INVESTIGATION OF PARAMETERS AFFECTING LOST FOAM CASTING

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ABSTRACT

The lost-foam casting process using expanded polystyrene foam pattern allows more complex and detailed passages to be cast directly into the part. The advantages of the lost-foam casting process involve, forms complex internal and external shapes without cores, reduces part mass with near net-shape capability, eliminates parting lines, and reduces machining operation and costs, Complex shapes with various sizes castings were produced in this technique in the foundry of the State Company for Electrical Industrials to evaluate the process. Successful complete castings were made. Many experimental works were done to further complements about fluidity parameter dealing with lost-foam casting process. Empirical linear and non-linear formulas were obtained from those experimental works to find the minimum temperature for pouring molten metal. Aluminum alloys were the material of choice for this work, due to the best combination of mechanical properties and castability, but the performance requirements and manufacturability issues will drive the choice of a specific aluminum that was aluminum-silicon alloy, which were used in this work.

The macroscopic properties of the alloy depend strongly on the microstructure. Therefore, photomicrographs of microstructures of various castings with different foam pattern densities were done and made comparisons with common sand castings. Mechanical tests were conducted on the castings which produced by the common sand casting and the lost-foam casting processes. These tests include tensile, hardness, and impact. Because of using the expandable polystyrene as a pattern that gave, more gasses in the cavity of the mold during casting, so the mechanical tests show some differences between the two processes.

الخلاصه:

السباكه بطريقة الرغوه المفقوده باستخدام نماذج رغوة البولستيرين المتبخر تسمح اكثر بانتاج مسبوكات ذات تفاصيل وقنوات واشكال معقده مبنيه في نفس المسبوكه. ميزات طريقة السباكه بالرغوه المفقوده هي: تكوين أشكال بسطوح خارجيه و داخليه معقده دون الحاجه الى استخدام القلوب، تقليل عدد القطع وامكانية انتاج الشكل المطلوب المقارب للشكل النهائي، عدم الحاجه لخطوط فاصله، تقليل عمليات التشغيل الاضافيه بعد انتاج المسبوكات وبالتالي تقليل الكلف. تم سباكة نماذج ناجحه معقده وباحجام مختلفه. تم اجراء تجارب عمليه عديده في مسبك الشركة العامه للصناعات الكهربائيه لغرض اضافة المعلومات المهمه لمتغير السيوبه ذات العلاقه بطريقة السباكه بالرغوه المفقوده. تم استنتاج صيغ عمليه بعلاقه خطيه وغير خطيه استنتجت من التجارب العمليه لايجاد أقل درجة حراره ممكنه لصب منصهر المعدن.

تم اختيار سبيكة كثيرة الاستخدام في مجالات مختلفه من سبائك الالمنيوم كونها تمتلك افضل جمع بين الخواص الميكانيكية المرغوبه وقابلية السباكه الجيده. ولكن متطلبات الاداء وقابلية التصنيع ادت الى اختيار سبيكه معينه (Al-Si) التي استخدمت في هذا العمل.

ان الخواص العامه تعتمد بقوه على التركيب المجهري للسبيكه. لقد تم أخذ صور ميلوغرافيه للتراكيب الداخليه للمسبوكات التي تم انتاجها في هذا العمل لنماذج مقطوعه من قطع البولستيرين المختلف الكثافة. تم اخذ صورمكبره للتراكيب الداخليه لمختلف المسبوكات باختلاف كثافة الرغوه للنماذج وعمل مقارنه مع مسبوكات تم انتاجها بالطريقه التقليديه. تم اجراء فحوصات ميكانيكيه مختلفه للمسبوكات المنتجه بطريقة الرغوه المفقوده ولكثافات مختلفه وكذلك بالطريقه التقليديه لغرض المقارنه فيما بينهم ، تشمل هذه الفحوصات فحص الشّد ، الصلاده والمتانه. بسبب استخدام نماذج مصنوعه من مادة البولستيرين التي تنتج غازات اكثر في تجويف القالب بسبب تحللها اثناء عملية السباكه، لهذا الفحوصات الميكانيكيه اعطت بعض الفروقات بين الطريقتين.

KEY WARDS

Lost-Foam Casting, Expanded Polystyrene, Fluidity, Aluminum-Silicon Alloy, Microstructure, Mechanical Tests.

INTRODUCTION

Casting processes are among the oldest methods of manufacturing date back to around 6000 B.C. (Groover 2002) when copper arrowheads and other tools were made. Shape casting involves the production of more complex geometries and almost all materials can be cast in, or nearly in the final shape. Varieties of shape-casting methods are available, thus making it one of the most versatile of all manufacturing processes. The production of a desired shape by a sand casting process first involves molding foundry sand around a suitable pattern which is made of wood or other materials in such a way that the pattern can be with- drawn to leave a cavity of the required shape in the sand. To facilitate this procedure the sand mold is split into two or more parts.

