Effect of Degassing Process of Squeeze Casting Aluminum Alloy on Tensile Strength Under Different Pressures

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ABSTRACT

Degassing technique currently applied to cast aluminum alloys due to its technological and economic advantages. The present work aimed to study the effect of degassing technique of cast aluminum alloy (LM2) under different pressures using squeeze casting process. Inert argon gas was pumped into the molten aluminum with flow rate (2,5-5-7)l/min. at constant pumped duration (5min.). Different applied pressures were used(17, 35, 52) MPa. The test was performed at room temperature. The physical and mechanical properties of degassed samples were measured and compared with non-degassing (ND) samples. The results showed that the best condition of degassing is found at 2.5 l/min flow rate and 35 MPa applied pressure. It was found that a slight difference is observed for the density and the lowest value of porosity was obtained at 2.5 l/min flow rate and 52 MPa applied pressure.

Keywords: Degassing, Density, Porosity, Tensile Strength, Aluminum Alloy.

تأثير عملية إزالة الغازات لطريقة السباكة بالعصر على مقاومة الشد لسبيكة المنيوم تحت ضغوط مختلفة

الخلاصة

تقنية أزالة الغازات تطبق في الوقت الحالي لصب سبائك الألمنيوم بسبب مزاياها التكنولوجية والاقتصادية. يهدف البحث الحالي إلى دراسة تأثير عملية إزالة الغازاتالناتجة من السباكة لسبيكة الالمنيوم (LM2)تحت ضغوط مختلفة باستخدام طريقة السباكة بالعصر. تم ضخ غاز الاركون الخامل إلى منصهر الالمنيوم بمعدلات تدفق (2.5- 5 - 7) لتر/دقيقة وبزمن ضخ ثابت (5) دقائق. تم تسليط ضغوط مختلفة (17 – 35 – 52 ميكاباسكال) . اجري الاختبار في درجة حرارة الغرفة. تم حساب الخواص الميكانيكية والفيزيائية لنماذج المصبوبات المزالة الغاز عنها وقورنت النتائج مع النماذج الغير مزالة الغازات عنها.أظهرت النتائج أن معدل ضخ 2.5 لتر/دقيقة وبضغط 35 ميكاباسكال حقق افضل

النتائج. وجد أن هنالك اختلاف طفيف في قيم الكثافة, وحصول على اقل قيمة للمسامية عند معدل ضخ 2.5لتر/دقيقة وبضغط 52 ميكاباسكال.

INTRODUCTION

Porosity has long been recognized as a major casting defect that is detrimental to the mechanical properties, pressure tightness and corrosion resistance of Al castings. Porosity occurs due to both the solidification shrinkage resulting from the volume decrease and the evolution of the dissolved gasses from the remarkable decrease in solubility of the gasses in the solid as compared to the liquid metal. Hydrogen is the only gas that is appreciably soluble in molten aluminum. Thus, eliminating the dissolved hydrogen in molten Al is critical for producing high quality castings [1].

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 [2]. The liquid metal solidifies under pressure in closed dies held together by a hydraulic press. Essentially, the metal is forged to near-net or net shape while it solidifies [3].

Ruizhi *et al.*[4]studied the difference between spray degassing and rotary impellor degassing techniques and they concluded that the spray degassing method is better than the rotary method in kinetic conditions, avoidance of hydrogen absorption and recycling purifying gas.

Wu Shusen *et al.*[5] showed the effect of the ultrasonic vibration on the gas content of both the melt and the semi-solid slurry of Al-Si alloys, and the variations of the gas contents in two kinds of aluminum alloys, i.e., A356 alloy and Al-20Si-2Cu-1Ni-0.6RE alloy (Al-20Si). The results show that ultrasonic vibration has an obvious degassing effect on the molten melt, especially on the semi-solid slurry of Al-Si alloy which is below the liquidus temperature by less than 20 °C.

Junwen li *et al.*[6] investigated the relations between porosity in the ingot and the effecting factors such as the ultrasonic power and the time of ultrasonic vibration (UV) treating to melt. Moreover, the mechanism of the porosity formation and the prevention method was studied. The results indicate that the effect of degasification was better when the intensity of UV is above threshold value. On contrary, the intensity of UV below the value resulted in the increase of the gas content in the ingot and the decrease of density.

