Study of the Microstructure Semi Solid Al-Si-Mg Casting

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ABSTRACT

Semi-solid metal processing involves processing metallic alloys between the solidity and the liquidity. The microstructure must be non-dendritic and consist of spheroids of solid in a liquid matrix. In this work two potential routes are used:
First, The superheated Al-Si-Mg alloy was continuously cooled down to various temperatures above its liquidity (620,630,640) ^{o}C . When the desired temperature of the melt has been reached, then mechanical stirring with rotational speed of (800)rpm for (30)sec. was started. The resultant slurry was bottom poured into a stainless steel mold placed below the crucible. The solidified samples were reheated to the semi-solid metal processing temperature, held there for (10) min, and rapidly quenched in into water tank to retain the semi solid microstructures. In the second set of experiments , the superheated melt was continuously cooled down to various temperature in semi solid range (610,600,595,590,580)^{o} C, then mechanically stirred at rotating speed(800)rpm for (30)sec. the resultant slurry was bottom poured into a stainless steel mold placed below the crucible. The metallic mold is then rapidly quenched in water to room temperature. Metallographic examinations indicate that the mixing method leads to highly globular semi-solid slurries of fine particle size. The particle sizes of slurry quenched at various temperatures within the semi solid metal range are much smaller when compared to the reheated structures. The particle size gradually increases as the slurry temperature decrease.

Keywords: Semisolid, Rheocasting, Thixocasting**.**

دراسة البنية المجهرية لسبيكة(ألمنيوم-سليكون- مغنيسيوم) الهلامية

الخلاصة

تتضمن المعالجة الهلامية , معالجة السبائك المعدنية مابين خط السيولة وخط الصلابة. ان البنية المجهرية يجب ان تكون غير شجيرية وتحتوي على صلب كروي في أساس سائل.في هذا البحث تم استخدام طريقتين:الطريقة الأولى تتضمن التبريد التدريجي لسبيكة(المنيوم-سليكون-مغنيسيوم) المفرطة التسخين إلى درجات أعلى من درجة حرارة السيولة (620,630,640) ^{o} م.وعند وصول

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المنصهر ا لى درجة الحرارة المطلوبة تبدأ عملية الخلط الميكانيكي بسرعة دوران (800) دورة/ دقيقة ولمدة (30) ثانية.بعد ذلك يتم صب المنصهر بطريقة الصب من الأسفل إلى قالب مصنوع من الصلب موضوع أسفل المنظومة.بعد تجمد العينات يتم إعادة تسخينها إلى درجة حرارة المعالجة الهلامية ويتم إبقاء العينات عند هذه الدرجة لمدة (10) دقائق,بعدها يتم تبريدها تبريدا سريعا في حوض ماء وذلك للإبقاء على التركيب المجهري الهلامي.

في الطريقة الثانية يتم تبريد المنصهر إلى درجات حرارية مختلفة ضمن مدى التجمد (610,600,595,590,580) ^{o} م. بتم التحريك والخلط عند هذه الدرجات الحرارية بسرعة (800) دورة/دقيقة ولمدة (30) ثانية.بعد ذلك يتم صب المنصهر بطريقة الصب من الأسفل إلى قالب مصنوع من الصلب موضوع أسفل المنظومة .بعدها يتم تبريد القالب في حوض ماء إلى درجة حرارة لغرفة.أظهرت فحوصات الميتالوغرافية إن طريقة التحريك والخلط تؤدي إلى الحصول على تركيب كروي بحجم صغير,وان حجم الخلايا للعينات المبردة تبريدا سريعا إلى درجات حرارية مختلفة ضمن مدى التجمد يكون اصغر بكثير من حجم الخلايا للعينات التي تم إعادة تسخينها ثم تبريدها.

INTRODUCTION

The requirement of reducing fuel consumption and CO_2 emission from engines can be fulfilled by vehicle-weight reduction .This is one of the most challenging issues for the transportation industry and requires the development of innovative materials for light weight design [1]. Al-alloys, as lightweight structural materials, play an important role in achieving vehicle weight reduction and improving fuel economy in the automotive industry. It is clear that the increase in aluminum applications in the transport industry will require a major advance in processing technologies [2].