This procedure may cause some defects in the products such as fins, misalignment of mold parts and cores in spite of mold distortion. Thus, the lost-foam casting (LFC) is a method of sand casting to eliminate the above defects; moreover, it simplifies and expedites the mold making. The process uses a mold of sand packed around a polystyrene foam pattern complete with necessary system, and it may contain internal cores **Fig. 1** (Higgins 1978)**.**

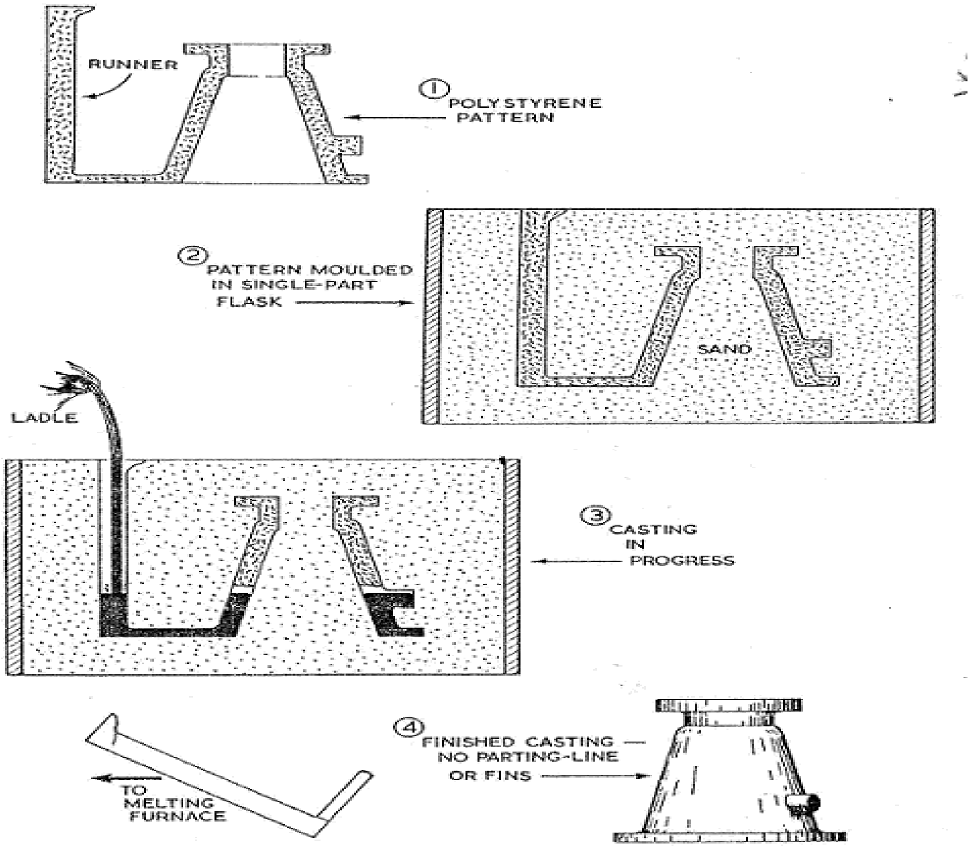
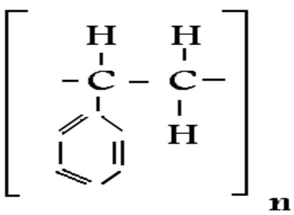


Fig. 1 Lost-foam casting process using EPS pattern (Higgins 1978).

Polystyrene is a polymer material with the formula: **$(C_8 H_8)$ n**



Where (n) is "between 1000 to 2000". Polystyrene is a material derived from benzene and ethylene and, in its expanded form, contains only 2% of actual solid polystyrene, which extremely low relative density. **Table 1** indicates the properties of the polystyrene material. Various methods for making the pattern can be used depending on the quantities of casting to be produced. For one of kind castings, the foam is manually cut with a sharp knives and heated stainless-steel wire from large strip. For large production runs, an automated molding operation can be set up to mold the patterns (Groover 2002).

Complex internal features are produced by assembling and gluing multiple foam sections together to form a single complex foam pattern, **Fig. 2** The pattern is normally coated with a refractory compound to provide a smoother surface on the pattern and to improve its high temperature resistance (Genske 2004).

Table 1 Polystyrene properties and other data.

Polymer	Polystyrene $(C_8H_8)_n$
Symbol	PS
Polymerization Method	Addition
Degree of Crystallization	None (amorphous)
Modulus of Elasticity	3200 MPa
Tensile Strength	50 MPa
Elongation	1%
Specific Gravity	1.05
Glass Transition Temp.	100°C
Melting Temp.	240°C
Approximate Market share	About 10%

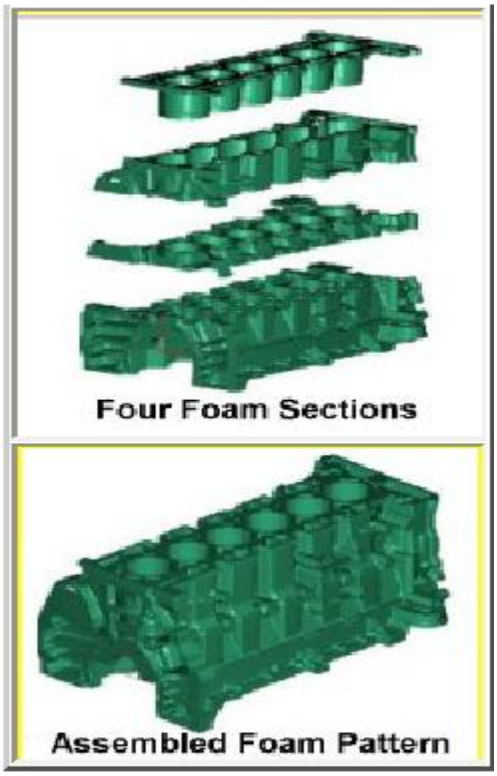


Fig. 2 Assembling and gluing multiple foam sections together to form single complex foam pattern (Genske 2004)**.**