Lei zhao *et al.*[1] investigated the evolution of porosity during re-melting of near-eutectic casting of Al alloys using in-situ X-ray micro-focus radiography. Several re-melting experiments were carried out with pure aluminum and a hypoeutectic Al-7%Si-0.4%Mg (A356) in addition to the near-eutectic Al-13%Si alloys. The results clearly show that the area fraction of porosity in the final Al castings decreases dramatically after re-melting one or two times.

Teng-Shih Shih and Kon-Yia Wen [7] studied the melts were degassed with and without a covering flux using a porous bar diffuser. After degassing and holding, the melts were poured to obtain chilled samples. The chilled samples were polished and treated by ultrasonic vibration to reveal any foggy marks and the area of that foggy marks and the pore count were measured.

H. Puga *et.al.*[8] evaluated the efficiency of ultrasonic degassing when applied to the $AlSi_9Cu_3$ alloy when compared with other degassing techniques. Ultrasonic degassing is compared with rotary impeller degassing using argon and nitrogen as purging gases. Results characterization focuses the assessment of alloy density and final hydrogen content of the samples. This study was carried out to determine the effect of squeeze casting pressures and argon flow rates of degassing process on mechanical and physical properties of Al-Si alloy.

Experimental work

Materials

Al-Si alloy (LM2) was used in this study. Table (1) shows the chemical composition of this alloywt%.

Table (1) Chemical composition of Al-Si aluminum alloy.

Element	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Ni%	Zn%	Al%
Actual Composition	10.42	0.961	0.894	0.240	0.124	0.029	0.079	0.399	Balance
Nominal [9]	9.0-11.5	1.0 max	0.7-2.5	0.5 max	0.30 max	0.30 max	0.50 max	2.0 max	Balance

Manufacturing Process

After preparing the press machine that found in state company for mechanical industries/ Iskandariyah to perform squeeze casting of molten aluminum, the squeeze die was preheated to (200 ^{o}C)for 30 min to obtain uniform distribution of heating throughout the die. Slag remover was used with 0.5% from total weight of charge. When the molten alloy reached to (750 ^{o}C), the argon gas was pumped into the melt with different flow rate (2,5 - 5 -7) l/min with constant duration of pump (5min.), then the molten aluminum was poured into a square die with dimension (102*40*20mm^{3}). The punch was move down to the die to squeeze the molten aluminum at different pressures (17, 35, 52 MPa), the applied pressure was held for 5 minutes. After holding pressure was completed, the punch was released and casting was ejected. Figure (1) shows the squeeze casting machine.

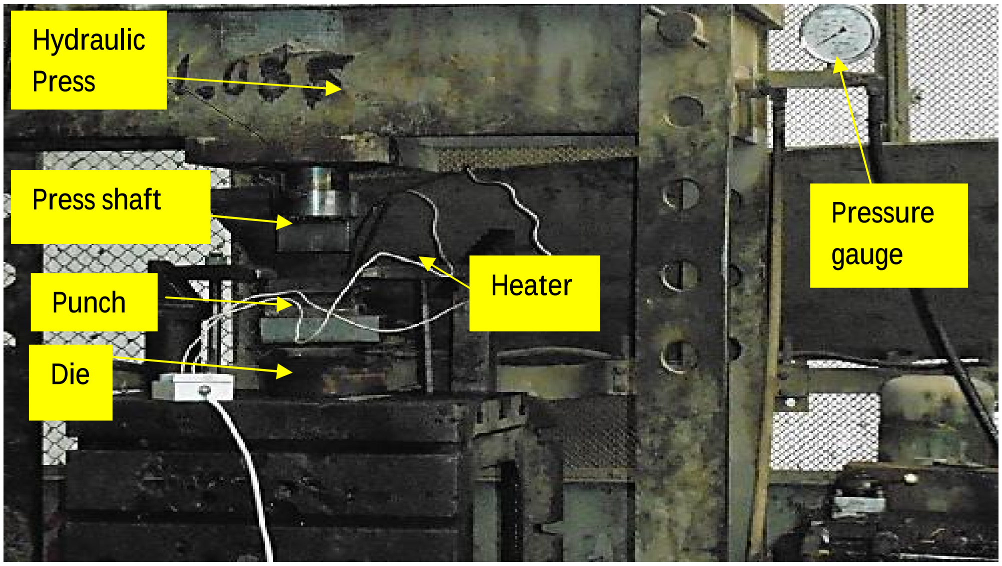

Figure (1) squeeze casting machine.

Squeeze casting pressure measurement:

Squeeze pressure was calculated in equation below [10].

