Effect of Superheating on Properties of Aluminium-Silicon Castings

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Abstract

This paper indicated that the strength and hardness of Al-Si alloys are influenced slightly by superheating and Si content. However the ductility (δ) is affected markedly by pouring temperature (i.e. superheating) and Si content too. For the hypereutectic Al-Si alloy the pouring temperature must be as minimum as possible to obtain the best properties. The Si segregation is influenced also by the Si content.

Introduction

Al-Si alloys are widely used in practice especially in automobile industry. This is due to its good properties, such as castability, low coefficient of thermal expansion, weldability, corrosion resistance, machinability, wear resistance, and good sliding properties [1].

Good mechanical properties for Al-Si alloys can be achieved by grain refinement i.e. inoculating the molten metal with different kinds of inoculants. These inoculants improve and inhance the casting nucleation process for the primary grains and eutectic silicon. The used inoculants depend mainly on the refined phase. The α solid solution is refined with Ti and B, but the eutectic silicon is refined with Sr. On other hand the refining of primary silicon of hyper-eutectic Al-Si alloys is achieved by P. The La, Ce, Yt ...etc are also used for inhancing the nucleation process. Not only the inoculation of molten metal affects the solidification process but also the pouring temperature (i.e. superheating), rate of mould diffusivity, and melt composition [7-9].

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If the pouring temperature increases, the mould wall temperature is also increased. This leads to a decrease in the rate of cooling from the mould wall. In this case the molten alloy would grow into large particles [2]. At the same time, the between grain segregation increases too. Therefore, the mechanical properties are decreased. However, when the superheating decreases, the solidification rate increases. This will exhibits more cellular form i.e. the dendrites are less ramified, which facilitates better feeding [10] as shown in Figure (1). The fast solidification rate introduces also fine grain size due to the increased number of potential nucleants evolved with fewer amounts of eutectic phases. This leads to an improve in the casting properties [9,11,12]. The solute undercooling (constitutional undercooling) is essential for the survival and growth of the nucleated equiaxial grains [9]. The relation between superheating (ΔT) and number of grains (N) per unit area is shown in Figure(2) [13]. The fine grain structure [i.e. great number of grains N] are achieved at smallest superheating [point 1&2]. As the value of superheating increases the grain size increases too [i.e. number of grains decreases] and the structure coarser till a definite superheating ΔT_{kr} [point 3]. At higher superheating over ΔT_{kr} the number of grains may increase [point 4] only if there are sufficient number of nuclei are present in the melt. The value of T_{kr} is influenced by the physical properties of the casting material [i.e. latent heat, thermal conductivity, melting point......etc].

The change of the alloy composition affects the solidification range (ΔT), additionally increasing the solidification range increases the size of the mushy zone [14], which increases the solidification time and decreases the porosity. This is may be due to a longer time available for interdendritic flow but on other hand decreases the mechanical properties due to the evolved coarse grains.

The Al-Si alloys are widely used in practice, and the controlling of the value of superheat before pouring is very important to achieve the required mechanical properties and surface finishing of castings.

Therefore this paper defines the relation between the superheating and the Al-Si alloys properties.

Experimental procedure:

This investigation emphasizes the effect of superheating on the properties of Al-Si alloys. This occurred in the following steps.

Materials:

Commercial Al-Si alloys were used. The chemical analysis are given in Table1.

Table (1): chemical composition of Al-Si alloys.

Al-Si alloy	Si %	Cu %	Mg %	Fe %	Mn %	Zn %	Pb %	Al %
Al-Si 7 %	7.00	0.08	0.09	0.40	0.21	0.04	0.01	rest
Al-Si 12 %	12.60	0.05	0.07	0.45	0.22	0.04	0.01	rest
Al-Si 17 %	17.45	0.03	0.04	0.40	0.20	0.04	0.01	rest

The raw materials used were in the form of virgin ingots supplied from Nagaa Hammady Aluminium Works.

Melting Procedure:

The melting process was achieved in a small potan gas crucible furnace of 2 Kgs molten aluminum capacity. Special precaution were taken into consideration to avoid the casting defects. A3% coveral 11 is used to cover the surface of molten metal to protect the melt from oxidation. After melting the slag is carefully skimmed off, the degaser of 1% is used. This is to minimize the oxygen content in the melt and to avoid the formation of bubbles or pinholes. The value of superheating for each melt was monitored with Ni-NiCr thermocouple K type. The value of superheat i.e. temperature over liquidus temperature for all melts are 40 °C, 80 °C, 120 °C, and 160 °C.

