Study the Effects of Squeeze Casting Parameters on the Corrosion Behavior of Al-Si-4Cu Alloy

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Abstract

This study investigated the effects of squeeze parameters on the properties of squeeze castings and the optimum parameters for producing squeeze castings from Al-Si alloy. It also compared the properties of the squeeze castings with those of gravity castings. Squeeze castings were made from Al-Si-4Cu alloy using pressures of 10,15,20,25 and 30 MPa with the alloy poured at 750, 800 and 850oC into a die preheated to 300oC. Squeeze time was 30s. The corrosion experiments were performed over a range of elevated pressure, pouring temperature and were carried out in sea water (3.5% NaCl solution). We have focused to determination of the rate of corrosion and other corrosion characteristics. Both as-gravity cast and squeeze specimens were tested, for comparison. Corrosion behavior of the materials was assessed by the corrosion potential by potentiostate (polarization) curves. It was found that for a specific pouring temperature,microstructure of squeeze castings became finer;mechanical properties were increased with increase in pressure to their maximum values. Compared with gravity casting process, squeeze casting enhanced the mechanical properties; it increased the hardness from Hv 18.083 Kg for gravity castings to a maximum of Hv 35.413 for squeeze castings which constitutes about 50.063% increase over those of gravity castings. Although squeeze casting parameter has decreased the corrosion current density (of about 2 μAcm^2) when compared to the results of the as-cast samples.

Keywords: Squeeze casting, pouring temperature, corrosion.

الخلاصة

في هذا البحث تم دراسة متغيرات السباكة بالعصر على خواص المسبوكات لتحديد المتغيرات المثلى لانتاج سبيكة المنيوم نحاس سليكون وكذلك مقارنة خواص السباكة بالعصر مع خواص السباكة التقليدية. المتغيرات المستخدمة في سباكة العصر لسبيكة الالمنيوم نحاس سليكون، الضغط المستخدم 30,25,20,15,10 Mpa ودرجة حرارة صب 850,800,750 درجة مئوية، مع تسخين مسبق للقالب الى 300c° وزمن الضغط 30 ثانية. استخدمت تجارب التاكل في ماء البحر بتركيز 3.5% NaCl. تم حساب سلوك التاكل للسبيكة بواسطة المجهاد الساكن (منحنيات الاستقطاب) حيث وجد ان الخواص الميكانيكية ومقاومة التاكل تزداد مع زيادة درجة حرارة الصب والضغط، حيث اصبحت البنية المجهرية دقيقة وازدادت الخواص الميكانيكية مقارنتا بالسباعة التقليدية. حيث ان صلادة فيكرز 18.083 للسبيكة التقليدية و 35.413 للسباكة بالعصر، الزيادة تقريبا 50.63 حيث ان متغيرات السباكة بالعصر قللت كثافة تيار التاكل 2 mAp مقارنة بالسباكة التقليدية.

الكلمات المفتاحية: ضغط الصب، صب في درجة الحرارة والتآكل

Introduction

Recently, great attention has been focused on aluminium and its alloys due to their high technological value and wide range of industrial applications. The effect of microstructure on metallic alloys properties has been highlighted in various studies, particularly the influence of dendrite arm spacing on mechanical properties and corrosion behavior relationships (Rosso *et al*.,2012;Konopkaa *et al*.,2009).Aluminum castings have played an integral role in the growth of the aluminum industry, Silicon is the main alloying element; it imparts high fluidity and low shrinkage, which results in good castability and weldability (Mehmet *et al*., 2006;Bogdanoff, 2009), combined with other physical properties such as mechanical properties and corrosion resistance. (Gilbert *et al*., 2004). Mechanical properties of Al–Si casting alloys depend not only on their chemical composition but are also significantly dependent on microstructural features such as the morphologies of the Al-rich a-phase and of the eutectic Si particles (Gilbert *et al*., 2004;Arthur,2009;WU Shu *et al*.,2012). The corrosion resistance of a metal tends to be adversely affected by the presence of a second phase. The presence of a second phase material may or may not increase the corrosion susceptibility, depending not only on the metal-reinforcement combination but also on manufacturing process parameters (Bogdanoff , 2009;Arthur, 2009).

Squeeze casting, compared with traditional sand casting which dates back, is a relatively new casting technology. It is a technology with a very bright future, based on its applications and advantages. Described squeeze casting as a casting process in which molten metal is solidified under the direct action of a pressure that is sufficient to prevent the appearance of either gas porosity or shrinkage porosity as opposed to all other casting processes in which some residual porosity is left (Gulnara *et al*.,2004;Taufikur *et al*., 2013).

Some of the advantages include the elimination of gas and shrinkage porosities, the reduction or elimination of metal wastage due to absence of feeders or risers (Taufikur *et al* .,2013;SENCER *et al*., 2004).