- in the case of 17 MPa:

The applied pressure (P_a) can be determined by

$$Pa = P_o \frac{D^2}{d^2} \qquad \ldots(1)$$

Where:

P_o = hydraulic pressure 100 bar =(10MPa), D = press shaft diameter = 95mm, d = diameter of the squeeze die punch i.e. outer diameter of the casting. The diameter of the casting (d)may be calculated from equating the casting area as $\frac{\pi d^2}{4}$ = 4080mm^2
And then d can be determined as 72.07mm.
Applying equation (1) the applying pressure to casting area can be calculated as Pa = 17.3MPa
Tensile test specimens were cut from casting already produced by squeeze casting method die with dimension (102x40x20mm) by milling machine to obtain each specimen with dimension (100x10x3mm) according to ASTM E8. Each specimen followed by grinding with emery papers to obtain smooth surface finish. A constant cross head speed of 1 mm/min. was used during the test. The final tensile specimen with the dimensions in mm can be shown in figure (2).

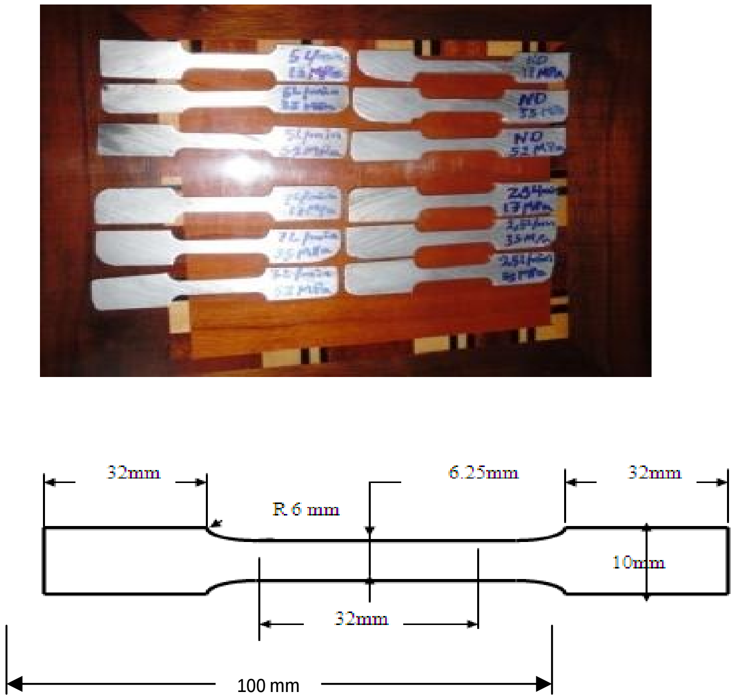

Figure (2) Tensile specimens according to ASTM E 8.

Physical Properties Calculations

In order to calculate the physical properties of aluminum cast, density and porosity for non-degassing and degassing specimens under a certain applied pressure. The density of the aluminum cast was determined using the Archimedes method[11]. The equipments used were a balance with accuracy 0.1 mg and 4 digits after decimal, a beaker 300ml and a copper wire. The density of the sample is determined as follows [12].

$$density \;=\rho l\,\frac{w_1}{w_1-w_2} \qquad \dots (2)$$

Where

ρl = density of water (gm/cm^3), $w_1\; = sample\; weight\; in\; air$ (gm.), w_2= sample weight suspended in water (gm).

Apparent porosity (P%) also determined as follows [13].

$$P\% \;=\; \left\{\frac{w_3-w_1}{w_3-w_2}\right\} * 100 \qquad \dots (3)$$

Where

w_1 = sample weight in air (gm.),w_2 = sample weight suspended (gm.), w_3 = sample weight saturated in water (gm.)

Results and Discussion

Table (2) gives the results of tensile strength (σ_u) in MPa for three applied pressure 17, 35, 52 MPa. It is clear that, when the applied pressure increased the value of (σ_u) increased. Average of three readings are taken for comparison.

Table (2) Tensile test of non-degassed(ND) samples with different applied pressures.

Sample	Applied Pressure MPa	Tensile Strength MPa			Tensile Strength AverageMPa
ND	17	100	103	106	103
	35	125	128	125	126
	52	145	152	149	148

It can be also noticed that a linear best fit relation between the applied pressure and the variation of average ultimate stress (σ_u) as shown in figure (3).