Semi-solid metalworking presents a solution to the problems associated with both conventional casting and metalworking processes due to its capability to use temperatures lower than those used in casting and a less energy used in metalworking as conventional forging and extrusion processes[3]. Thus, semi-solid forming has great advantages over than conventional techniques, for example less tendency for hot tearing; besides that longer die life is achieved. Another great advantage of forming in the semi-solid state provides a sound, globular microstructure with relatively higher ductility values. This transformation from dendritic structure to globular structure enables the material to deform much easier with less porosity and segregation [4, 5].

The key of semi-solid state processing consists of obtaining a precursory material with a spherical, nondendritic microstructure. This globular structure is completely different from the typical dendritic structure of the cast alloys and has the role of share thixotropic properties to the alloys which are in a semi-solid state. [6]

Rheocasting is an innovative semi-solid forming process for light and cost-effective applications in different industrial sectors. In rheocasting, alloy is cooled into the semi-solid state "partial solidification" and injected into a die without intermediate solidification. The non-dendritic microstructure can be obtained by mechanical stirring or by mechanical stirring and stimulated nucleation of solid particles]. Thixocasting initially requires a controlled solidification of billets, i.e., it utilizes a pre-cast billet with a non-dendritic microstructure, which is subsequently re-melted before casting].In thixocasting, the material is initially solid, and the alloy has been treated in such a way that, when it is reheated into the semi-solid state, a spheroidal microstructure is obtained. [7, 8]

Technically, the globular structure can be achieved by a number of different techniques. They can be categorized into two different mechanisms. The first mechanism involves partial solidification of a melt under forced convection induced by either electromagnetic or mechanical stirring, or partial solidification under the influence of an external field, such as ultrasonic vibration or pulsed electrical current. The second mechanism involves partial re melting of a solid feedstock material which has been solidified earlier under specific conditions or worked thermo- mechanically [9-13].

The aim of this study is to produce Semi Solid Al-6Si-2Mg casting, and characterize the micro structural variation of the casting.

EXPERIMENTAL PROCEDURES

Slury preparations

Figure (1) schematically illustrates the semi solid casting set up used in the experiments. A graphite crucible is placed in the tube resistance furnaces, Stopper rod is used to plunge the exit hole in the bottom of the crucible, a stainless steel mold site just below the exit hole .Stainless steel rod (stirrer) ,15mm in diameter is used to stir and cool the melt, equated with electrical motor . Calibrated thermocouple- type K, with stainless steel protection tube is inserting in to the crucibles to monitor and record the temperature of the melt.

The alloy used in this study is Al-6Si-2Mg; the Chemical composition of the alloy is listed in Table (1). The freezing range of the alloy is (615-557) ^{o} C , the solid fraction F_S is calculated according to Schell's equation[14]:

$$F_S=1-f_L-\{T_m-T_L / T_m-T\}^{1/1-K_o} \quad ......(1)$$

Where

Tm: is the melting temperature of pure metal.

$\boldsymbol{T_L}$: is the liquidus temperature of the alloy.

$\boldsymbol{K}_o$: is the equilibrium distribution coefficient.

The alloy was melted to 700 ^{o} C , continuously cooled down to various temperatures. Two different set of experiments were used:

First, The superheated alloy was continuously cooled down to various temperature above its liqudus 620,630,640 ^{o} C .When the melt was reached the desired temperature, then mechanically stirred at rotating speed 800 rpm for 30sec. after that the stopper rod is pulled and unplugs the crucible exit hole, the resultant slurry was bottom poured into a stainless steel mold placed below the crucible. The solidified samples were reheated to the semi-solid metal processing temperature (corresponding 0.4%solid fraction of α- Al), held there for 10 min, and rapidly quenched in into water tank to retain the semi solid microstructures. The aim of re-heating treatment is to provide the globularisation of the primary particles (α-Al) generating a suitable microstructure for thixo forming.

In the second set of experiments, the superheated melt was continuously cooled down to various temperature 610,600,595,590,580 ^{o}C in semi solid range, then mechanically stirred at rotating speed 800 rpm for 30 sec. after that the stopper rod is pulled and unplugs the crucible exit hole, the resultant slurry was bottom poured into a stainless steel mold placed below the crucible. The metallic mold is then rapidly quenched in water to room temperature.