Metallugraphic and mechanical properties:

The melt was poured in a metallic mould after the melting process, and after controlling the pouring temperature. From each casting specimens prepared for micrographic examination and mechanical properties. The 0.5% HF etchant was used for revealing the grain structure.

Results and discussion:

The results showed that the superheating affects the properties of Al-Si alloys especially for high silicon content castings.

The examined properties were σ_u , δ% and HB are given in table (2) and illustrated in Figures 3,4, and 5.

Figures 3 and 4 show a slight decrease for σ_u and HB as the superheating ΔT increases. At the same time σ_u and HB increases with the Si content. The casting ductility δ% not only influenced markedly as superheating increases, but also by increasing Si% content as shown from Figure (5).

Table (2): Effect of superheating [ΔT] on mechanical properties of Al-Si alloys.

Exp. No.	Si content	Pouring Temp. C°	Super Heating ΔTC°	Average Value of σ_u (MPa)	Average value of δ%	Average value of HB
1	Al-Si 7%	680	40	130	15.5	125
2		720	80	120	16.5	110
3		760	120	110.5	17	105
4		800	160	100	18.5	95
5	Al-Si 12%	620	40	150	8	147
6		660	80	150	12	145
7		700	120	140	14	135.5
8		740	160	110.5	16	105.5
9	Al-Si 17%	700	40	170	4	164
10		740	80	162	5.5	156
11		780	120	159	6	150
12		820	160	160	8	145

The changes in properties (σ_u and HB) are attributed to the dispersion strengthening by the primary β phase. On other hand δ is affected pronouncly by increasing the Si % content and the value of superheating ΔT i.e. Figure (5). This is due to the formation of coarse grains as a function of superheating beside the grain segregation for the Si% content as shown in Figure (6a, 6b) and Figure (7a,7b) where the Si content reached in some places in fracture to 26.97 % [Exp. 12].

The microstructure is influenced also markedly by the value of superheating (ΔT) as shown in Figures (8 a, b, c, d, e, f) where the samples with smaller superheating ΔT exhibits better (fine) microstructure which in turn affected the strength, at the same time increasing the Si % content decreases sharply the value of (δ).

The obtained results are attributed to the effect of superheating on the microstructure and in turn on the mechanical properties. The superheating affects on both the rate of heat flow from the casting and the mould, where the rate of heat flow becomes smaller at high superheating. This is due to the smaller evolved heat gradient in the casting and the mould wall. Also the superheating eliminate the formation of constitutional undercooling which has a great influence on the solidification process of all alloys.

The results obtained from this investigation show that, higher superheating exhibits coarser grains but, low superheating introduces fine grain structure as shown in Figure 8a,b. The same results were observed in Figure 8c,d and 8e,f. where the superheating leads to coarse primary silicon especially for hypereutectic alloy as shown in Figure 8c,d. This is due to the higher superheating which permits longer time for primary silicon formation. The formation of coarse a circular crystals reduces sharply the alloy ductility, also the silicon precipitates in large irregular shape which have an adverse influence on the mechanical properties. Therefore, the increase of σ_u with smaller superheating (Δ T) are due to the fine structure, as shown in Figures 3,4,5 and Figures 8a,c,e. On other hand the smaller value of σ_u is due to the formed coarser grain structure i.e. Figures 3,4,5 and Figure 8b,d,f.

Statistical study for results by using T-test :

T-test is a type of statistical tests that is used for if the hypothesis that the two normal populations have equal means or not. The real difference between the two results means that there is an improvement in the developed composition. This technique is utilized to test the hypothesis that the change of casting conditions (T_p and ΔT) affects the properties of cast (σ_u, δ% and HB) as the composition of Al-Si is changed.

In this part we compared the change in results obtained by changing casting conditions of Al-Si on the cast properties of Al-Si 12% and Al-Si 17% compared to that of Al-Si 7% as a base study. Table (3) shows a statistical verifications of experimental results.

Table (3): Statistical verification of the experimental results.