Squeeze casting is a very important manufacturing process that combines the advantages of forging and casting and is used for the production of a wide range of products from monolithic alloys and metal-matrix composites parts. Such parts include vane, ring groove reinforced piston, connecting rod, bolt, joint of aerospace structure, rotary compressor vane, shock absorber cylinder, diesel engine piston, cylinder liner bearing materials among many others used in automobile, nuclear, aeronautical components, sports equipment and many industrial equipment(SENCER *et al*., 2004;Raji *et al*., 2006).This study was carried out to determine the effect of squeeze pressure and pouring temperature on corrosion behavior of aluminum-silicon alloy squeeze cast products.

Experimental procedure

1- Material

The raw material used in this study was commercially purchased Al-Si-4Cu aluminum die casting alloy and its chemical composition is shown in Table 1. The Al-Si-4Cu alloy family is the most widely used aluminum die casting alloy due to the best combination of material properties. The chemical composition test in the General Company for Engineering Equipment Baghdad.

Table1: Chemical composition (wt. %) of alloy used in this study

Element	Si	Fe	Cu	Mg	Zn	Ni	Ti	Cr	Mn	Al
Content (wt.%)	6.3	0.81	3.98	0.08	0.63	0.31	0.12	0.001	0.45	Rest.

2- Melting of Alloy

2-1 Alloy preparation

The test specimens were fabricated by squeeze casting using cylindrical tool steel molds with an average internal radius of 15 mm, external radius of 30 mm and a height of 50 mm (Fig. 1). The lower die was mounted on a supporting unit and the upper die was attached to a hydraulic press ram with pressure velocity was 20 min/s. and an electric resistance furnace. About 1 kg of Al-Si-4Cu alloy was prepared in a carbolite furnace using a SiC crucible, and then the melt was poured into the lower die.

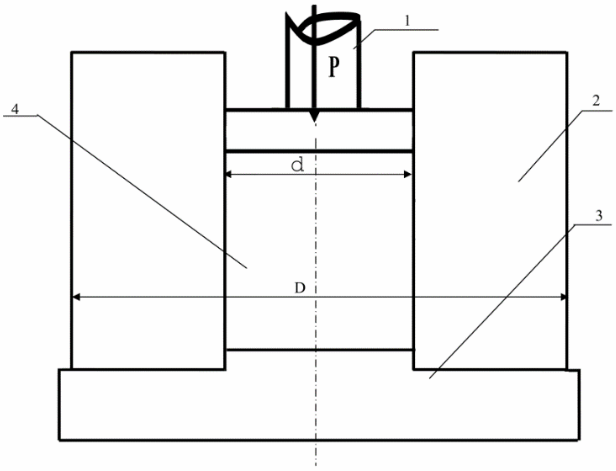


Fig.1 Schematic diagram of squeeze casting test rig
1-upper punch, 2-cylindrical steel mould, 3-die support, 4-die cavity

2-2 Casting conditions

For the gravity die cast, a two part steel die was used. The die was preheated to 300◦C, which was the same as the temperature for the dies used in squeeze casting. The same alloy was melted in the furnace and after degassing the liquid metal was poured into the preheated die cavity. The cast piece was allowed to remain in the steel die for about 10 min and then removed.

Squeeze casting was done in a 50 ton hydraulic press. The upper die was lowered into the lower one for heating and just before the casting process it was with- drawn. Then the prepared liquid metal was poured into the lower die and the required squeeze casting pressure was applied for 30 s, long enough for solidification. The cast piece was removed from the mold with the assistance of an ejector at the bottom of the die. To investigate effect squeeze parameters on the microstructure and properties. Five sets of squeeze castinga were made for each combination of 10, 15, 20, 25 and 30MPa and pouring temperatures of 750, 800 and 850ºC.

Corrosion Tests

Electrochemical investigation of the Al-Si-4Cu was performed with potentiostat polarization. All experiments were carried out with a computer-controlled potentiostat (PCI4/750, GAMRY Instruments, Inc.,Warminster, PA) in 3.5% NaCl solution in 1 liter of distilled water at room temperature. Ag/AgCl and platinum (Pt) electrodes were used as a reference and auxiliary electrode, respectively as shown in Fig 2. Specimens were immersed into the solution until obtaining a steady open circuit potential (OCP).The exposed area of the test specimens was about 10 mm^2, and all data have been normalized according to the surface area. Impedance parameters were calculated by fitting the experimental results to an equivalent circuit model by using the Echem Analyst software.

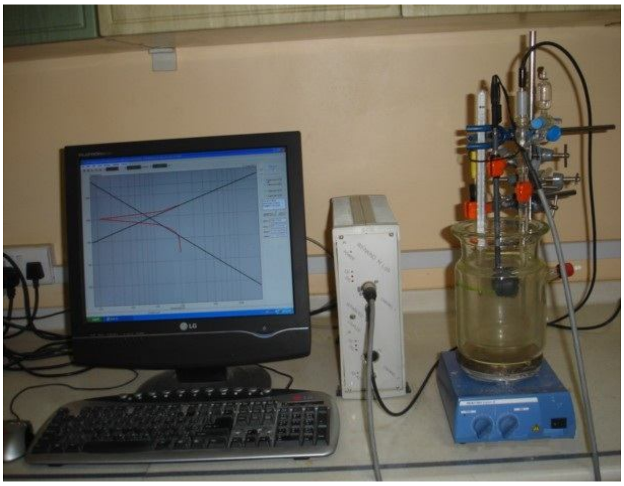


Fig 2. The electrochemical corrosion unit.