FLUIDITY

Fluidity can be defined as the capability of the molten metal to flow into the cavities of the mold and to fill all internal details of the mold before freezing in the casting process. Fluidity is a commonly used term that combines fluid flow and heat flow characteristics (Serope 1989). Fluidity is related to viscosity, but it is not a single property as viscosity or density but a complex characteristics. So, empirical tests have been devised to measure the overall characteristics. Factors affecting fluidity include pouring temperature, metal composition, viscosity of molten metal, casting geometry, and heat transfer to the surroundings, moreover in LFC process another factors affects fluidity such as foam material, glue lines and coating. The unit of fluidity is expressed as a distance in the length unit such as (cm, mm). Fluidity is a function of producing successful complete castings.

EXPERIMENTAL WORK

Many experiments were done to measure the fluidity of aluminum-silicon alloys using the LFC process. The tests of the fluidity measurement were done by forming standardized strip fluidity test. They were done with different variables. Three commercial expanded polystyrene foam densities – 12, 15, and 20 kg/m³ were examined in these experiments along with four average thickness fingers – 4, 6, 8, and 12 mm – and six pouring temperature. The final strip fluidity pattern and finished casting are shown in **Fig. 3**

(b)

Fig. 3 Strip fluidity model (a) EPS pattern (b) finished casting.

It was designed as a general factorial with two replicates per condition. The factors and their associated values are given in **Table 2**.

Table 2 Factors and levels for Al-Si alloy fluidity test.

Factor	Levels					
Foam Density (kg/m^3)	12		15		20	
Thickness Pattern (mm)	4	6		8	12	
Pouring temperature (°C)	690	700	720	740	750	800

The results of the fluidity measurement castings, which were done in the foundry of the State Company for Electrical Industries, were summarized in the **Table 3**.

Table 3 Experimental values of fluidity measurement tests.

Pouring Temperature °C	*Thickness Channel Pattern (mm)*											
	ρ=12 kg/m^3				ρ=15 kg/m^3				ρ=20 kg/m^3			
	4	6	8	12	4	6	8	12	4	6	8	12
690	28	37	45	72	25	30	41	51	21	30	33	48
700	33	40	46	85	32	38	44	81	30	34	42	78
720	36	56	71	101	33	49	70	98	32	35	44	88
740	37	62	76	125	37	60	71	109	32	52	61	94
750	63	87	124	137	53	76	113	132	47	73	105	124
800	128	138	143	159	125	135	140	155	122	134	139	148

The relationship between pouring temperature, thickness of channels, and the fluidity amount for each relative foam density are shown in **Figures 4, 5, 6** as a 3-D bar chart. **Fig. 7** shows the effect of foam density on the fluidity measurement.

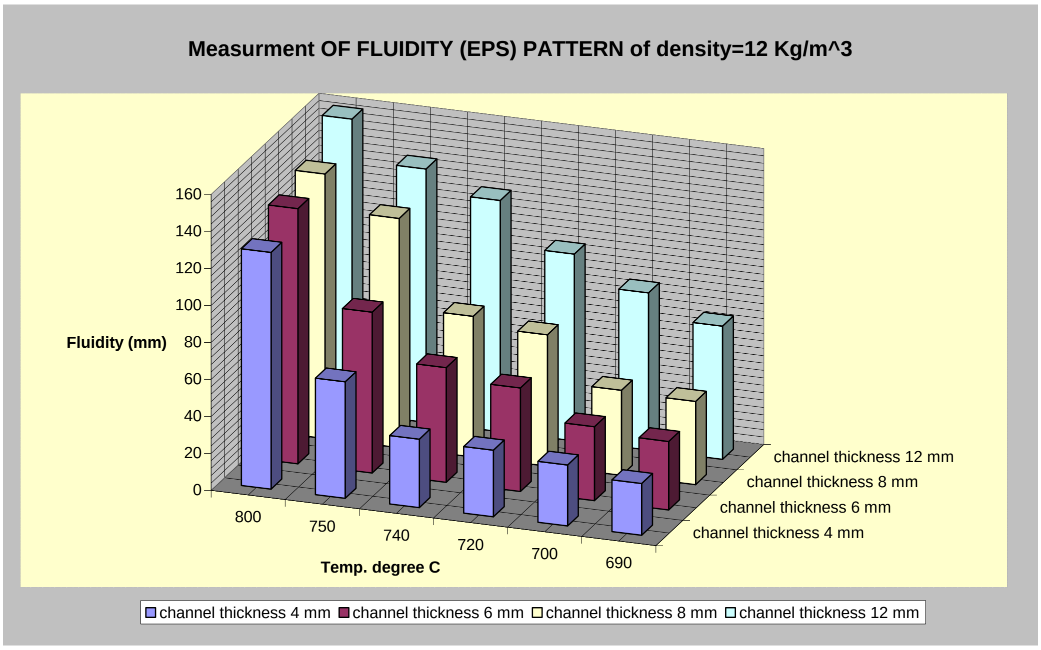


Fig. 4 Bar chart for fluidity measurement test using EPS (Density 12 kg/m³)