Properties	σ_u		δ%		**HB**	
The used aluminum alloys	**Al-Si 7% Al-Si 12.6%**	**Al-Si 7% Al-Si 17.6%**	**Al-Si 7% Al-Si 12.6%**	**Al-Si 7% Al-Si 17.6%**	**Al-Si 7% Al-Si 12.6%**	**Al-Si 7% Al-Si 17.6%**
|T|	**3.9686**	**11.81**	**4.81**	**21.23**	**4.92**	**12.04**
T	**1.94**	**1.94**	**1.94**	**1.94**	**1.94**	**1.94**
Statistical results	**All results indicate a real difference in all tests**					

All results are compared to the confidence limit of 95%. A detailed calculations are illustrated in appendix A.

Conclusions:

The statistical analysis using T-test verified the obtained experimental results therefore:-

1- the Al-Si castings strength and hardness are influenced slightly by increasing the superheating ΔT °C.

2- the Al-Si castings ductility increases as superheating decreases.

3- The Al-Si castings ductility is influenced markedly by Si content and superheating.

4- The segregation is significantly as affected the Si content increases.

5- The superheating must be small as possible for better mechanical properties especially for eutectic and hypereutectic Al-Si castings.

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Appendix:

- The average value of δ% for the Al-Si 7% and Al-Si 17.45%.

- Assume there is a difference between the two results.

- Enter two-tailed significance level : P=0.05

- Sample sizes:

n1=length(d1) n2=length(d2)

n1=4 n2=4

$$d1 = \begin{pmatrix} 18.5 \\ 17 \\ 16.5 \\ 15.5 \end{pmatrix} \qquad d2 = \begin{pmatrix} 8 \\ 6 \\ 5.5 \\ 4 \end{pmatrix}$$

- Means:

m1=mean(d1) m2=mean(d2)

m1=19.875 m2=5.875

- Standard deviations:

c1=0,1..3 c2=0,1..3

$D1_{c1}=(d1_{c1})^2$ $D2_{c2}=(d2_{c2})^2$

$$S1 = \sqrt{\frac{\sum D1}{n1} - \left(\frac{\sum d1}{n1}\right)^2} \qquad S2 = \sqrt{\frac{\sum D2}{n2} - \left(\frac{\sum d2}{n2}\right)^2}$$

$S1=1.08253$ $S2=1.43069$

$$D1=\begin{Bmatrix}342.25\\289\\272.25\\240.25\end{Bmatrix}\qquad D2=\begin{Bmatrix}64\\36\\30.25\\16\end{Bmatrix}$$

- Degrees of freedom : $\phi = n1+n2-2$

$\phi = 6$

- Est. standard error of the difference :

$$S=\sqrt{\frac{S1^2+S2^2}{\phi}}$$

$S=0.73243$

- T Statistic :

$$t=\frac{m1-m2}{S}\sqrt{\frac{n1*n2}{n1+n2}} \qquad t=21.23927$$

- From tables at $P=0.05$ and $\phi = 6$ $T=1.94$
- Reject the null hypothesis if $|t| < T$. $|t|>T$

There is a real difference between the two results.