3- Metallographic Studies

Preparation of Al-Si samples for micro- examination involved mainly sampling, grinding, polishing and etching. The samples were filed and ground. Grinding was done in succession on a roll grinder using silicon carbide abrasive papers of 220-, 320-, 400-, and 600-grits. Rough polishing and final polishing were done using a paste made from silicon carbide powder (1000 grit) and a paste made from pure heavy grade of alumina (Al_2O_3) respectively on a cloth on the circular disc machine polisher. Final rinsing was done with warm water and the specimens were blown dry with a hand dryer and then kept in a desiccator. Etching of the specimens was done using approximately Hydrofluoric acid (HF). Each specimen was then mounted on an optical microscope and the microstructure observed and photographed at a magnification of x125.

4- Determination of Hardness Properties

Hardness test was carried out on a Vickers type hardness-tester using an 0.5kg. Measurements at three different locations were made and the average value of Vickers number was noted.

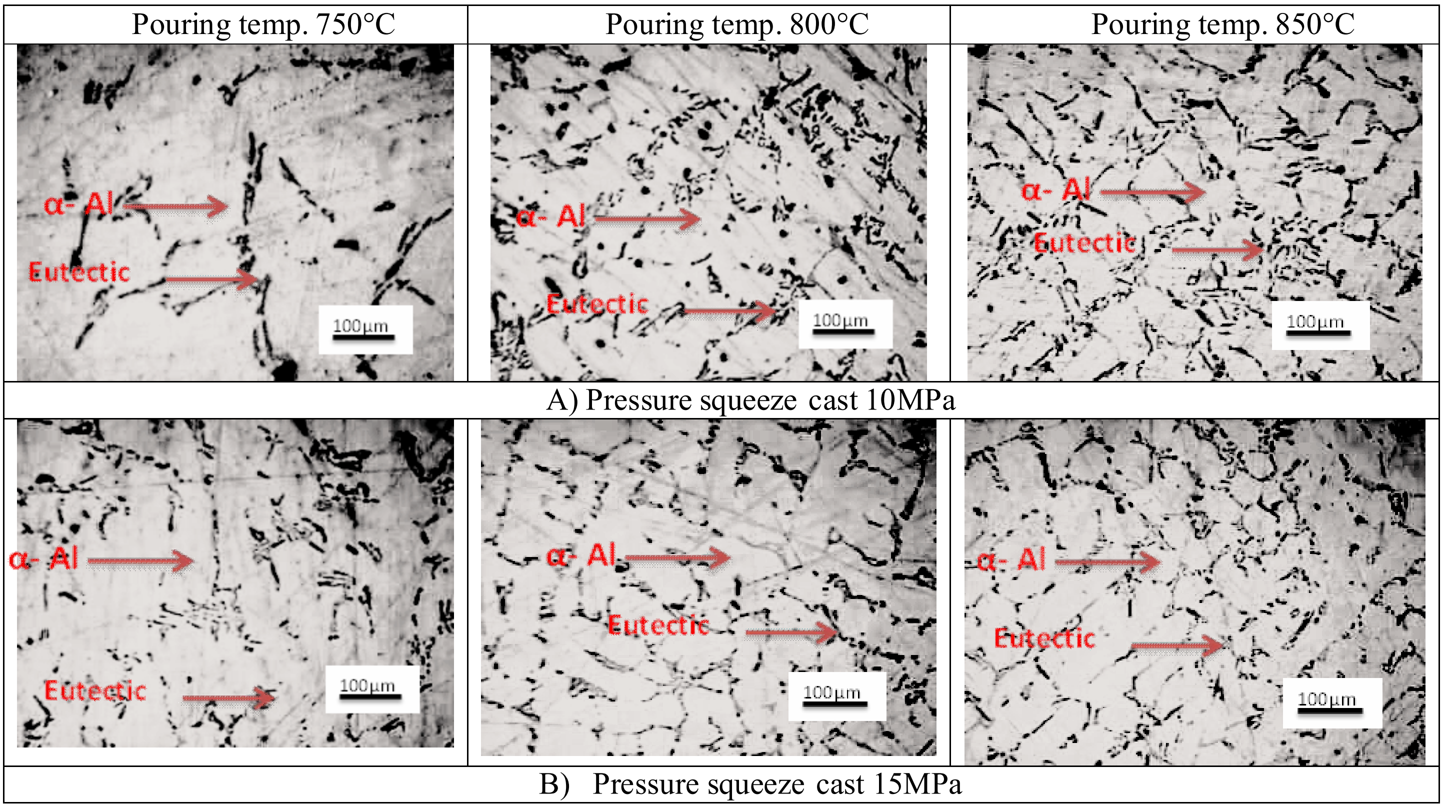
Results and Discussion

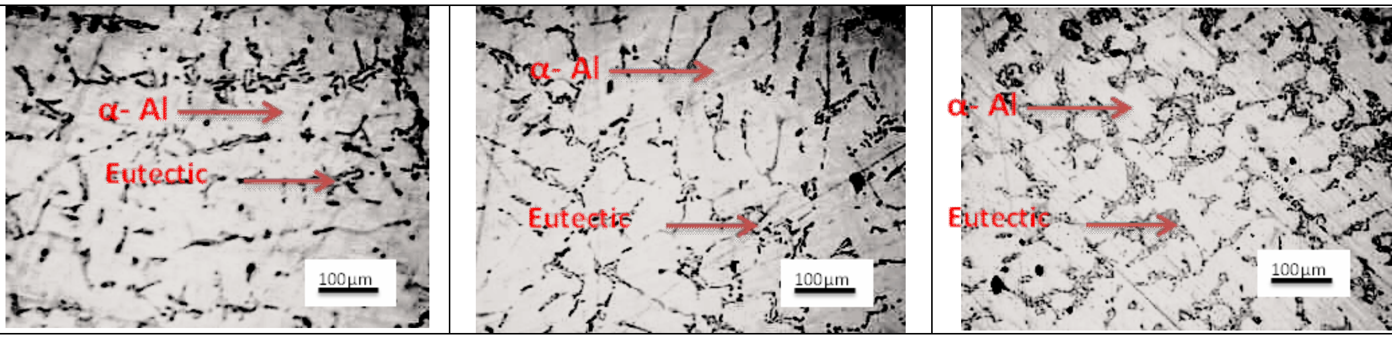
Metallographic Studies

The results of metallographic studies of the cast samples showed that in all cases, the microstructure of the cast samples were of hypoeutectic structure consisting of primary alpha solid solution of silicon in aluminum (α) in a matrix of eutectic (α+Si). However, the grain sizes differed for various castings (Bogdanoff , 2009)(WU Shu *et al*.,2012).The results of micro-examination revealed that the dendrites of aluminum in squeeze castings are fine