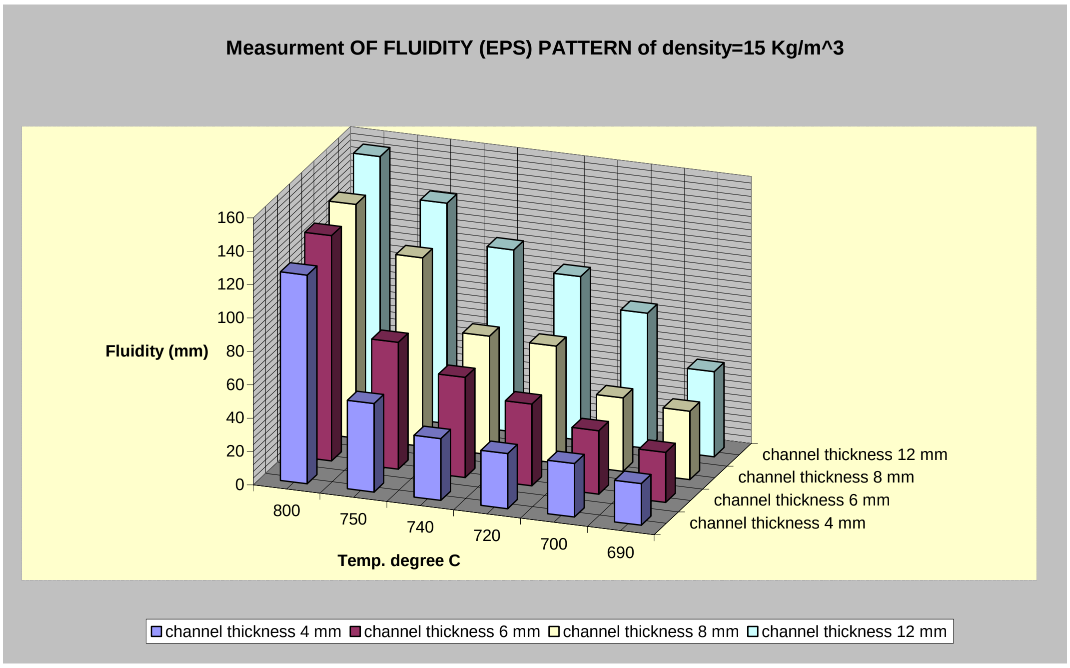


Fig. 5 Bar chart for fluidity measurement test using EPS (Density 15 kg/m³)

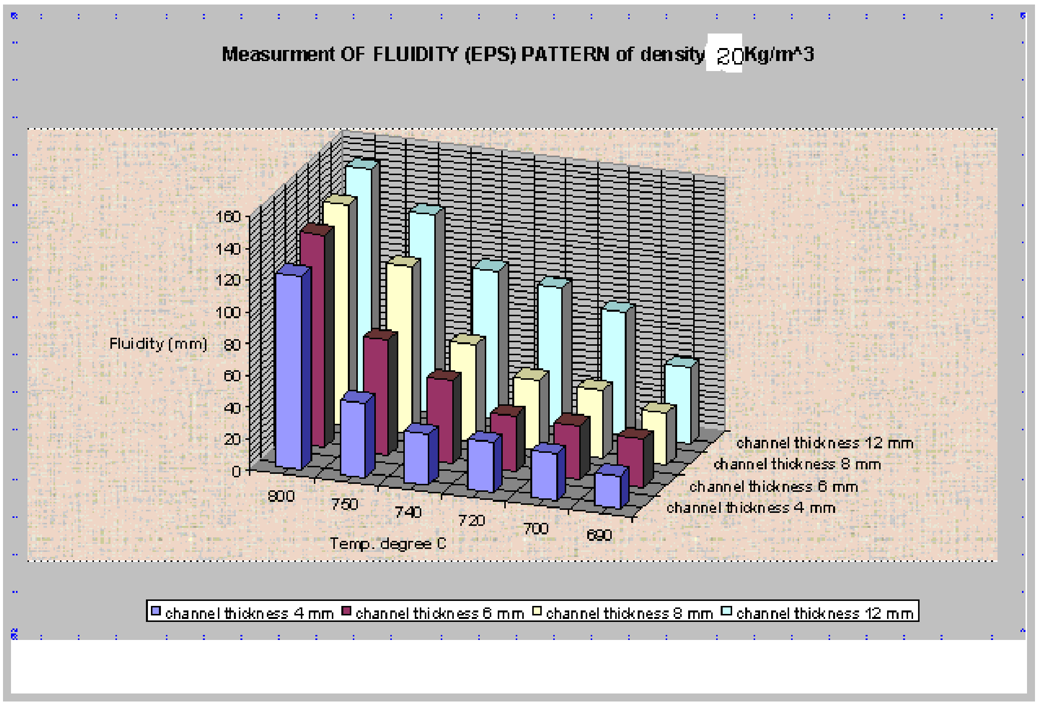


Fig. 6 Bar chart for fluidity measurement test using EPS (Density 20 kg/m³)

