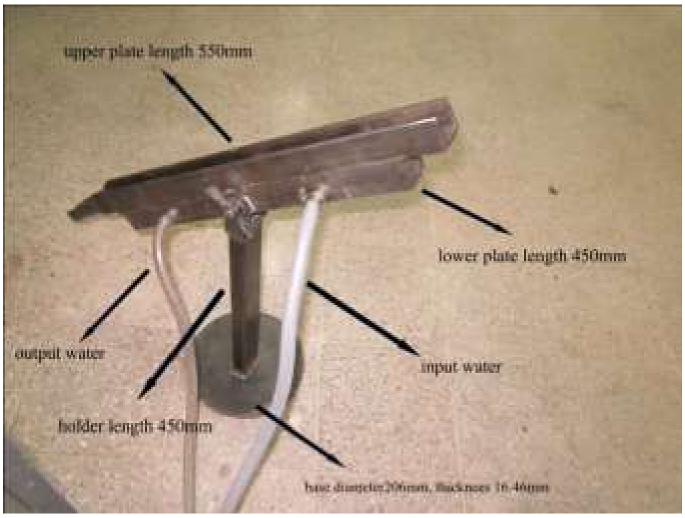


**Figure (2) The instrument of oblique cooling slope.**

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.(2). The distance between the input and output of water holes was about 350mm. The casting mould was made from mild steel T45 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) as shown in figure (3).

**Figure(3) the mould**

**The Experimental Parameters:**

This procedure depends on three important parameters:

**The Percentage Magnesium; Pouring Temperature; Inclination Angle of Cooling Slope:**

A Varity of magnesium percentages of (1%, 5%) has been added and coated with aluminum foil then added to aluminum molten and mixed with stirring device. This procedure was used on every pouring temperature (750,800,850C°), and inclination of cooling angles was (30°, 40°, 50°, 60°).

**Tests and Measurements:**

The rheocast samples were tested for micro structural and mechanical tests, these are as follows:

**Micro Structural test:**

In order to examine the rheocast samples for micro structure, these rheocast samples were cut and ground with SiC paper of (400, 600, 800, 1000 and 1200) grit to remove the damaged layer. After each stage, rheocast samples were cleaned with water. The second step is polishing process, the rheocast samples were polished by using cloth and diamond paste of (1μm) to remove the damaged layer due to grinding process. Etching process was made on rheocast specimens surfaces they were immersed in etching solution (1ml HF+50ml distilled water) for 20 sec [3], the microstructures were examined by using optical microscope type (MBL3000) KRUSS/Germany.

**X-Ray Diffraction Test for Rheocast Alloy:**

This test is done to measure and identify the resulting phases. The device type (Philips PW 1846) uses Cu target which has $\lambda$=1.54A°, Ni=filter.

**Scanning Electron Microscope Test:**

The rheocast alloy Al-1% Mg and Al-5% Mg alloys were subjected to scanning electron microscope to reveal the resultant phases. This device Tescanne Vega with easy probe electron gum, made in Germany. The rheocast alloy had dimension (13mm*20mm).

**Results and Discussion:**

**Optical Micro Structural Test:**

Figures (4)to (15) show the topography across section of Al-1%Mg ,Al-5%Mg rheocast alloy, which was cast over cooling slope plate at different pouring temperatures (750,800,850)°C using a tilt angles of (30°,40°,50°,60°) at cooling length of (380)mm.From the microstructure figures, it can be seen that the pouring temperature has a significant effect on the size and shape of Al-Mg rheocast alloy grains .the size of grains will be slightly decreased with increase in pouring temperature at constant tilt angle .In addition these grains have a coarse shape at 750°C - 30° -5%Mg and in other region have a very fine spherical grain, but in fewer number

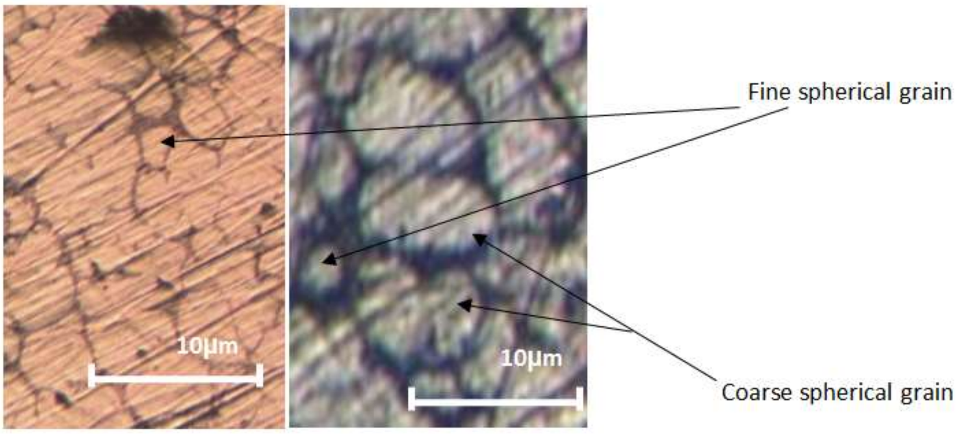



**Figure. (4) Structure of rheocast alloy. a) 750°C - 30°-5%. b) 750°C - 30°-1%**

The size of grains will be nearly 78μm .In addition these structures have a globular shape at 750°C -30° -5%Mg , For Al-1%Mg at 750°C-30° this structure have a grain size neraly63μm.When pouring, temperature increased from 800°C to 850°C for (1%-5%) Mg at constant angle (30°), for 800°C-30°-5% Mg, shows a grain size90μm. While the second 1% Mg has a grain size 82μm