with the fineness increasing with increase in squeeze pressure for all pouring temperatures as shown in Figs. 2 and 3; the structure in Fig. 3 being finer than that in Fig. 2. The grain sizes (ASTM grain size number) of squeeze cast products made at squeeze pressure of 10 MPa were 6.63, 6.66 and 6.69 for pouring temperatures of 750oC, 800oC and 850oC, respectively. Increasing the squeeze pressure to 30MPa yielded finer grain sizes of 7.07,7.46 and 7.23 for pouring temperatures of 750oC, 800oC and 850oC, respectively. Further increase in squeeze pressure to 30MPa did not yield any meaningful refinement for pouring temperatures of 750oC and 850oC while for pouring temperature of 800oC it yielded further refinement of grains (7.16) (Gilbert *et al*.,2004). The fine structures of squeeze castings were brought about by the high cooling rates of the dies aided by the squeeze pressure. The results of micro-examination showed that gravity castings were characterized by fairly fine structures (5.27-5.45) due to high cooling rate of the moulds only. The structures were however, coarser than those of the squeeze castings(Gilbert *et al*., 2004;Raji *et al*., 2006).

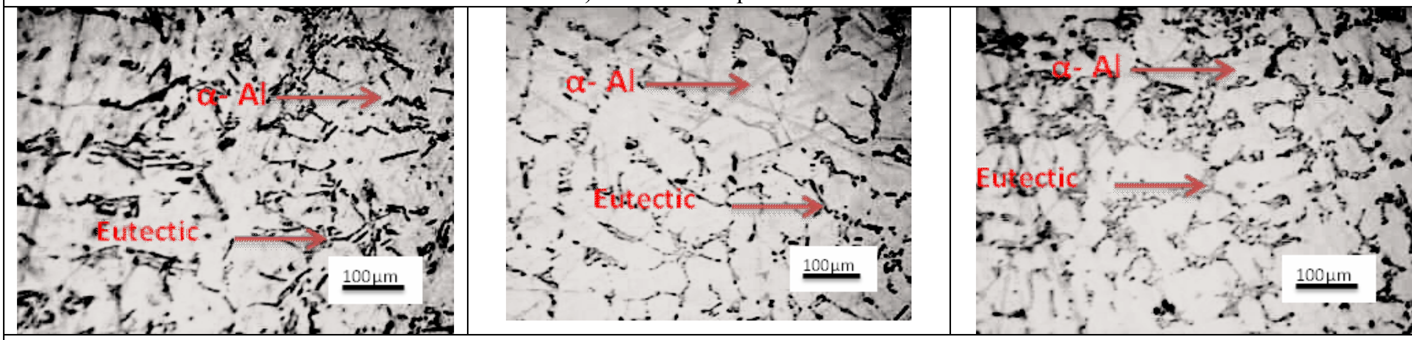
It is know that the solidification consists of two simultaneous processes (Gulnara *et al*., 2004). The first process is the formation of structure (nucleation and growth of dendrite crystal in the cooling melt). The second process is the formation of the different defects – segregations, shrinkage cavities and pores. The combination of these structures parameters defines the properties of alloy (Boschetto *et al*., 2007; Obiekea *et al*., 2012).