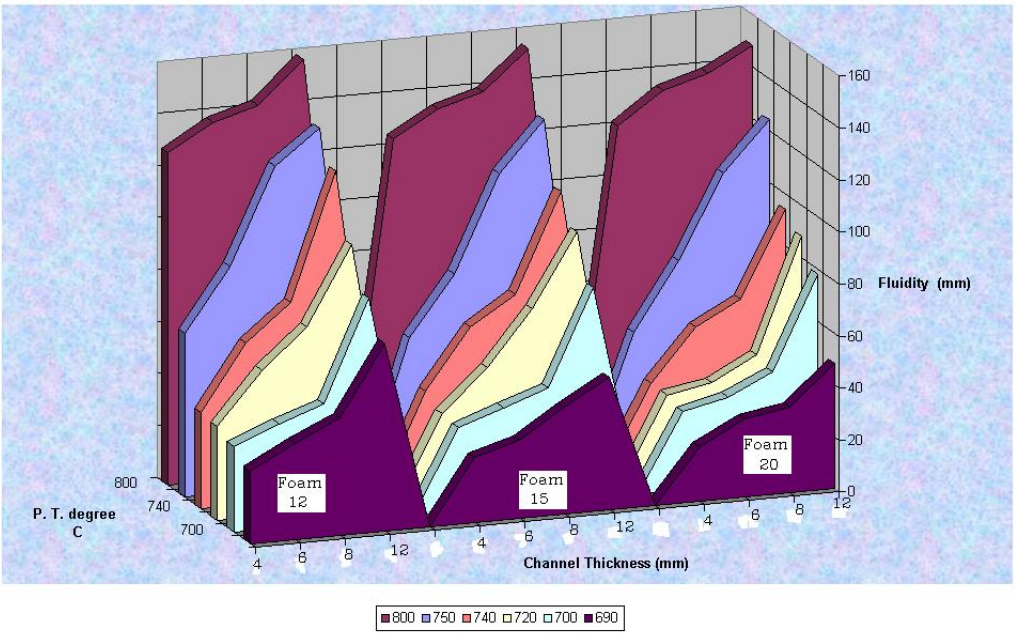


Fig. 7 Effects of foam density on fluidity measurement.

EMPIRICAL EQUATIONS

It was suggested to construct an empirical equations from the data obtained of the fluidity test. They demonstrate the relationship between the associated variables that affecting the LFC process, which examined in this work. There are two group equations, one for linear relation, and the other for non-linear relation. The pouring temperature is the depended variable that required to be calculated for pre-design samples (minimum channel thickness and the related length). The minimum pouring temperature is the desired parameter in the foundries to minimize the consumption of the power required to melt the metal and oxidation of the molten metal.

Therefore, that, multiple linear regressions for some variables associated with fluidity parameter of experimental test:

$$f\,(T, t, L, \rho) = 0 \qquad \text{eq. (1)}$$

Where:
T: minimum pouring temperature (ºC)
t: the smallest thickness in the sample section (mm)
L: the length of the smallest section (mm)
ρ: The foam density (Kg/m^3)

$$T = f\,(t, L, \rho) \qquad \text{eq. (2)}$$

Linear relation with the effect of foam density

The last equation (2) modified for linear relationship between the related variables. Therefore:

$$T = a_0 + a_1\, t + a_2\, L + a_3\, \rho \qquad \text{eq. (3)}$$

Alternatively, as a matrix form:

$$T = a_0 + \sum a_i\, x_i \qquad \text{eq. (4)}$$

Where, “i” is the repeated of the experimental tests.
The best values of (a0, a_1, a_2, a_3) are determined by setting up the sum of squares of residual error (S_r).

$$S_r = \sum (T_i - a_0 - a_1 t_i - a_2 L_i - a_3 \rho i)^2 = \min. \qquad \text{eq. (5)}$$

$$\delta S_r / \delta a_0 = -2 \sum (T_i - a_0 - a_1 t_i - a_2 L_i - a_3 \rho i) = 0 \qquad \text{eq. (6)}$$

$$\delta Sr / \delta a_1 = -2 \sum ((Ti - a_0 - a_1 t_i - a_2 L_i - a_3 \rho i) \times t_{i)} = 0 \qquad \text{eq. (7)}$$

$$\delta S_r / \delta a_2 = -2 \sum ((T_i - a_0 - a_1 t_i - a_2 L_i - a_3 \rho i) \times Li) = 0 \qquad \text{eq. (8)}$$

$$\delta S_r / \delta a_3 = -2 \sum ((T_i - a_0 - a_1 t_i - a_2 L_i - a_3 \rho i) \times \rho i) = 0 \qquad \text{eq. (9)}$$

Alternatively:

$$n\, a_0 + \sum a_1\, t_i + \sum a_2 L_i + \sum a_3\, \rho_i = \sum T_i \qquad \text{eq. (10)}$$

$$\sum a_0\, t_i + \sum a_1\, t^2_i + \sum a2\, L_i\, ti + \sum a_3\, \rho_i\, ti = \sum Ti\, ti \qquad \text{eq. (11)}$$

$$\sum a_0\, Li + \sum a_1\, t_i\, Li + \sum a_2 L^2_i + \sum a_3\, \rho_i\, L_i = \sum T_i\, Li \qquad \text{eq. (12)}$$

$$\sum a_0\, \rho_i + \sum a_1\, t_i\, \rho_i + \sum a_2 L_i\, \rho_i + \sum a_3 \rho^2_i = \sum T_i\, \rho_i \qquad \text{eq. (13)}$$