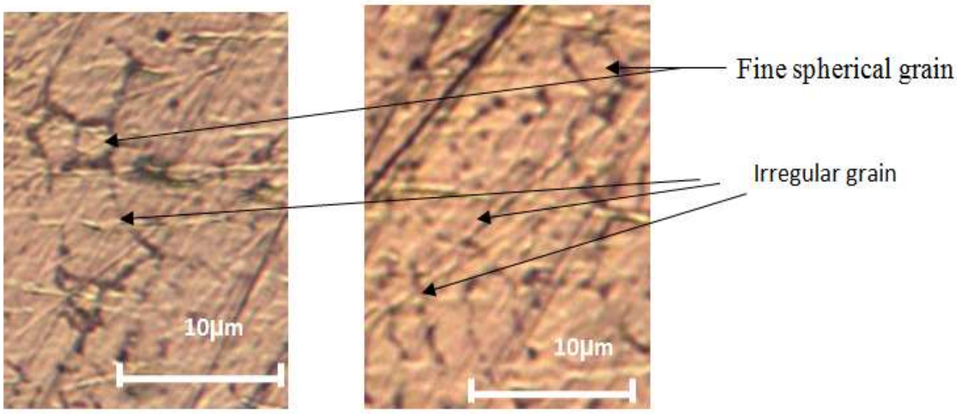
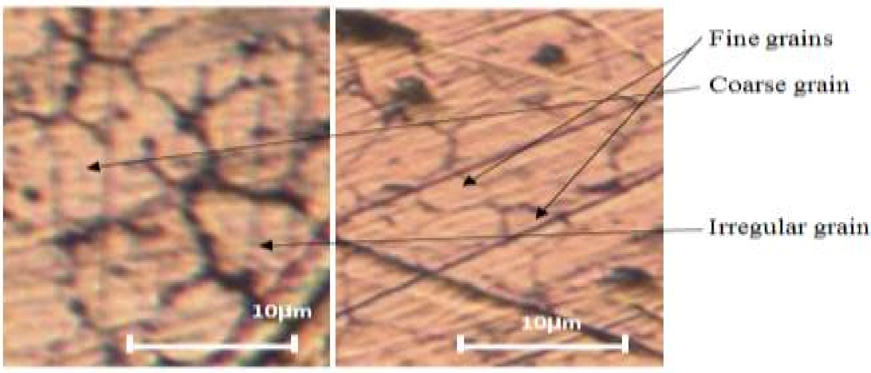



**Figure (5) structure of rheocast alloys. a) 800°C-30°-5%.**
**b) 800°C - 30°-1%**

And the structure of spherical, and irregular grains will be found in this rheocast alloys for Al-1%Mg, Al-5%Mg:



**Figure(6) The structure of rheocast alloys. a) 850°C-30°-5%. b) 850°C - 30°-1%**

For 850°C-5%-30°, this sample has a high number of grain size nearly to 127µm , 850°C- Al-1%Mg-30° have grain size nearly to 72µm

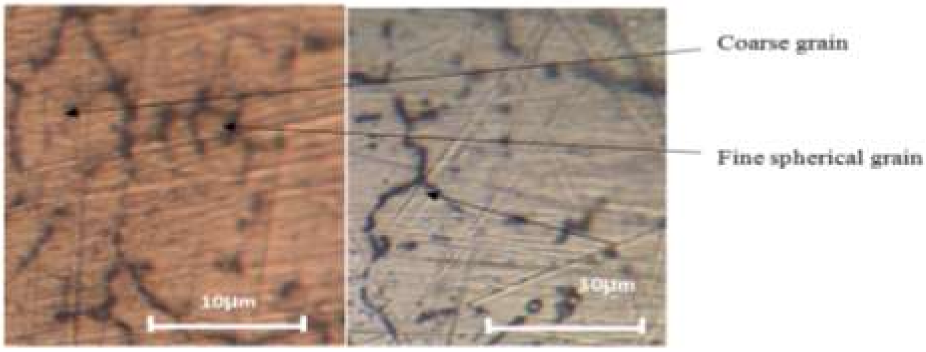
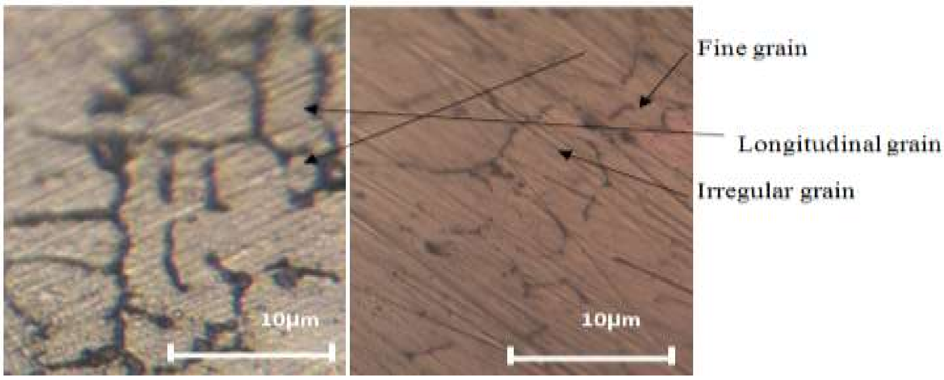
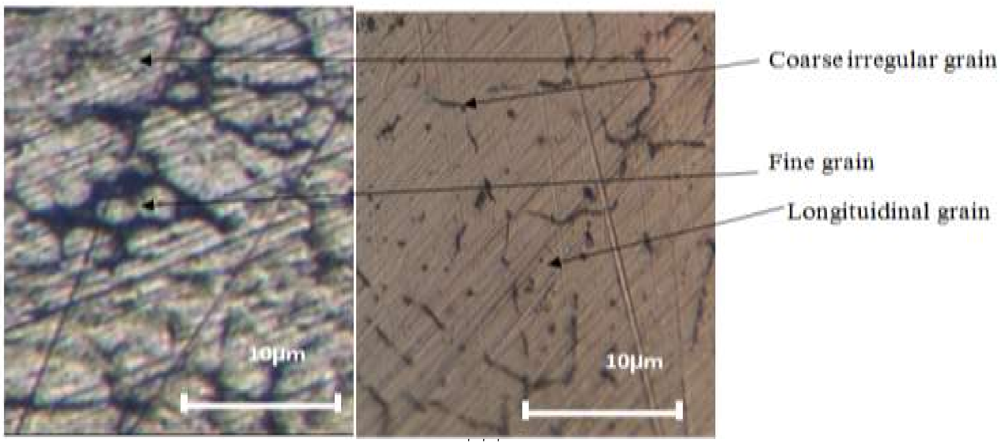