The macrostructure of cast billets was mainly characterized by two crystallization regions: (i) the regions of columnar dendrite crystals adjoining normally to the surfaces of the die and punch and (ii) the region of equiaxed dendrite crystals in the centers of billets. Figure (3) shows the width of the regions of columnar crystals non-monotonically changed with the die temperature and applied pressure (Obiekea *et al*., 2012),(Rosliza, 2012).

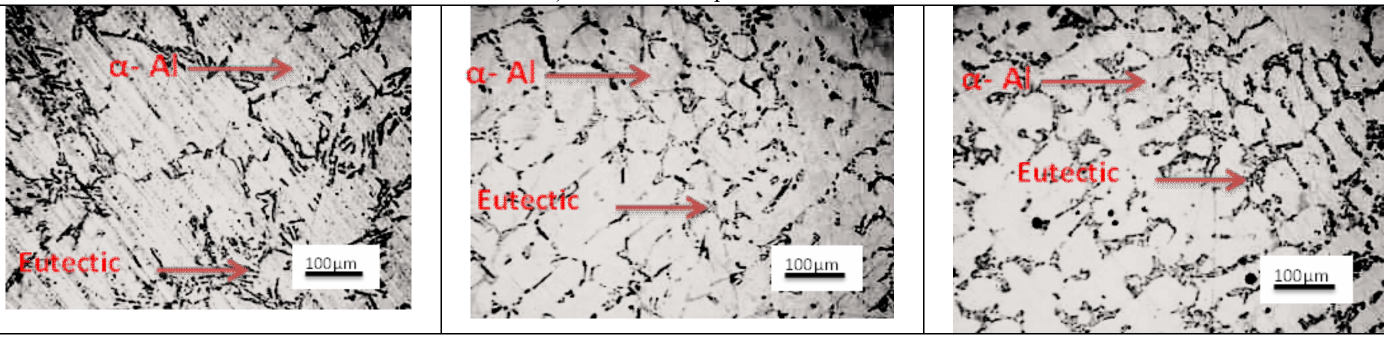




C) Pressure squeeze cast 20MPa



D) Pressure squeeze cast 25MPa



E) Pressure squeeze cast 30MPa

Fig. 3. Micrograph of Al-Si alloy squeeze cast at a pouring temperature of 750,800 and 850 ^{O}C and a squeeze pressure of 10,15,20,25,30MPa (x 125).

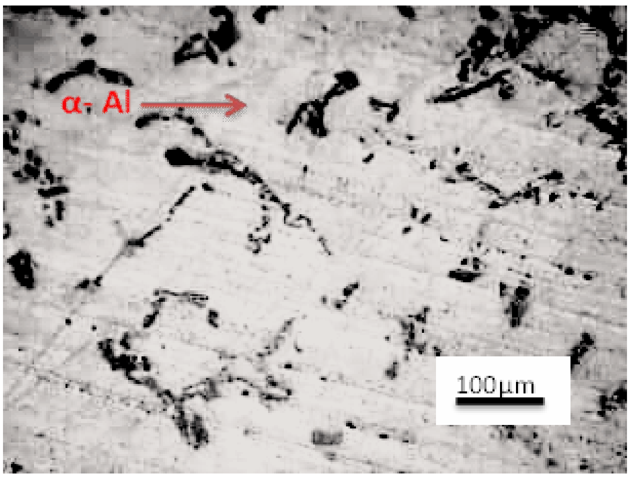


Fig. 4. Micrograph of Al-Si-4Cu alloy as gravity castings

Hardness

The relationship between hardness of Al- Si alloy gravity castings as well as squeeze castings for various pouring temperatures is shown in Fig.5.The results showed an increase in hardness of Al-Si4Cu alloy from Hv 18.083 Kg for gravity castings to a maximum of Hv 35.413 for squeeze castings which constitutes about 50.063% increase over those of gravity castings. The increase in the hardness of squeeze cast products is brought about by the faster cooling rates giving rise to grain refinement and elimination of porosity and hence increased hardness of squeeze cast products (Rathod *et al.*,2013).