In matrix form:

$$[A]\, \underline{a} = \underline{b} \qquad \text{eq. (14)}$$

Where:

$$[A] = \begin{pmatrix} n & \sum ti & \sum Li & \sum \rho i \\ \sum ti & \sum t^2 i & \sum ti\, Li & \sum ti\, \rho i \\ \sum Li & \sum Liti & \sum L^2 i & \sum Li\, \rho i \\ \sum \rho i & \sum \rho i\, ti & \sum \rho i\, Li & \sum \rho^2 i \end{pmatrix}$$

$$\underline{a} = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} \qquad \underline{b} = \begin{pmatrix} \sum Ti \\ \sum Ti\, ti \\ \sum Ti\, Li \\ \sum Ti\, \rho i \end{pmatrix}$$

And n is the number of repeated tests.
To solve the matrix to find (a'_s) values …………multiple $[A]^{-1}$

$$[A]^{-1} [A]\, \underline{a} = [A]^{-1}\, \underline{b} \qquad \text{eq. (15)}$$

Therefore:

$$\underline{a} = [A]^{-1}\, \underline{b} \qquad \text{eq. (16)}$$

From **Table 3,** substitute the data in the matrix;
The matrix [A] and b will be:

$$[A] = \begin{pmatrix} 72 & 540 & 5409 & 1128 \\ 540 & 4680 & 44680 & 8460 \\ 5409 & 44680 & 522247 & 83470 \\ 1128 & 8460 & 83470 & 18456 \end{pmatrix} , \quad \underline{b} = \begin{pmatrix} 52800 \\ 396000 \\ 4053330 \\ 827200 \end{pmatrix}$$

By using eq. (16) the constant will be:

$a_0 = 682, a1 = -6.51, a2 = 1.0, a_3 = 1.62$

Substitute (a'$_s$) values in eq. (3) therefore the linear relationship of the related variables will be;

T=682 -6.51 t +F + 1.62 ρ eq. (17)

<u>Linear relation without the effect of foam density</u>

In this case the foam density will be fixed, therefore the eq. (3) modified to:

$T = a_0 + a_1 t + a_2 L$ eq. (18)

Moreover, this equation will be repeated for three-foam density.

1. while the foam density is (12 Kg/m^3), by the same procedure the matrix [A] and b will be;

$$[A] = \begin{pmatrix} 24 & 180 & 1965 \\ 180 & 1560 & 16152 \\ 1965 & 16152 & 198481 \end{pmatrix} , \quad \underline{\mathbf{b}} = \begin{pmatrix} 17600 \\ 132000 \\ 1469750 \end{pmatrix}$$

$a_0 = 701 \qquad a_1 = -6.9 \qquad a_2 = 1.0$

Therefore eq. (18) will be;

T=701 -6.9 t + F eq. (19)

2. The foam density equal to (15 Kg/m^3) and (20 Kg/m^3); by the same procedure respectively eq. (18) will be;

T=709 -6.7 t + F eq. (20)

T=712 -6 t + F eq. (21)

Non-linear relation with the effect of foam density

It was suggested the relation between the variables associated with LFC process as shown below;

$$T = a_0 + a_1F^3 + a_2 F^2 + a_3 F + a_4 t^2 + a_5 t + a_6 \rho \qquad \text{eq. (22)}$$

By the same procedure, the dimension of the matrix is (7×7).

$$[A]=\begin{pmatrix} 72 & 5.9\times10^{7} & 5.2\times10^{5} & 5409 & 4680 & 540 & 1128 \\ 5.9\times10^{7} & 1.2\times10^{14} & 9.5\times10^{11} & 7.3\times10^{9} & 5.3\times10^{9} & 5.3\times10^{8} & 9\times10^{8} \\ 5.2\times10^{5} & 9.5\times10^{11} & 7.3\times10^{9} & 5.9\times10^{7} & 4.4\times10^{7} & 4.5\times10^{6} & 8\times10^{6} \\ 5409 & 7.3\times10^{9} & 5.9\times10^{7} & 5.2\times10^{5} & 4.2\times10^{5} & 44680 & 83470 \\ 4680 & 5.3\times10^{9} & 4.4\times10^{7} & 4.2\times10^{5} & 4.7\times10^{5} & 45360 & 73320 \\ 540 & 5.3\times10^{8} & 4.5\times10^{6} & 44680 & 45360 & 4680 & 8460 \\ 1128 & 9\times10^{8} & 8\times10^{6} & 83470 & 73320 & 8460 & 18456 \end{pmatrix}$$

$$\underline{b} = \begin{pmatrix} 52800 \\ 4.5\times10^{10} \\ 4\times10^{8} \\ 4\times10^{6} \\ 3.4\times10^{6} \\ 396000 \\ 827200 \end{pmatrix}$$

It was used Gauss-Seidle Method to solve the matrix for finding **a**'s.
Therefore the constant **a'**s are:

a$_0$ = 776, **a**$_1$ = 1.2× 10^{-4}, **a**$_2$ = - 0.002, **a**$_3$ = - 0.25, **a**$_4$ = 1.87**a**$_5$ = - 85.6, **a**$_6$ = 25.3

The empirical equation for this case is:

$$\mathbf{T = 776 + 1.2\times10^{-4\ F3} - 0.002\ F^2 - 0.25\ F + 1.87\ t^2 - 85.6\ t + 25.3\ \rho} \qquad \text{eq. (23)}$$

CHEMICAL COMPOSITION

Many samples were taken from the castings that produced with LFC process to analyze the chemical composition. These samples were cut from the castings that were produced at the foundry of the State Company for Electrical Industries during the fluidity measurement tests. The chemical composition analysis was done in the Central Quality Control Office at Nasser State Company for Mechanical Industries. The average results of tests are shown in **Table 4.**

Table 4 Chemical composition of the alloy is used in this work.