**Figure (7) The structure of rheocast alloys. a) Al-5%Mg-750°C-40°**
**b) Al-1%Mg-750°C-40°.**



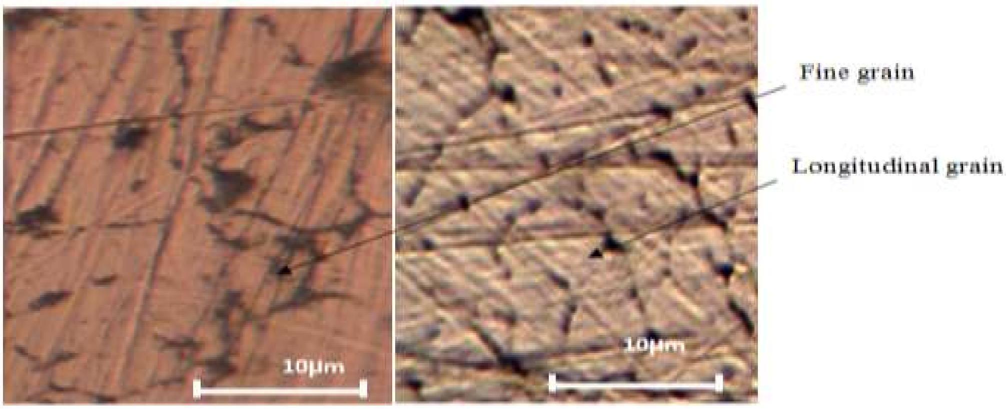

**Figure(8) The structure of rheocast alloys. a) Al-5%Mg-800°C-40°**
**b) Al-1%Mg-800°C-40°.**

At temperature of 750°C-850° C with increase in tilts angles of 40°-50°, these shapes indicate with microstructure graphs for each rheocast alloy below Al-5%Mg and in Al- 1%Mg rheocast alloys as following:
For Al-5%Mg at 750°C -40° this rheocast alloy has grain size nearly to 100µm . While for750°C -40°, 1 Mg%has a graim size 63µm, the rheocast alloy Al -5%Mg-800°C-40°, have a grain size80µm, for Al-1%Mg- 800C-40 rheocast alloy there is grain size92µm

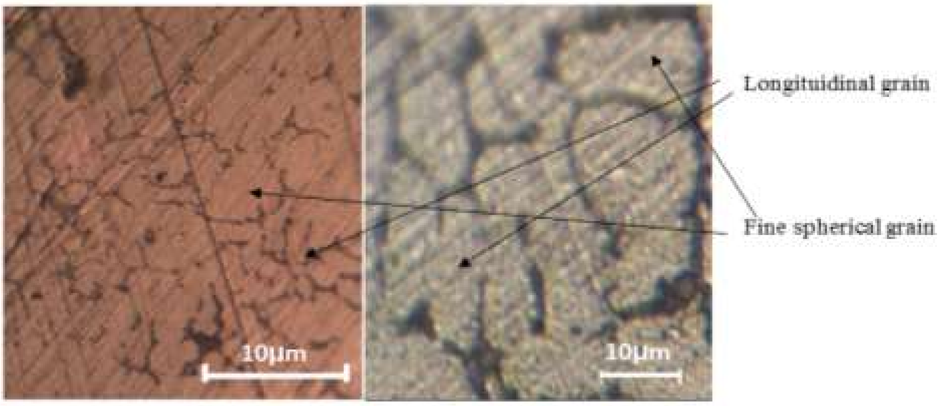


**Figure(9) The structure of rheocast alloys. a) Al-5%Mg-850$^{o}$C-40$^{o}$**
**b) Al-1%Mg-850$^{o}$C-40$^{o}$.**

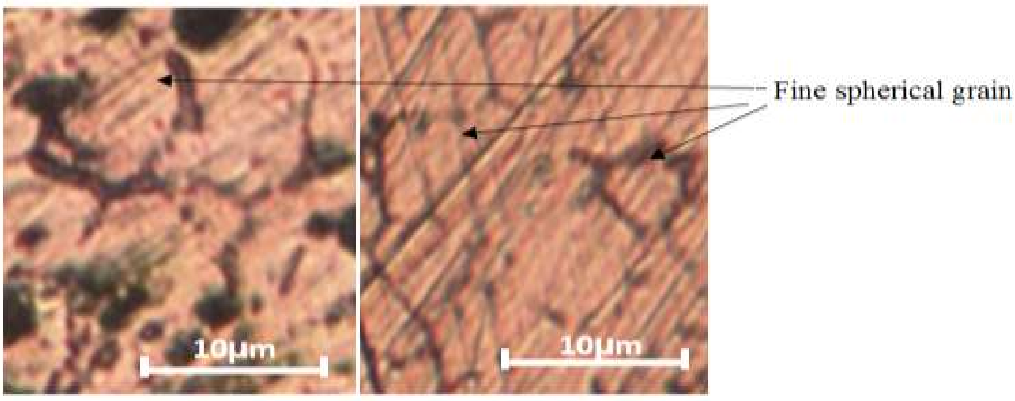
shows the rheocast Al-5-%Mg-850$^{\circ}$C-40$^{\circ}$ alloys this structure has agrain size 110µm . For Al - 1%Mg-850C-40 the structure has grain size170µm but there is a longitudinal grains