MICROSTRUCTURE INVESTIGATION

Samples for the metallographic examination were cut, ground from320 grit up to 1000 grit emery paper. Initial polishing employed a 1μm followed by a 0.3 μm alumina suspension, and final polishing was carried out using diamond past; Samples were etched with Keller's agent for about 5 sec. The microstructures were examined using optical microscope equipped with Smarty - digital Camera. Metallographic analysis of both the as-solidified and reheated samples was carried using a J- image analyzing system with 4.3 version software. Image analysis was performed to characterize the structural variation quantitatively by measuring the average circular diameter (D) and shape factor (F) of Primary -Al using the following formulas [15].

$$D = (4A/\pi)^{0.5} \qquad \ldots\ldots (2)$$

$$F = (A\pi/P^2) \qquad \ldots\ldots (3)$$

Where:
A : value of one represents perfectly circular particle morphology μm^2.
p: represents the particle perimeter μm.

RESULT AND DISCUSSION

Microstructures observation

Figure (2) shows the resulting microstructures of alloy after gravity casting from a temperature of 700 ^{o}C into a cold cylindrical steel mould. The microstructure clearly demonstrates typical dendritic growth morphology with long columnar dendrites observed in a matrix of a fine eutectic. Figure (3) show the microstructures of the sample that immediately quenched from various super heated temperatures. Each microstructures is highly refined compared to typical as-cast alloy, the primary α-Al particles are small with non-dendritic morphology, (The smallest particles seen are less than 15μm in diameter, and the larger ones are less than 40μm), which is to be expected since there is very little time allowed for growth. The fine structure of eutectic phase shows that the cooling rate during quenching was very fast.

The reheated structure shows globular morphology, as shown in Figure (4). The structure shows globular α-Al particles distributed in eutectic matrix. It is clear that the entrapped liquid in these samples results from coarsening of irregular (semi-dendritic) particles during reheating. Increasing the superheat clearly results in larger particle size in both the as-solidified and reheated samples. Even at high superheat, the particles are for the most part non- dendritic but increasing superheat does not affect the morphologies (Shape factor) of the particles as shown in Figure (6). This may be due to the long residence times of the reheated samples in the SSM temperature. Longer residence times lead to coarsening of the particles; therefore initially irregular particles may become more spherical due to the driving force for these particles to reduce surface area.[16] This also explains why for each experiment the particles in the reheated samples are larger than in the as-solidified ones.

When, slurry quenched at various temperatures within the semi solid metal range, the structures are so far superior to those obtained with the first set of experiments. The particle sizes are much smaller when compared to the reheated structures, and the particle size gradually increases as the slurry temperature decease as shown in Figure (5). average particle grain sizes change with temperature is shown in Figure (7), the results give evidence that the liquid mixing method leads to highly globular semi-solid slurries of fine particle size. This behavior can be explained as follow:

Under the intensive mixing action, both the temperature and composition fields in the melt are uniform. During the continuous cooling, heterogeneous nucleation takes place throughout the whole volume of the under cooled liquid and all the nuclei will survive. In addition, the intensive mixing action is likely to disperse the clusters of potential nucleation agents, giving rise to an increased number of potential nucleation sites. The overall effect of the mixing mechanism would be an increase in number of primary particles and consequently finer particle size. The non-dendritic particles are developed from the initial dendritic morphology, under dynamic agitating conditions through the following mechanism. The initial dendrites are fragmented through dendrite arm detachment either by a shear force or re melting at the dendrite arm roots. With increasing shear time, those fragmented dendrite arms change gradually to spheroids via stages of dendrite growth, rosettes and ripened rosettes [3,7]. The remaining liquid in the Semi Solid Metal slurry will solidify without shear during its solidification. It has a uniform temperature and composition throughout the liquid. According to the previous analysis, nucleation would occur throughout the entire remaining liquid, and every single nucleus would survive and contribute to the final microstructure. [17]

CONCLUSIONS

- The microstructures of immediately quenched samples (from various super heated temperatures) show primary α-Al particles with non-dendritic morphology.
- The microstructures of reheated samples show globular α-Al particles distributed in a liquid matrix.
- Increasing the overheating temperature led to increase the particle size of α-Al, in both the as-solidified and reheated samples.
- The microstructures of samples quenched from various temperatures within the semi solid metal range shows globular α-Al particles, smaller in size when compared to the reheated structures.
- Increasing the semi solid temperature will decrease the α-Al particle sizes.