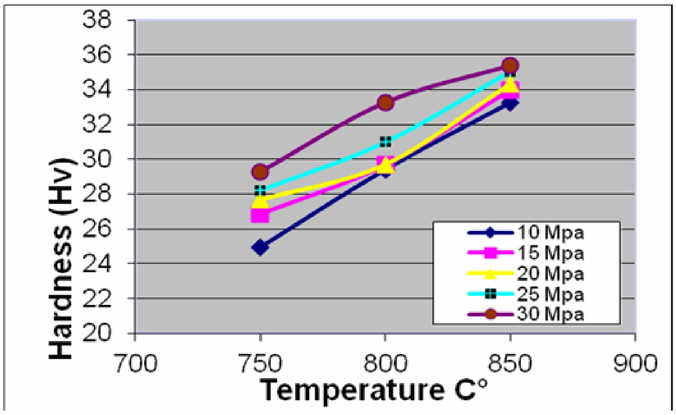


Fig. 5. The effect of squeeze pressure on hardness of squeeze cast Al-Si-4Cu alloy hardness at squeeze pressure of 0.1MPa refers to those of gravity castings.

Electrochemical characterization

Potentiostate polarization curves for as-cast and squeeze casting Al-Si-4Cu alloy samples in 3.5% NaCl in1 liter of distilled water solution at 25 ^{o}C are shown in Fig. 6. Such results permit to reinforce the corrosion resistance tendency which has been observed when analyzing experimental and simulated plots for the Al-Si-4Cu alloy, with the SQC samples providing higher corrosion rate. Although squeeze casting parameter has decreased the corrosion current density (of about 100 mV) when compared to the results of the as-cast samples, a considerable displacement on the corrosion potential towards the nobler side (at -792mV) can be observed and show in tables (2,3,4,5and 6). The shapes of the cathodic and anodic branches of the as-cast Al-Si-4Cu alloy sample characterize typical pitting reactions, differently to that exhibited for the parameter squeeze casting sample, as shown in Fig (6).

Table 2: summaries the value of polarization curves: The i_{corr} (mA/cm^2), and E_{corr} (mV) for Pressure squeeze cast 10MPa.

At pressure 10 MPa		
Pouring temp.	Ecorr (mV)	icorr (mA/cm^2)
750°C	-762.3	4.85
800°C	-755	10.47
850°C	-614.6	15.36
Gravity casting	-792.3	14.85

Table 3 :summaries the value of polarization curves: The i_{corr} (mA/cm^2), and E_{corr} (mV) for Pressure squeeze cast 15MPa.

At pressure 15 MPa		
Pouring temp.	Ecorr (mV)	icorr (mA/cm^2)
750°C	-749.5	4.31
800°C	-708.2	4.44
850°C	-766.2	13.97
Gravity casting	-792.3	14.85

Table 4 :summaries the value of polarization curves: The i_{corr} (mA/cm^2), and E_{corr} (mV) for Pressure squeeze cast 20MPa.

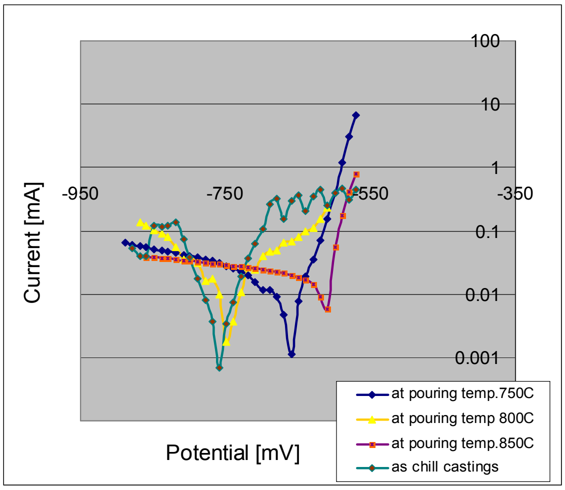
At pressure 20 MPa		
Pouring temp.	Ecorr (mV)	icorr (mA/cm^2)
750°C	-612.1	10.93
800°C	-634.8	5.47
850°C	-714.6	6.36
Gravity casting	-792.3	14.85

Table 5: summaries the value of polarization curves: The i_{corr} (mA/cm^2), and E_{corr} (mV) for Pressure squeeze cast 25MPa.

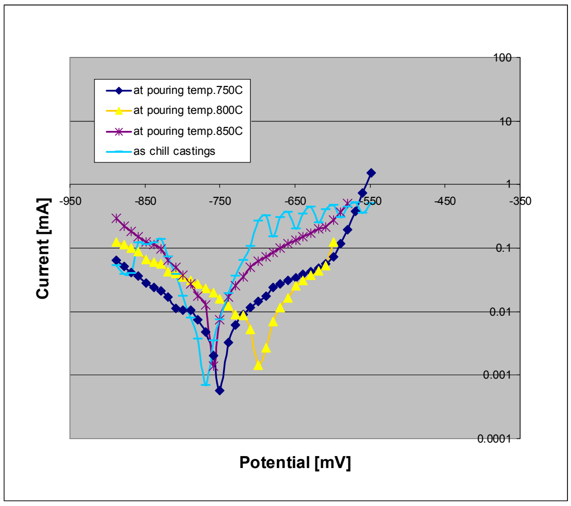
At pressure 25 MPa		
Pouring temp.	Ecorr (mV)	icorr (mA/cm^2)
750°C	-632.7	9.54
800°C	-688.6	6.35
850°C	-632.4	4.75
Gravity casting	-792.3	14.85

Table 6:summaries the value of polarization curves: The i_{corr} (mA/cm^2), and E_{corr} (mV) for Pressure squeeze cast 30MPa.