**Figure(10) The structure of rheocast alloys. a) Al-5%Mg-750$^{o}$C-50$^{o}$**
**b) Al-1%Mg-750$^{o}$C-50$^{o}$.**

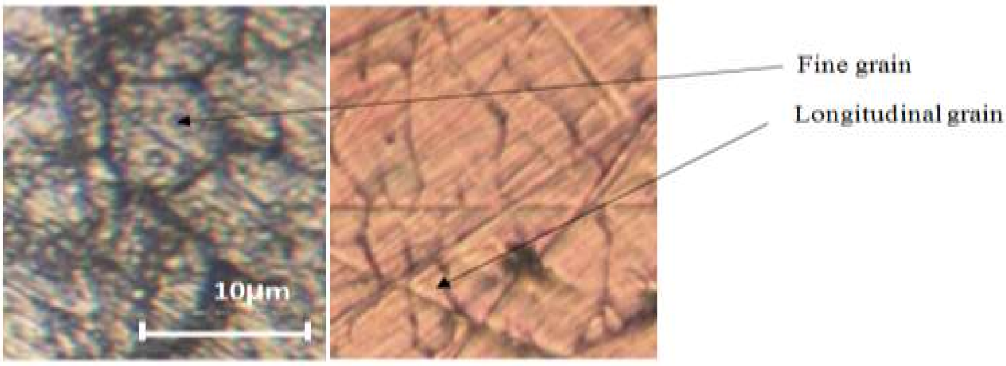



**Figure(11) The structure of rheocast alloys. a) 800$^{o}$C-50$^{o}$-5%. b) 800$^{o}$C - 50$^{o}$-1%**



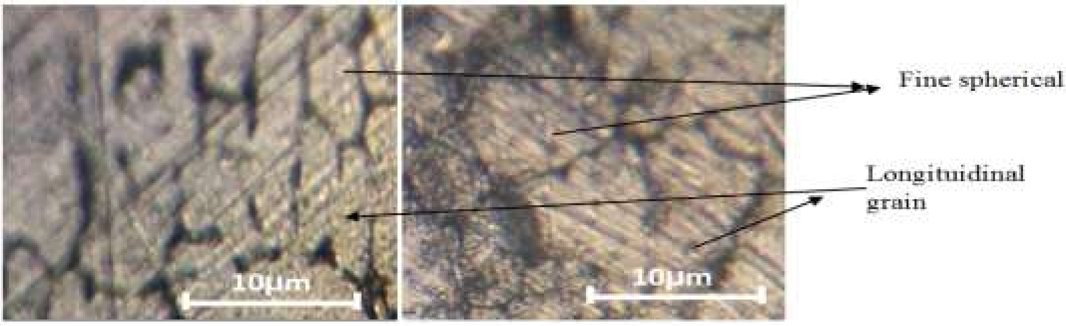

**Figure(12) The structure of rheocast alloys. a) 850$^{o}$C-50$^{o}$-5%. b) 850$^{o}$C- 50$^{o}$-1%**

For 850-5%-50 alloy the structure contains a grain size nearly71µm ,other hand the structure of Al-1% Mg rheocast alloy for 850°C-50° this structure has high grain size 100µm compared with other rheocast alloy, The tilt angle increases till reaching 60°from 750°C to 850°C for each sample (1%-5%) Mg



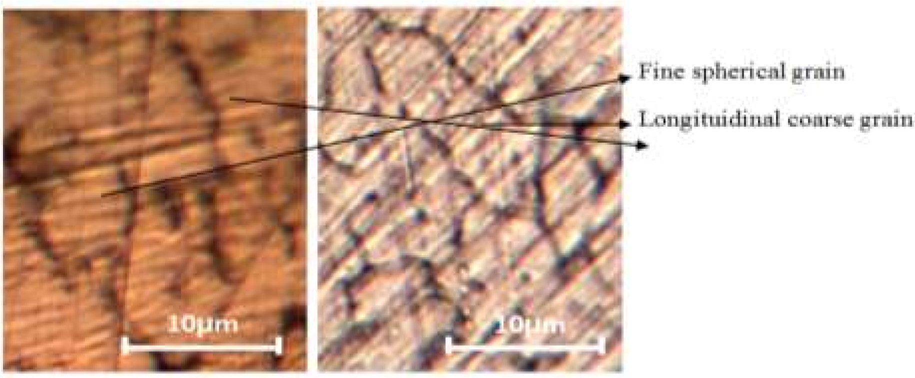

**Figure(13) The structure of rheocast alloys. a) 750°C-60°-1%. b) 750°C - 60°-5%**

the structure of 750 °C-1%-60° which has a grain size 90µm and some grains have a longitudinal shape, but this alloy could not be cast at 750 °C-1%-50° and in 60On the other hand for rheocast Al- 5%Mg alloy, for 750°C-5%-60° , the grain size nearly to 100µm without any nearly globular grains. For 800°C-1%-60° there are a grain size81µm but there is another type of shape. For 800°C-1%-60° there are a grain size81µm but there is another type of shape which is a longitudinal shape. For 800°C-5%-60° this structure has a grain size 94µmape which is a longitudinal shape .For 800°C-5%-60° this structure has a grain size 94µm