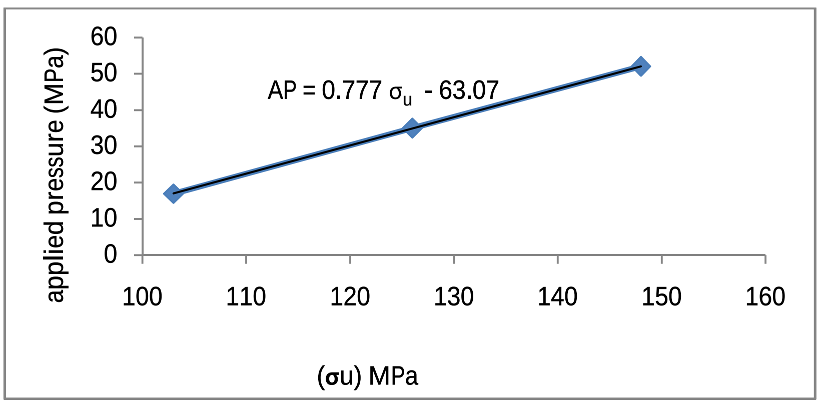

Figure (3) Relationship between applied pressure and ultimate strength (σ_u).

This relation may be written in the form

$$AP = A\sigma_u - B \quad \ldots (4)$$

Where

AP is the applied pressure (MPa), and (A, B) are coefficients which can be obtained experimentally. Table (3) shows the tensile test results at room temperature (20 ^oC) under the same conditions done in table (2) but with degassing process using three different flow rates, namely 2.5, 5, 7 l/min. It can be observed that regardless of the amount of applied casting pressure, the degassed samples have higher tensile strength of non-degassed samples. In all casting samples in this study, the tensile strength increased with increase the amount of applied pressure, these results agree with the results of reference [14], in the case of aluminum casting. Also higher tensile strength values of degassing samples came from pumping inert gas into molten aluminum. The inert gas collects soluble hydrogen atoms and other impurities, and then floated up and pure molten metal will be obtained. The general mechanism of hydrogen removal is by diffusion of hydrogen across the metal/gas interface[15].

Table (3) Tensile test of degassed (DG)samples with different applied pressures.

Flow rate l/min.	Applied Pressure MPa	Tensile Strength (σ_u) MPa			(σ_u) Average MPa
2.5	17	129	134	135	132
	35	172	188	186	182
	52	198	210	207	205
5	17	120	121	125	122
	35	160	170	168	166
	52	160	177	167	168
7	17	110	114	115	113
	35	129	134	130	131
	52	151	157	151	153

Comparison of the Results of Tensile Strength with and Without Degassing

Table (4) shows the tensile test results with and without degassing process and strength improvement factor (SIF) of (DG) samples which may be written in the form [16].

$$\text{SIF\%}=\frac{\sigma_u(DG)-\sigma_u\,(\text{ND})}{\sigma_u\,(\text{ND})}*100 \qquad \dots (5)$$

Table (4) Results of tensile test and SIF values of DG samples.

Flow rate l/min.	Applied Pressure MPa	DG samples (σ_u) MPa	ND samples (σ_u) MPa	SIF%
ND	17	--------	103	-----
	35	--------	126	-----
	52	-------	148	-----
2.5	17	132	-----	28.15
	35	182	------	44.44
	52	205	------	38.51
5	17	122	------	18.44
	35	166	-----	31.74
	52	168	-----	13.51
7	17	113	-----	9.7
	35	131	-----	3.96
	52	153	-----	3.37

The variation of flow rate with the SIF% for three different applied pressures can be seen in Figure (4).

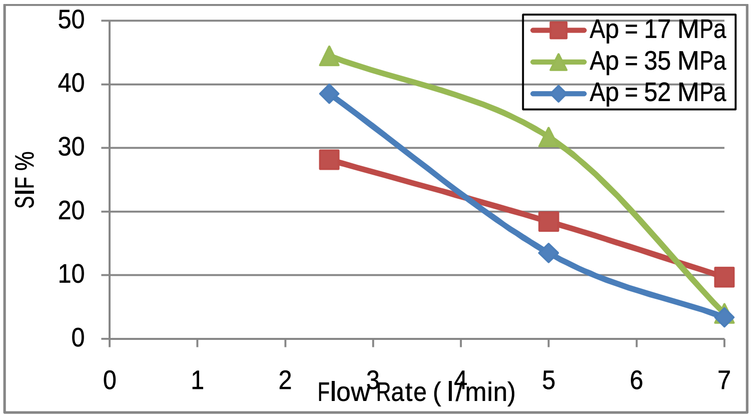

Figure (4) Flow rate against SIF% of degassing samples.