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Table (1) Chemical composition of Al–6Si-2Mg alloy used in weight percent

element	Si	Mg	Zn	Fe	Mn	Al
Wt%	6.11	2.1	0.003	0.1	0.01	balance

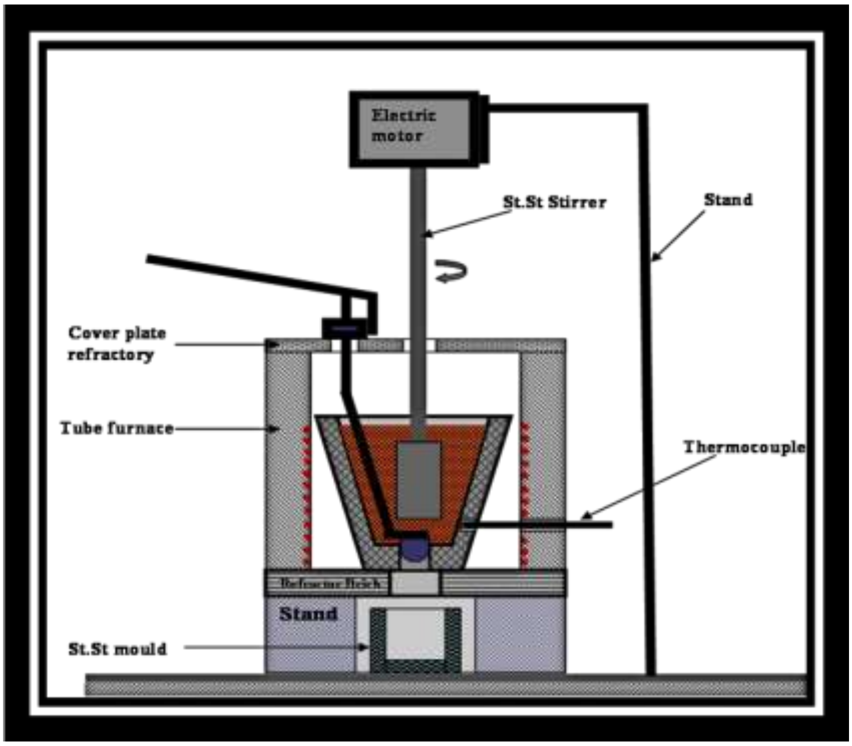


Figure (1) The semi-solid casting set up used.

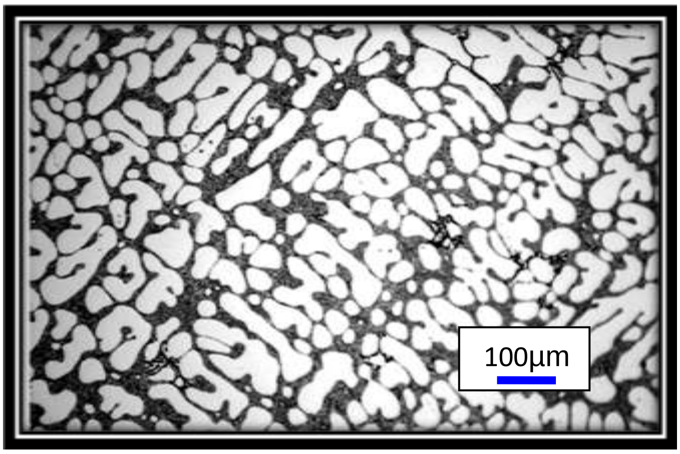
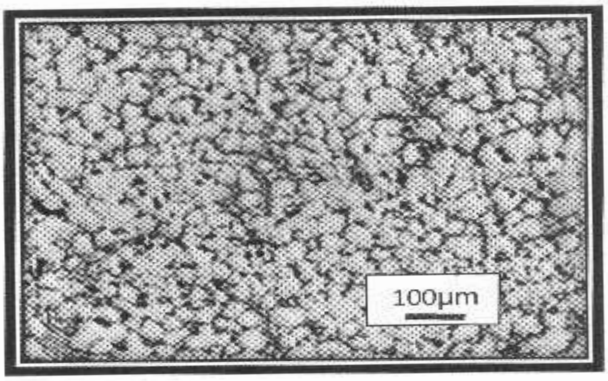
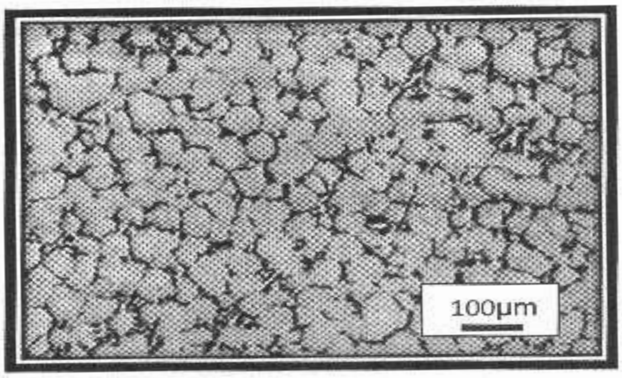