**Figure(14) The structure of rheocast alloys. a) 800°C-60°-1%. b) 800°C - 60°-5%**

For 850°C-1%-60° this structure will be contain a grain size 95µm, For 850°C-5%-60° this structure has grain size 100µm



**Figure(15) The structure of rheocast alloys. a) 850°C-60°-1%. b) 850°C - 60°-5%**

The fluctuation in grains shapes may be due to some reasons, the first is the effect of adding Magnesium to aluminum alloy that has several problems like the sensitivity to oxidization when adding Mg to Al alloy, second according to L.F. Mondolfo [5] Magnesium has a little or no effect on the grain size, and third according to S. Kumar [6] there is a segregation of magnesium that happens in the structure, Magnesium rich cells were also found at the central segregated region. In addition, a considerable amount of magnesium was also found in the interdendritic region. The maximum solid solubility of magnesium in aluminum is17.4%, due to non-equilibrium solidification, magnesium tends to segregate along the dendrites. Since the strength in Al–Mg alloy:

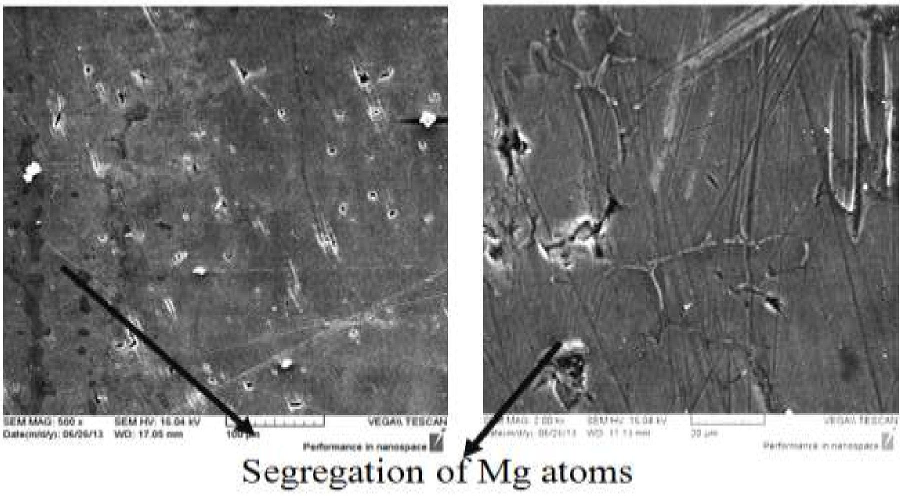
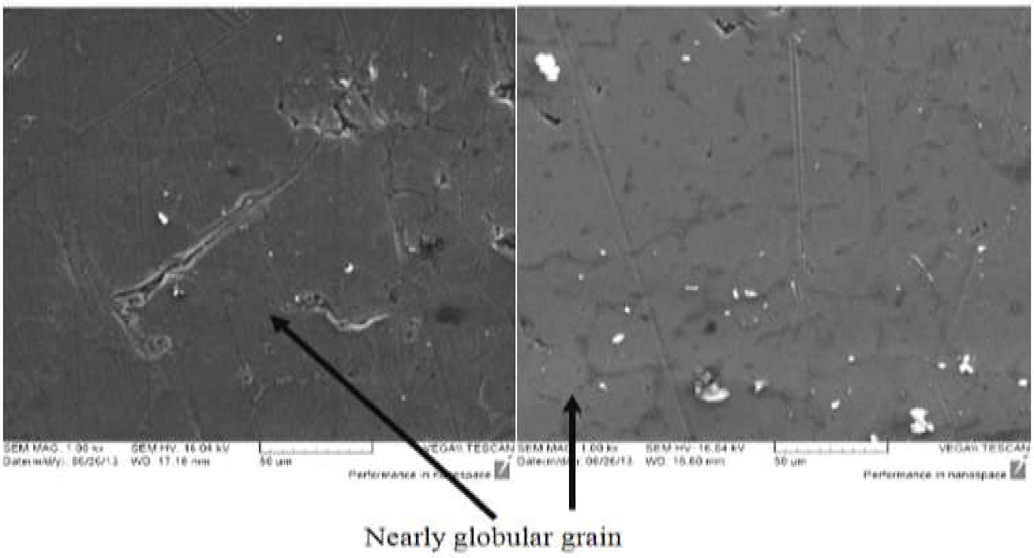



**Figure (16) The segregation of Mg atoms**




**Figure(17) SEM for the microstructure of Al Mg rheocast alloys**

**The Result of X-Ray Diffraction:**

As shown Fig (18) through fig(23) indicate the result of X-ray diffractions for each rheocast alloy Al-1%Mg, and Al-5%Mg which contain intermetalic compounds, of : α-Al, $Al_3Mg_2$, AlMg. Also these peaks show different phases such as: $\delta Al_2O_3$, MgO these peaks are the same for all (1%,5%) rheocast alloys.