Chemical Composition of the Alloy in w_t %											
Elements	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**	**Ni**	**Sn**	**Al**	**Others**
	8.59	**1.29**	**1.59**	**0.12**	**.066**	**.737**	**.026**	**.07**	**.01**	**87.48**	**0.02**

MECHANICAL PROPERTIES TESTS

Tensile tests

The tension specimens cast with pouring temperature (**720**°C) to size in sand casting without chills, the dimensions of specimens used in this test prepared according to the ASTM B 26/B 26M – 88. There were four groups of samples used in this test, one of them cast in common sand casting, and the others in LFC process the difference between them were in the foam density. Each group had two sets the difference between them was in thickness only; these thicknesses were (4.1, 2.2 mm), although of the same material and process there are variation in the results between two thicknesses for each group because of the residual stresses due to the machining of cutting the samples. The velocity test was (**0.5** mm/min.).

From this test, ultimate tensile stress, yield stress (proof stress), and elongation were obtained. The results are shown in the **Table 5**.

Table 5 Mechanical properties obtained from tensile tests.

process	***UTS (MPa)***		***Y.P (MPa)***		***Elongation %***	
	Thickness (mm)		Thickness (mm)		Thickness (mm)	
	2.2	**4.1**	**2.2**	**4.1**	**2.2**	**4.1**
Common Casting	**145**	**152**	**92**	**97**	**1.2**	**1.4**
LFC 12kg/m³	**125**	**142**	**86**	**93**	**1.5**	**1.7**
LFC 15kg/m³	**118**	**139**	**80**	**91**	**1.6**	**1.9**
LFC 20kg/m³	**112**	**137**	**74**	**86**	**1.6**	**1.9**
STM (328 alloy)	**170**		**95**		**1.0**	

Hardness tests

Hardness is being a macroscopic property and a measure of the resistance to indentation. This test was done by using (**Vickers Hardness**).
The magnitude of the load was exerted to the specimen (0.5 kg); the results were calculated by this equation: $VHN = 1.854\ P / L^2$
Where; P= applied load, L =the average diagonals of the diamond indentation.
Two reading in each specimen were taken one (20×20 mm) and the second (10×10 mm) apart from the edge. The comparison results are recorded in **Table 6**

Table 6 Hardness tests

Process		Common Sand Casting	LFC Process with 12kg/m³	LFC Process with 15kg/m³	LFC Process with 20kg/m³	ASTM (328 alloy)
HV No.	M	**74**	**63**	**53**	**51**	**60**
	E	**75**	**64**	**54**	**52**	
HB No.	M	**67**	**58**	**49**	**48**	**55**
	E	**68**	**59**	**50**	**48**	

Where (HB) is equivalent to Brinell number, (10mm) ball and 500 kg load.
(M) 20×20 mm apart from the edge, and (E) 10×10 mm apart from the edge of specimen.

Impact tests

The Charpy V-notch test (simply supported beam test) was used to measure the impact strength test. The samples were prepared as the standardization of (ASTM-E 23). The results of the test are shown in **Table 7**.

Table 7 Charpy impact test

process	***Energy (kg.m)***
Common Sand Casting	**4.2**
LFC Process with 12kg/m³ Foam density	**3.7**
LFC Process with 15kg/m³ Foam density	**3.6**
LFC Process with 20kg/m³ Foam density	**3.5**

MICROSTRUCTURES

The structure of a casting is in the first instance a function of alloy composition and casting geometry. It is also sensitive to measure of variation in cooling rate within the mold. This test had done using available equipments in Production and Metallurgy Engineering Department at the University of Technology. The samples were cut from the strip. The strip dimension is (2, 5, 20 cm) that cast with three different foam density as a pattern in LFC process and one another cast by common sand casting. The samples had prepared by grinded, polished, and etched with (HF) 2% and (H_2O) 98% before the photomicrographs were taken. The photomicrographs of microstructure are shown in **Fiq. 8**