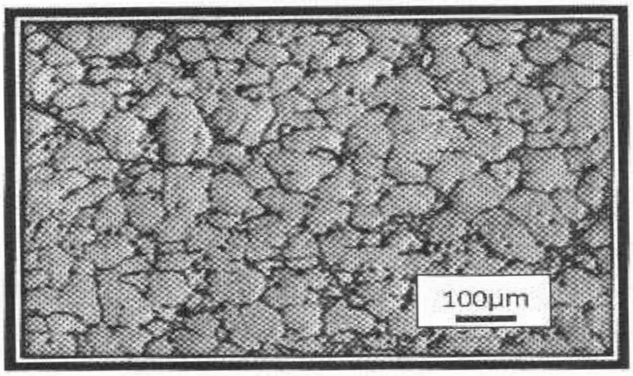
Figure (2) The microstructure of as-cast sample.



(620) °C

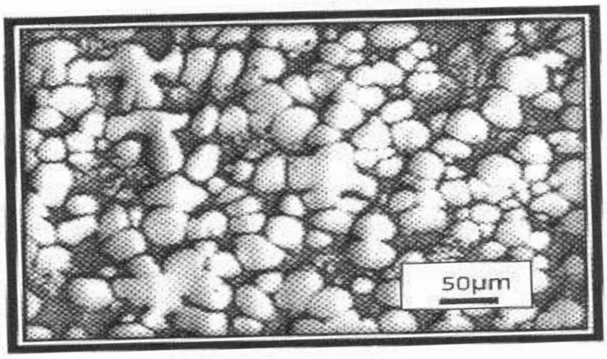


(630) °C

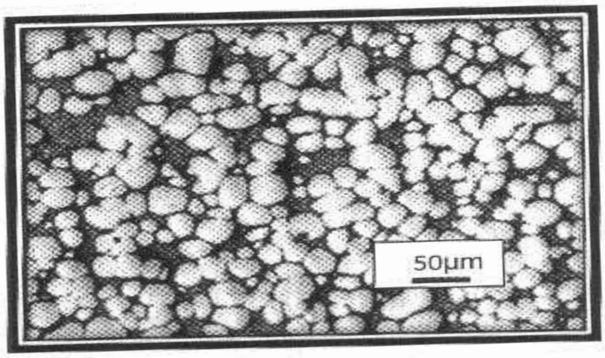


(640) °C

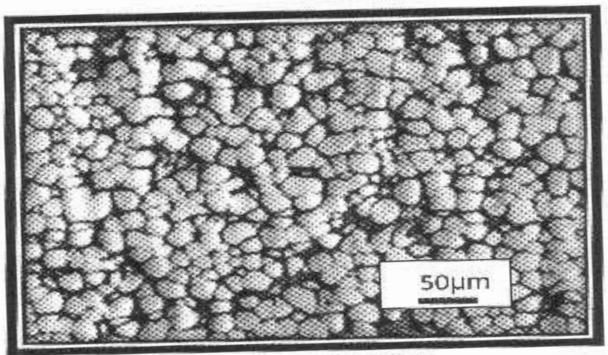
Figure (3) quenched sample from various superheat temperature.