Table (3) show the peaks values for each alloy

| Alloy No. | phase | 2Θ/degree standard | $d_o$/standard | d | 2Θ/degree |
|---|---|---|---|---|---|
| 5% | Al | 38.47 | 2.33 | 1.7 | 39.5 |
| 5-1% | = | 44.73 | 2.02 | 0.79 | 45 |
| 5-1% | = | 78.22 | 1.22 | 1.73 | 78.5 |
| 5-1% | = | 82.43 | 1.16 | 1.22 | 82.5 |
| 5% | $Al_3\ Mg_2$ | 45.06 | 2.01 | 1.08 | 45.2 |
| = | = | 52.94 | 1.72 | 1.04 | 50 |
| = | = | 65.28 | 1.42 | 0.93 | 65.2 |
| = | = | 75.93 | 1.25 | 3.9 | 78.9 |
| 5% | $\delta Al_2O_3$ | 46.49 | 80 | 75 | 45.1 |
| = | = | 37.44 | 16 | 12 | 38.5 |
| = | = | 53.85 | 5 | 4.3 | 55 |
| = | = | 75.01 | 30 | 25 | 75.2 |
| = | = | 83.4 | 20 | 23 | 82.5 |
| 1% | MgO | 22.2 | 5 | 7.57 | 20 |
| = | = | 38.47 | 10 | 10.4 | 38.5 |
| = | = | 59.23 | 25 | 19 | 20 |
| = | = | 44.4 | 40 | 39.5 | 40 |