Figure (5) gives the relation between SIF% and applied pressure at constant flow rate .

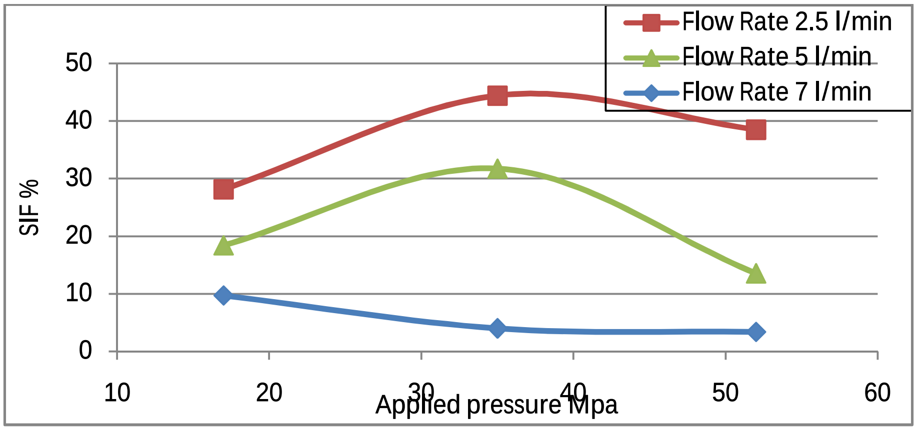

Figure (5) SIF% against applied pressure at constant flow rate.

It can be observed from the above Figures (4), (5) that

- The best SIF% is for Ap = 35MPa.
- Increasing the flow rate reducing the SIF% .
- The best flow rate is 2.5 l/min which gives highest SIF% for all the Ap used.
- The highest SIF% occurred at Ap = 35MPa and 2.5 l/min flow rate. While the lowest SIF% is occurred at flow rate 7 l/min and 52 MPa applied pressure.

The solubility of hydrogen decreases as the aluminum melt solidifies. A high cooling rate was obtained and quantity of remaining liquid phase is reduced greatly in the case of squeeze casting used. Using optimum pressure value which leads to a high cooling rate sufficient to avoid porosity. Table (5) illustrates the actual density and porosity values of the test casting samples. These values are different according to the applied pressure and the amount of gas flow rate. The density of cast aluminum used is high at pressure of 52 MPa for all casting samples and it has the lowest value in the case of 17MPa. Density of the LM13 aluminum alloy samples decreased with application of 20MPa external pressure and it increased steadily for higher applied pressures up to about 100MPa [17].

The applied pressure presses the liquid phase between the dendrites arms solid phase plus the increasing of cooling rate so the pressure in squeeze casting lead to increase the density value[18].For higher flow rate degassing, density remains low and porosity increases. The results of density in table (5) indicates that a slight variation of density is observed and the degassing process doesn't affect the density of the cast aluminum used for all flow rates and applied pressures. While the porosity becomes higher at applied pressure 35MPa and then reduced at 52 MPa applied pressure for all flow rates used. The lowest porosity is found at 2.5 l/min flow rate and 52 MPa applied pressure.

Table (5)Density and porosity values.

Flow rate l/min.	Applied Pressure MPa	Density g/cm^3	Porosity %
ND	17	2.4552	4.8631
	35	2.5019	15.9081
	52	2.5206	5.9230
2.5	17	2.6186	1.5426
	35	2.6486	6.6181
	52	2.7026	1.0611
5	17	2.5280	1.5423
	35	2.6009	12.685
	52	2.6375	2.3953
7	17	2.5061	1.5423
	35	2.5450	12.6980
	52	2.6001	2.3988

CONCLUSION

The following conclusions may be drawn from the current work :

1- For Non degassing process, increasing the applied pressure gives increase in tensile strength.

2- The flow rate of 2.5 l/min is the better for degassing of Al-Si alloy, while higher flow rates (5-7 l/min) have lowered the mechanical and physical properties.

3- An increase in flow rate and applied pressure do not necessarily increase the SIF% of Al-Si alloy.

4- The best SIF% is occurred at 35MPa applied pressure and 2.5 l/ min flow rate , while the lowest value of SIF is observed at 52 MPa applied pressure and 7 l/ min flow rate.

5- Density and porosity values depend on the amount of applied pressure and variation of gas flow rates.

6- The lowest porosity is obtained at 2.5 l/min flow rate and 52 MPa applied pressure.

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