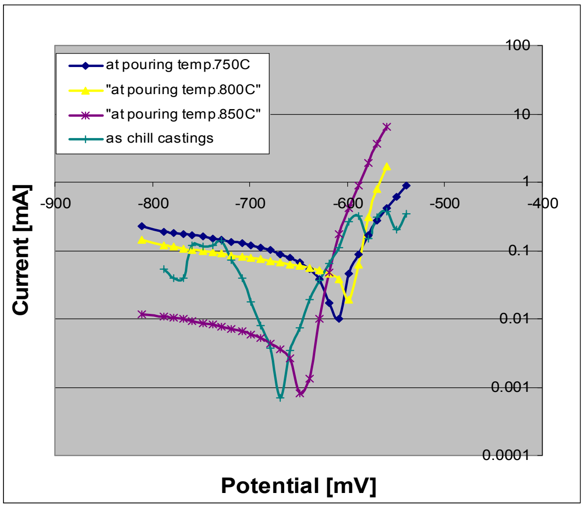
At pressure 30 MPa		
Pouring temp.	Ecorr (mV)	icorr (mA/cm^2)
750°C	-597.3	7.55
800°C	-608.6	10.59
850°C	-614.1	4.46
Gravity casting	-792.3	14.85



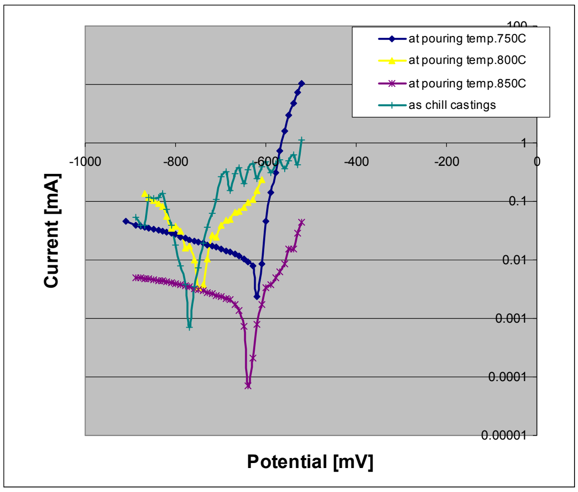
At pressure 10 MPa



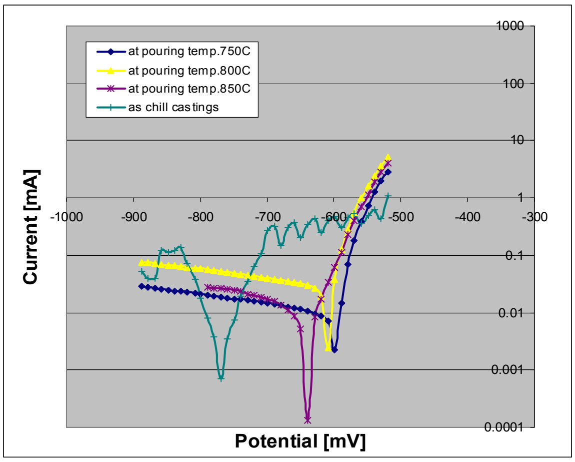
At pressure 15MPa



At pressure 20 MPa



At pressure 25MPa



At pressure 30 MPa

Fig. 6 : The polarization curve of effect pressure squeeze casting and pouring temperature on corrosion behavior .

Although the microstructural refinement is hardly desired by major foundry industries in order to increase the mechanical properties, the corrosion resistance can be significantly affected. Therefore mentioned experimental and simulated impedance parameters provide sufficient information to conclude that the use of the treatment has provoked a deleterious effect on the corrosion behavior of the Al-Si alloy. In this particular case, such tendency of reduction on the corrosion resistance induced by the SQC process is associated with an increase of boundaries between the Al-rich (α) phase and Si particles that have dissimilar growth behaviors(Rosliza, 2012;Rana, 2007;Wan *et al*., 2010). The boundaries are imperfectly conformed due to a certain deformation in the atomic level, mainly on the Al-rich phase side of the interface, since Si grows from the melt in a faceted manner (smooth growth interface) while the α phase solidifies with surfaces that are rough. Such localized deformation induces an increase on the corrosion action for very fine microstructures .Recent studies dealing with the corrosion resistance of hypoeutectic Al-Si alloys have reported a similar result, i. e., with refined microstructures being connected to a decrease on the corrosion resistance.Fig.7 shows microstructures illustrating tendencies for pitting corrosion for as-cast samples (Konopkaa *et al*., 2009; Gilbert *et al*., 2004; Jamaludin *et al*., 2008; Rathod *et al*., 2013).