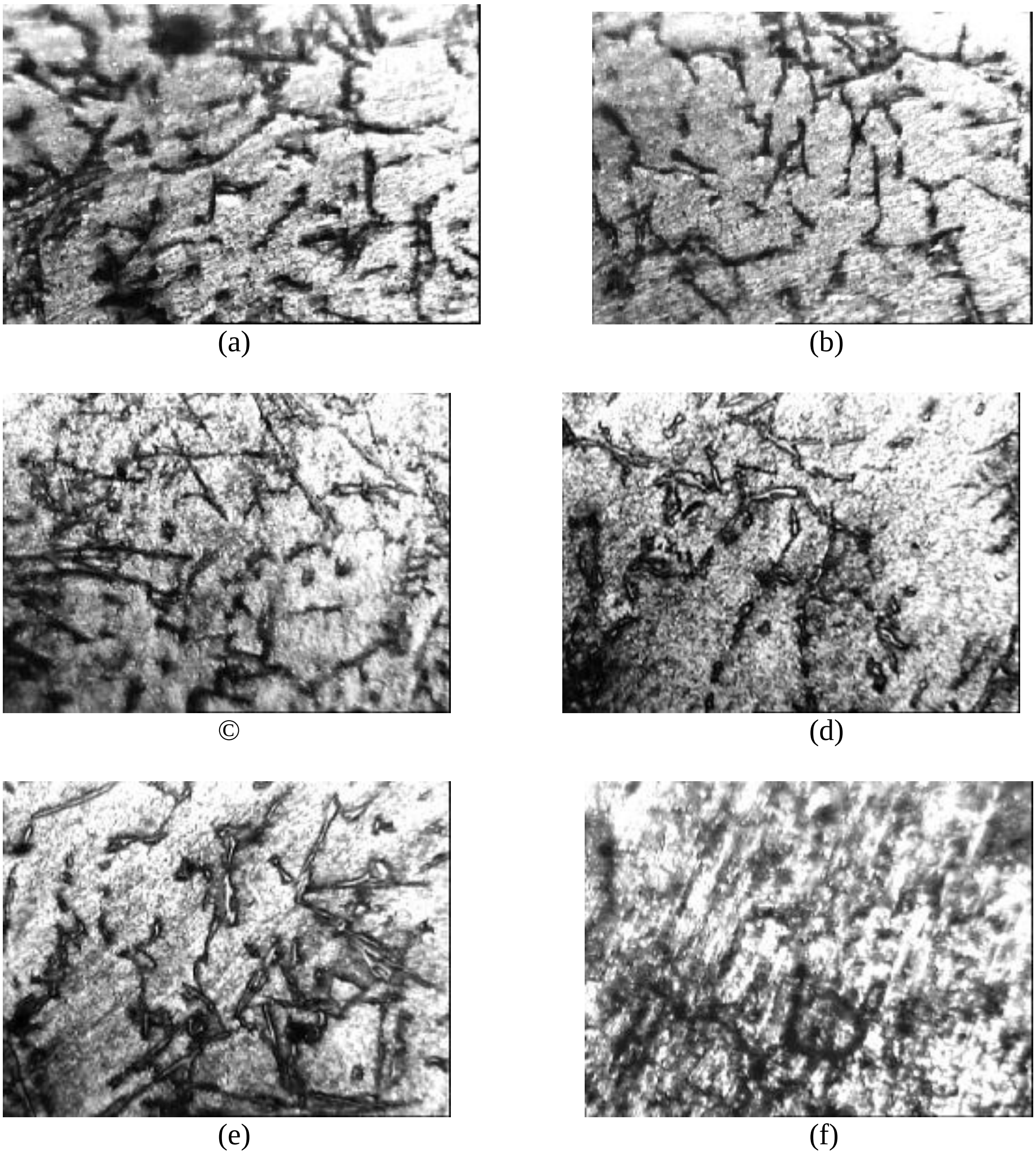


Fig. 8 Photomicrographs showing the microstructures of Al-Si alloy (a), (b) common sand casting. (c), (d), (e), (f) LFC process x500

In **figures (8-a, and 8- b)** are showing the specimen for common sand casting. It shows regular structure of Al-Si alloy.

In **figure (8-a)** shows clear observation of the segregation of the eutectic silicon in the portion near the edge due to the high cooling rate.

Figures (8- c, d, e, f) show the microstructures of the castings that produced by LFC process. The darker area of the micrograph of these figures contains more silicon particles, indicating the high silicon content.

Figures (8 – c and d) show the microstructures of the casting used LFC process with foam density of (**12** kg/m³); the **figure (8- c)** is for the edge portion and **figure (8- d**) of the middle portion specimen of LFC process. These two figures show less segregation and less microporosity as was expected than **figures (8- e and f)** which were used foam densities (**15, 20** kg/m³) respectively because of more Pyrolysis products.

CONCLUSIONS

Based on the experimental investigation of the mechanism of the LFC process, the following conclusions can be drawn from this work:

- Fluidity is affected by foam density, increasing foam density decreasing fluidity because of the combined result of molten metal front energy loss and an increase in backpressure from decomposition products.
- Empirical formulas were obtained to calculate minimum pouring temperature for a specific thickness section and its length with using specified pattern foam density. The first formula based on linearity relation between variables and the second as a power relation. The first formula gives good results while checking some data obtained from this experimental works.

$$\mathbf{T=682-6.51t+F+1.62\rho}$$

$$\mathbf{T = 776 + 1.2\times10^{-4}\ F^{3} - 0.002\ F^{2} - 0.25\ F + 1.87\ t^{2} - 85.6\ t + 25.3\ \rho}$$

- In this work, examination was done on the feasibility of using Al-Si alloys in the LFC process, and the experimental tests indicated that this alloys have similar castability with traditional sand casting.
- The microstructures of the final castings were examined, and the photomicrographs show little different between the castings produced by the traditional sand casting and LFC process.
- The grain size particles of microstructures are fluctuated between large and small size related with the location of it, if it is near the edge or in the middle of the casting. Fine grain sizes locate near the mold wall due to the high cooling rate.
- The mechanical properties tests were done on the castings produced with LFC process and that with the common sand casting. The tests gave good results and agreements with standardization of the nearest alloy. The effect of the foam density is relatively little in some cases on the mechanical properties, increasing foam density decreasing the mechanical properties. The percentage differences between the two processes range from (4% to 31%).

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SYMBOLS

EPS: Expanded Polystyrene
HB: Brinell number
L: The length of the smallest section (mm)
LFC: Lost-Foam Casting
T: Minimum pouring temperature (°C)
t: The smallest thickness in the sample(mm)
UTS: Ultimate Tensile Stress
VHN: Vickers Hardness number
Y.P: Yield Point
ρ: The foam density (Kg/m^3)