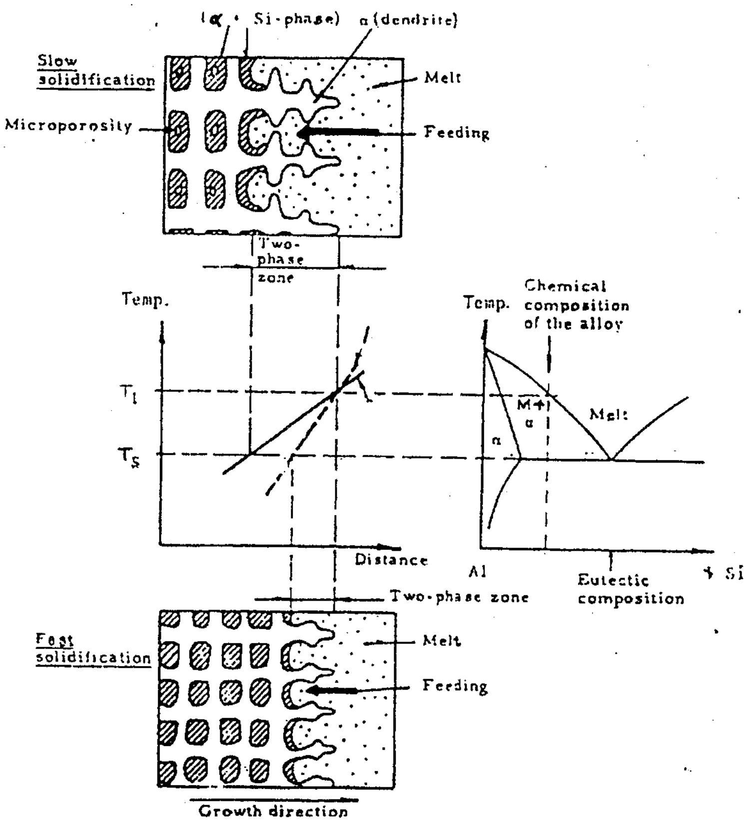

Figure (1) Schematic presentation of micro-feeding conditions at various solidification rates of hypoeutectic Al-Si alloys [10].

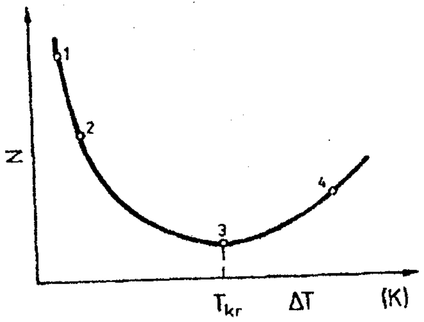

Figure (2) Effect of superheating ΔT on grain size

N= no. of grains/cm^2 - ΔT superheating

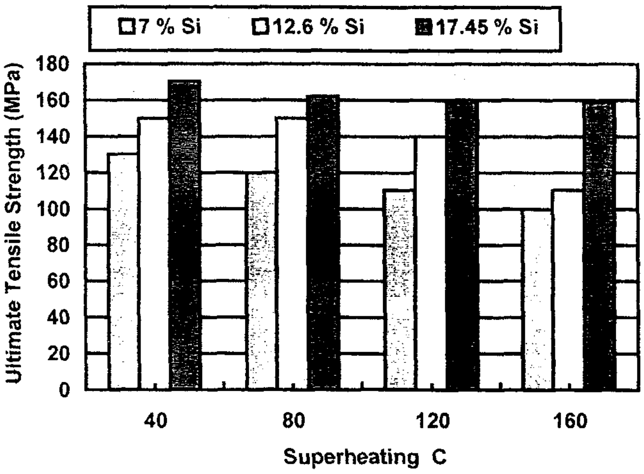

Figure (3) Effect of superheating (ΔT) on Ultimate tensile strength (σ_u)

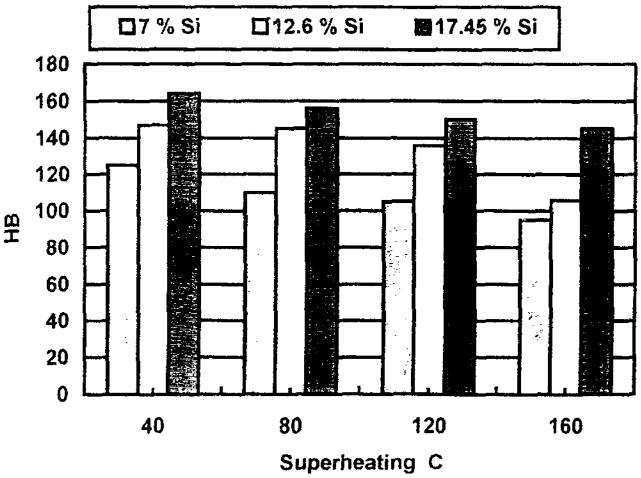

Figure (4) Effect of superheating (ΔT) on Hardness (HB)

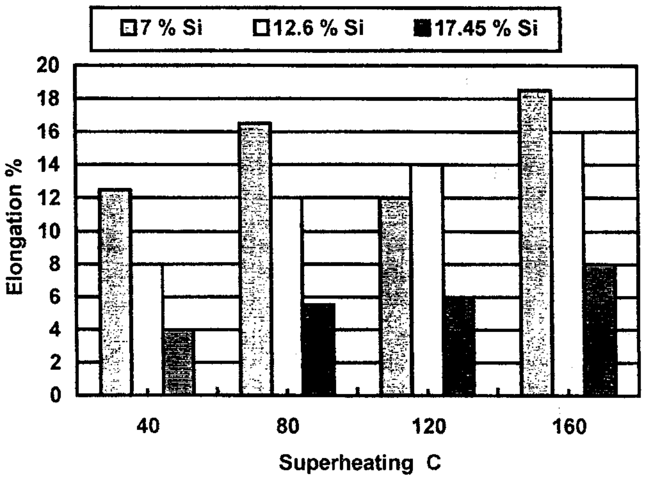

Figure (5) Effect of superheating (ΔT) on elongation % (δ)