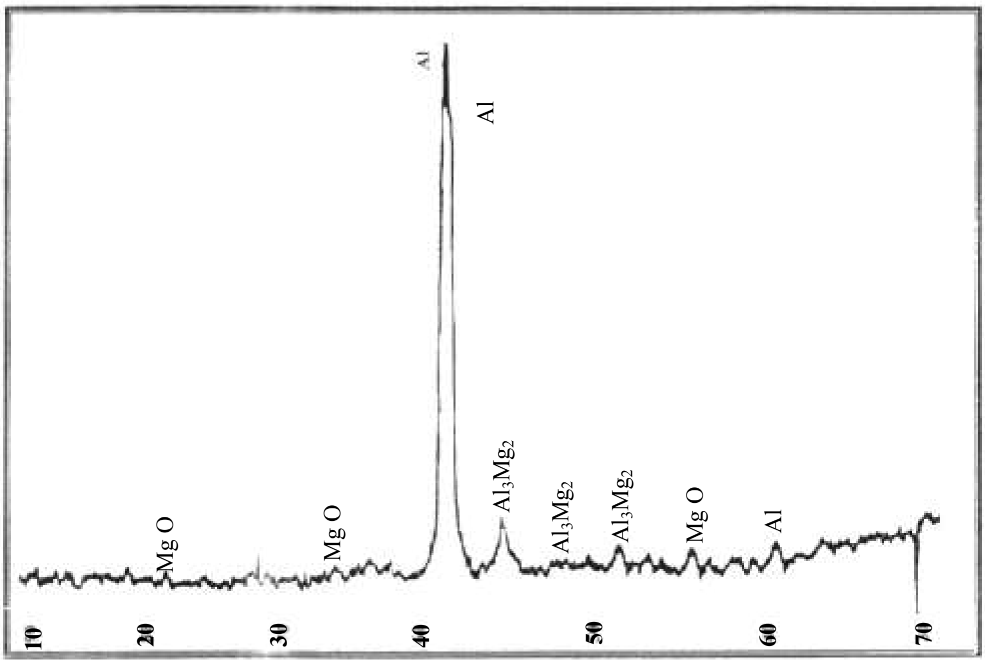



Figure (18): X-ray for Al – 5% Mg – 850°C – 50°

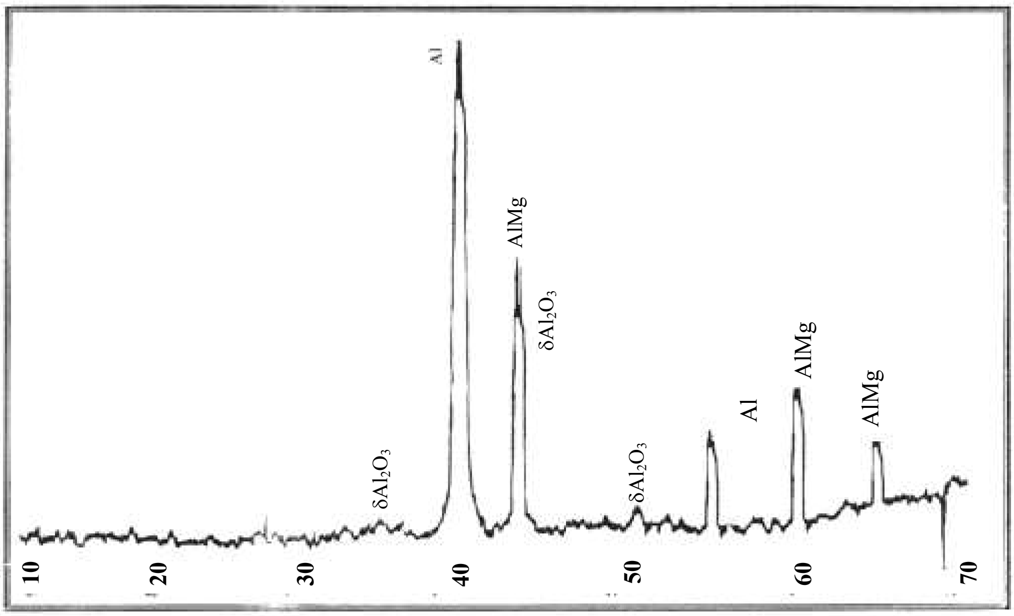



**Figure (19): X-ray for Al – 1% Mg – 850°C – 30°**

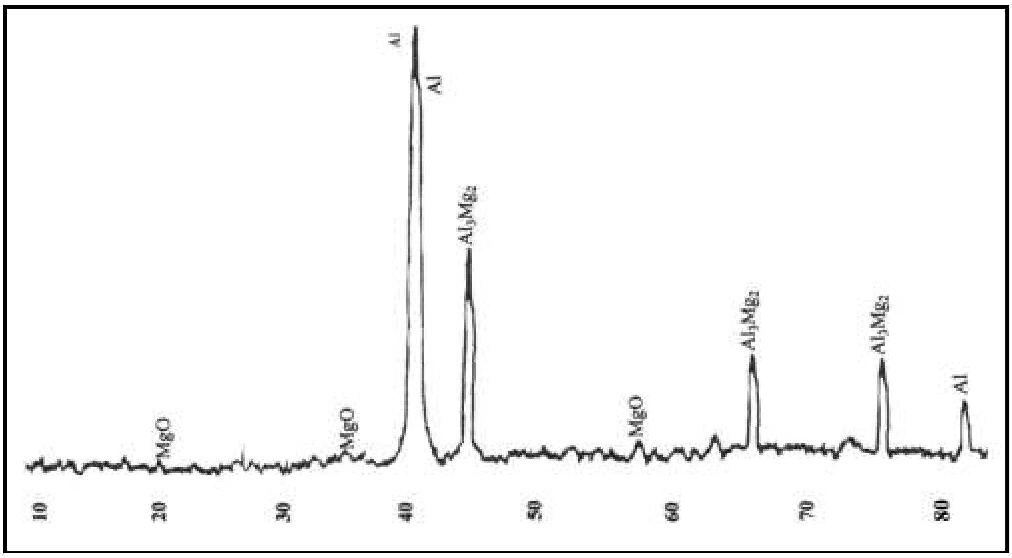



**Figure (20): X-ray for Al – 5% Mg – 750°C – 60°**

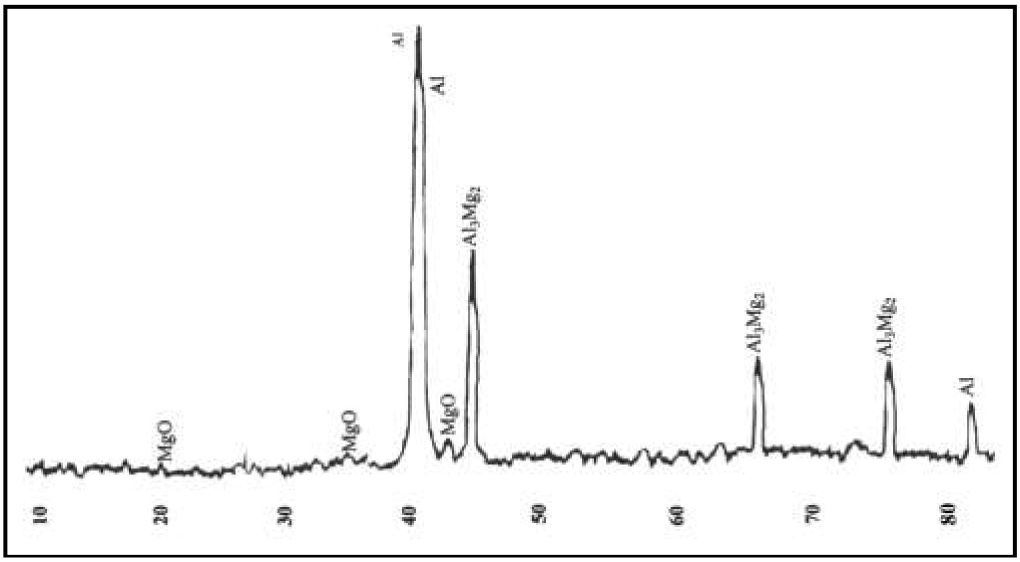



**Figure (21): X-ray for Al – 5% Mg – 800°C – 30°**

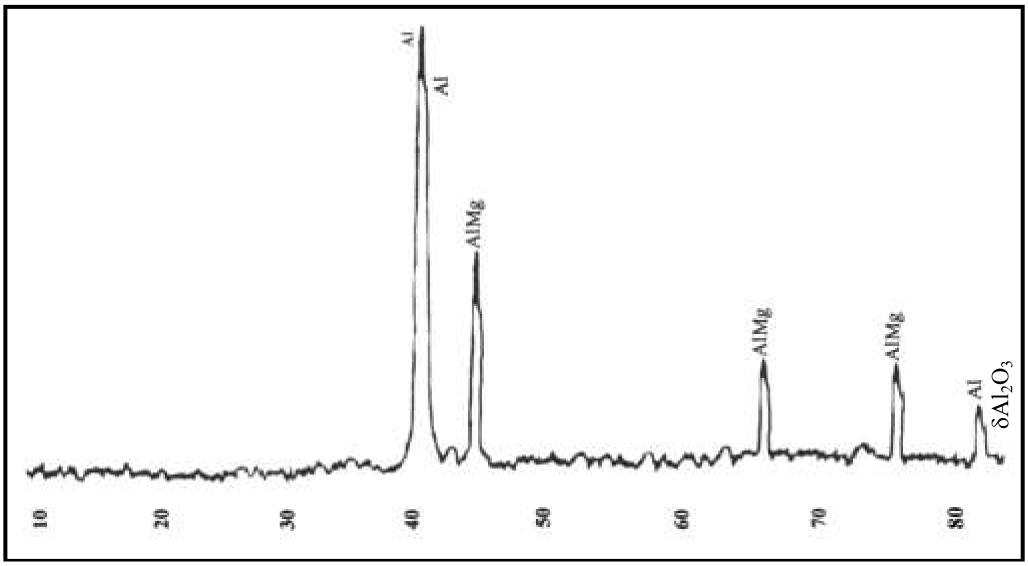



**Figure (22): X-ray for Al – 1% Mg – 800°C – 40°**

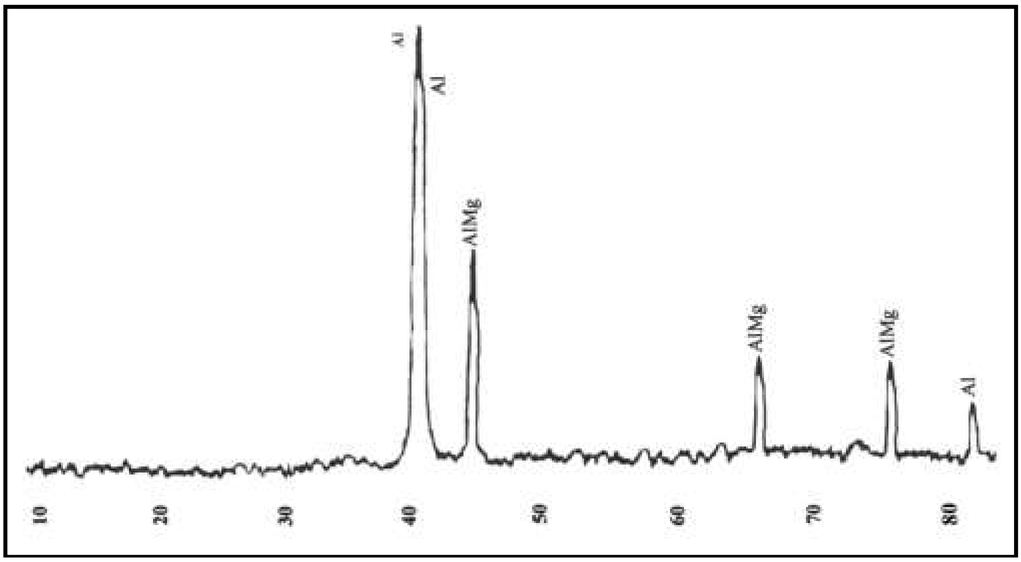



**Figure (23): X-ray for Al – 1% Mg – 750°C – 30°**

X-ray diffraction analysis shows that there is peak for pure Aluminum and $Al_3Mg_2$ slightly decreases for 1.6%Mg rheocast alloy and there is a peak for MgO. Al-0.46%Mg namely at (750,800,850 °C) shows a peak for Al-pure, while $\delta Al_2O_3$, results in marked decrease in their intensity of the peak that is related to small percent of Magnesium in the rheocast alloy. Typical micrographs obtained by SEM investigation were obtained from Tescan Vega, they reveal the Al solid solution in light gray, while the $Al_3Mg_2$ in dark gray in all micrographs shown in below: [4]

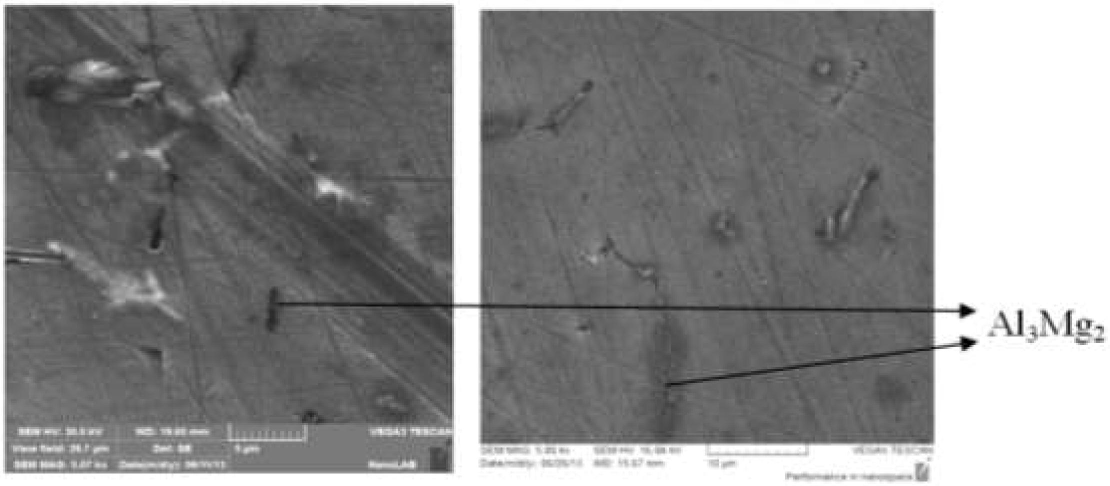