(640) °C

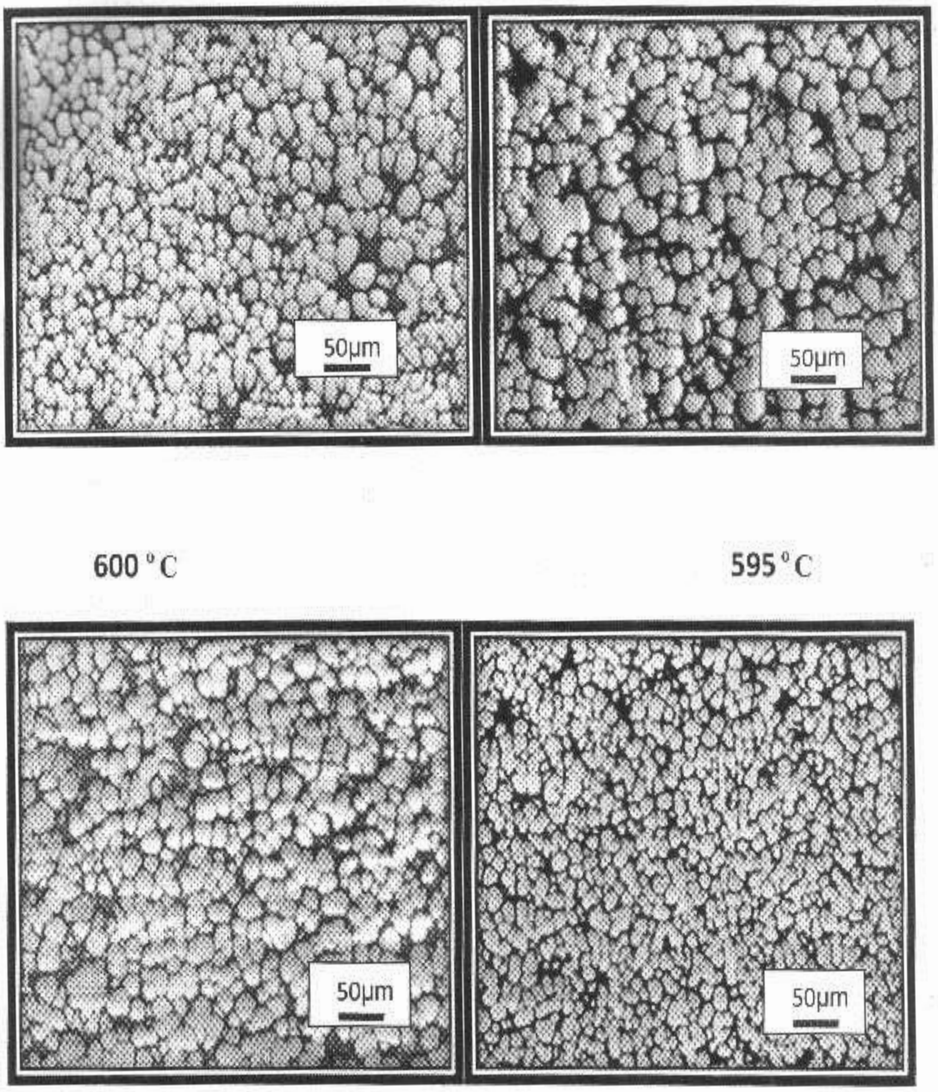


(630) °C



(610) °C

Figure (4) Strucfure of sample superheated of various temp and reheated to Semisolid temperatuer.



600 °C 595 °C

590 °C 580 °C

Figure (5) Structure of slurry quenched at various temps within the Semi Solid rang.