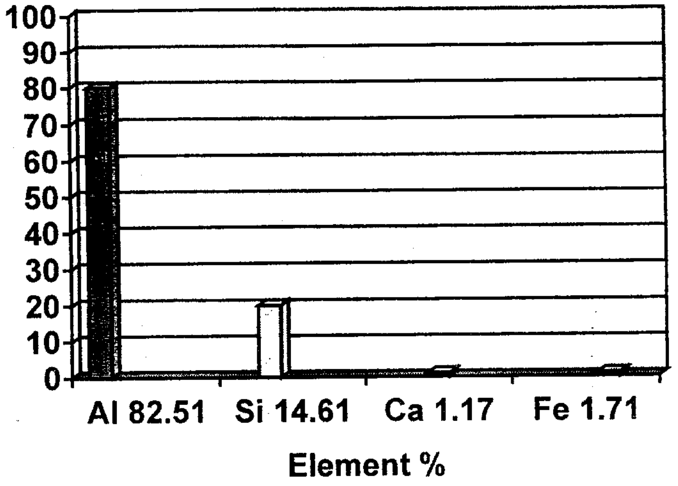

Figure (6a)

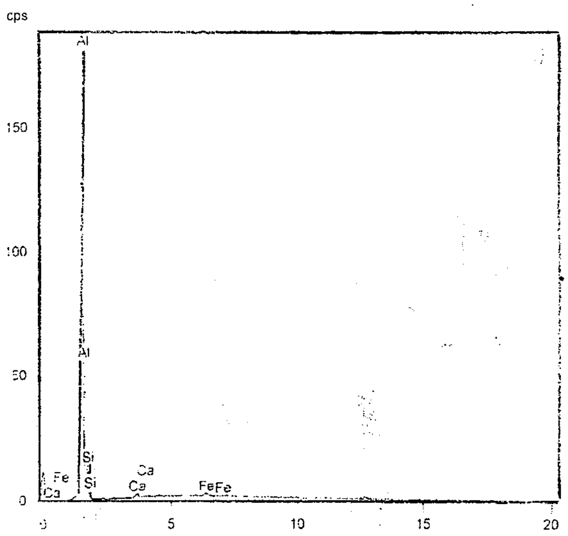

Figure (6b)

Figure (6 a.b) Spectrum microprobe analysis of the phases in the Al-Si 7% alloy [exp.4]

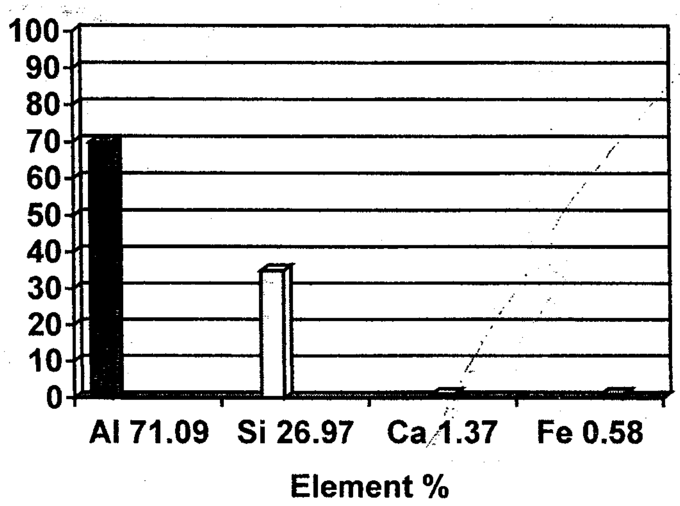

Figure (7a)