**Figure (24) SEM of $Al_3Mg_2$ as dark light.**

The X-ray spectra for rheocast alloy (1%.5%) Mg shows that the majority of phases are a solid solution of Mg in Al matrix, and $Al_3Mg_2$, AlMg. It is obvious that the intensity of the high peaks is related to presence for $Al_3Mg_2$ phase in Al-5%Mg rheocast alloy at (750, 800, 850 °C) where it appear in a coarse size at 750 °C but increases in pouring temperature it will appear in fine structure which can be seen in micrograph of optical micro structure, Fig (18-23) illustrates the microstructure of Al-1%Mg and Al-5%Mg.it consists of a coarse matrix (αAl) and intermetallic compound ($Al_3Mg_2$,AlMg) which precipitated along the (α Al) as a part of structure , and other phases $\delta Al_2O_3$, MgO.

## CONCLUSIONS:

From this work the following conclusions are drawn:

1) It is possible to produce castings that have nearly fine globular grains by using a cooling slope plate technique.

2) The formation of nearly fine globular grain can be enhanced by using Mg and cooling slope plate technique.

3) It is preferable in pouring to tilt the slope by angles ($30^{\circ}$, $40^{\circ}$, $50^{\circ}$) which is much more than ($60^{\circ}$) and these angles have more semi globular grains than in ($60^{\circ}$).

4) SPC technique is attributed to change the morphology and size of Al-Mg grains.

5) Each pouring temperature of (750,800$^{\circ}$C) decreases the size of grains than (850 $^{\circ}$C).

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