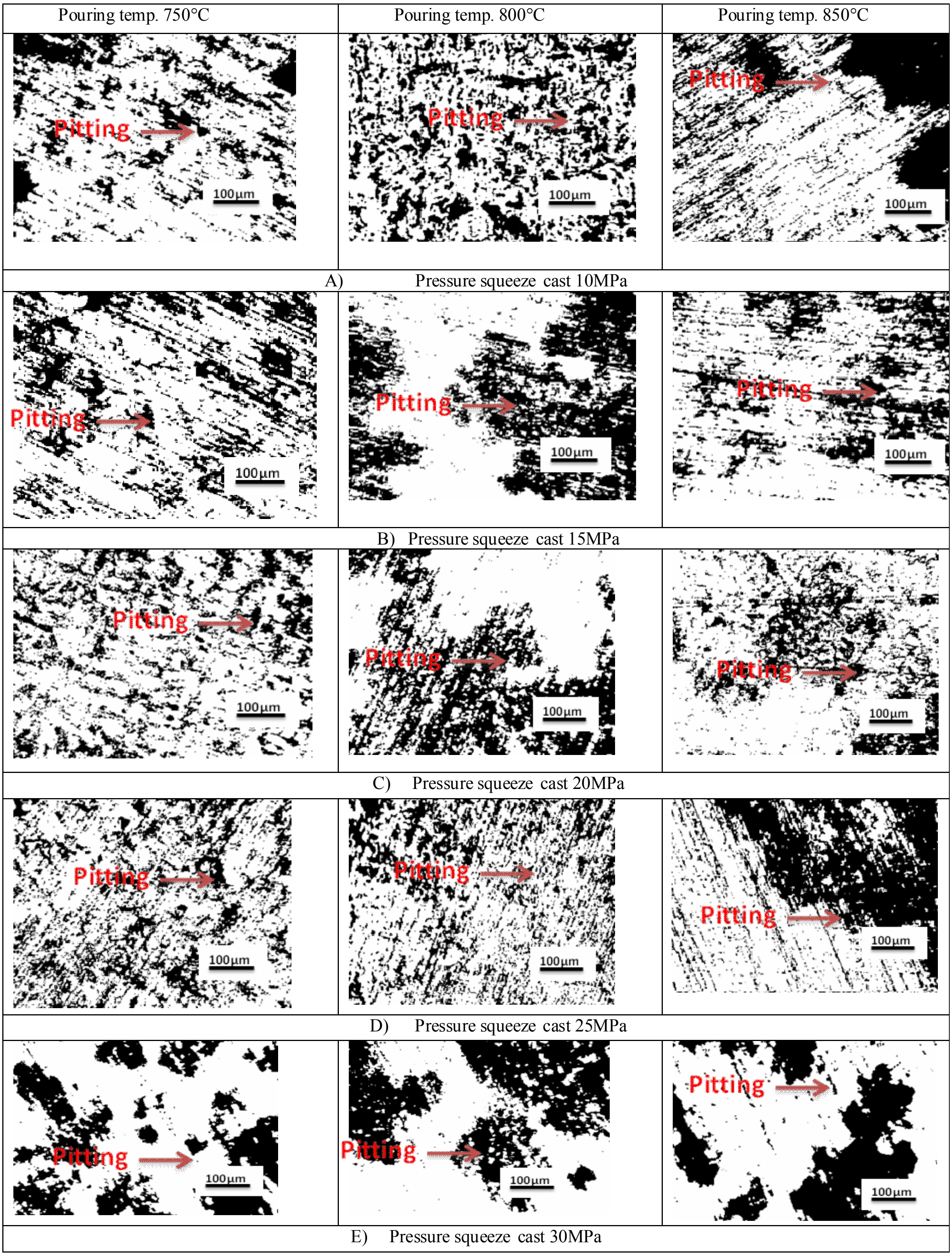


Fig.7. Typical microstructures of the Al-%Si-4Cu alloy after corrosion tests evidencing pitting corrosion.

4. Conclusions

1. The corrosion rate of Al-Si-Cu are the lowest at all the three pouring temp and pressures squeeze casting compare with as cast gravity.
2. Squeeze casting helps to refine the microstructures of castings and thus, leads to better mechanical properties of the castings.
3. Optimum pouring temperature of 850 C and squeeze pressure of 25MPa can be utilized for squeeze casting of Al-Si-4%Cu alloys products having an aspect ratio (high to section thickness ratio) not greater than 2.5:1.
4. Increasing hardness proportional relationship with the increase in pressure and the degree of pouring temperature.

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