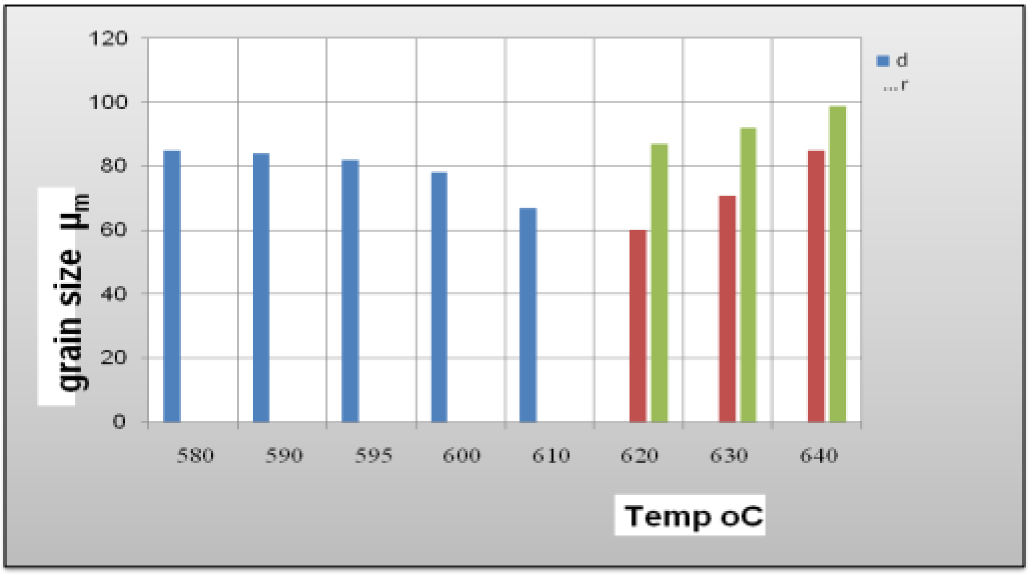


Figure (6)Effect of process temperature on the grain size of (α- Al).

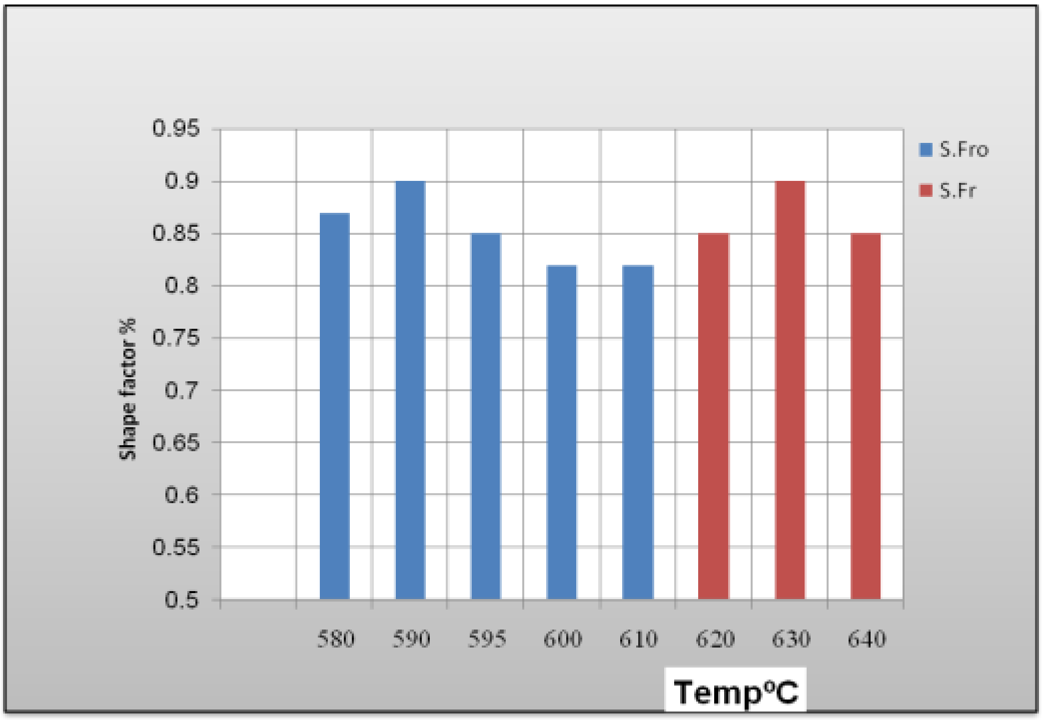


Figure (7) Effect of process temperature on the shape factor of (α-Al).