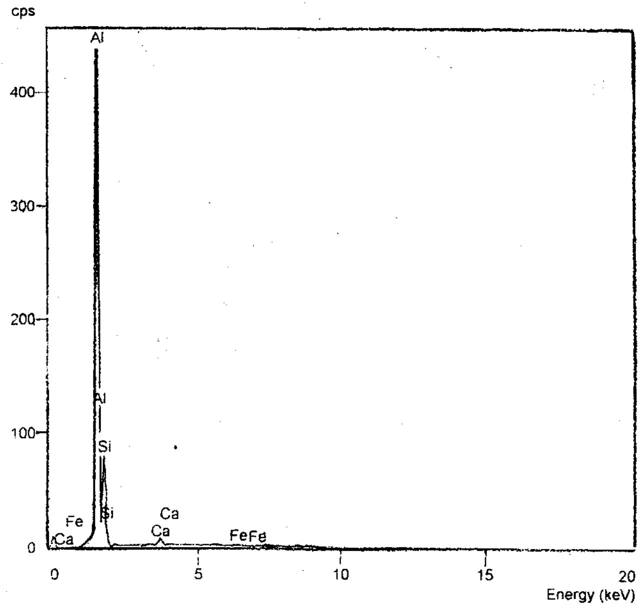

Figure (7b)

Figure (7 a,b) Spectrum microprobe analysis of the phases in the Al-Si 17.45% alloy [exp.9]

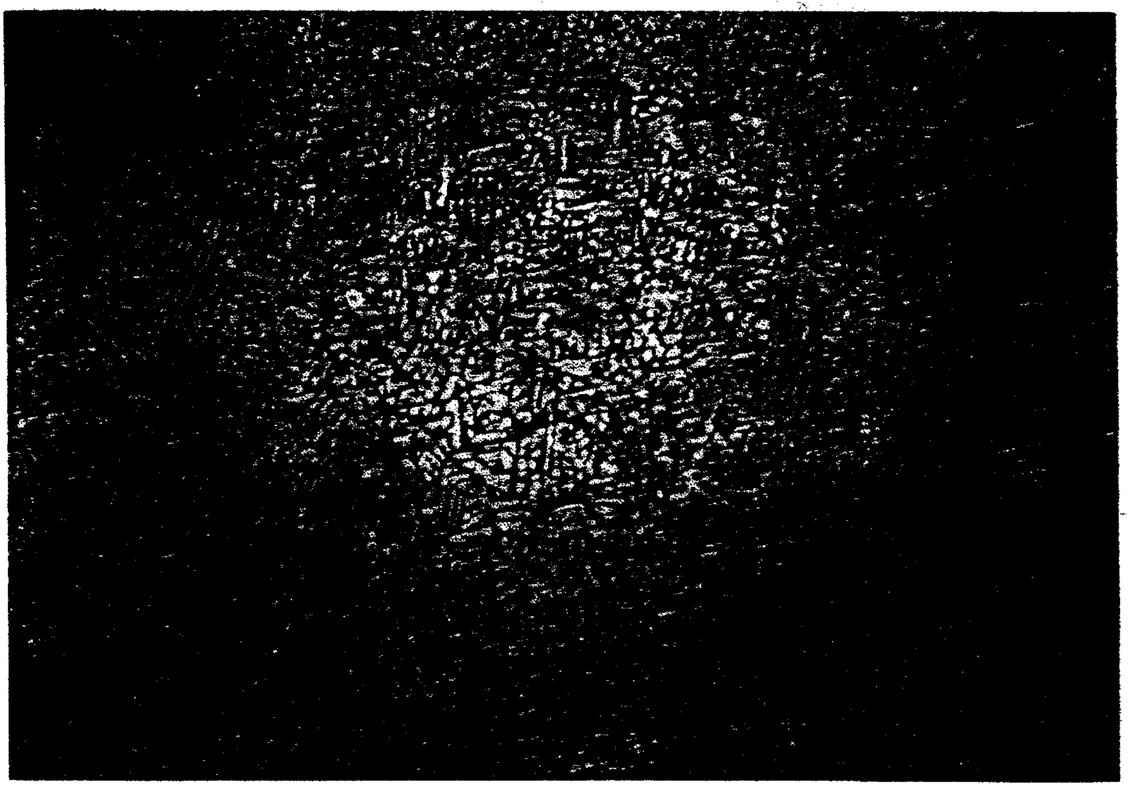

Figure (8a) × 100 [exp.1]

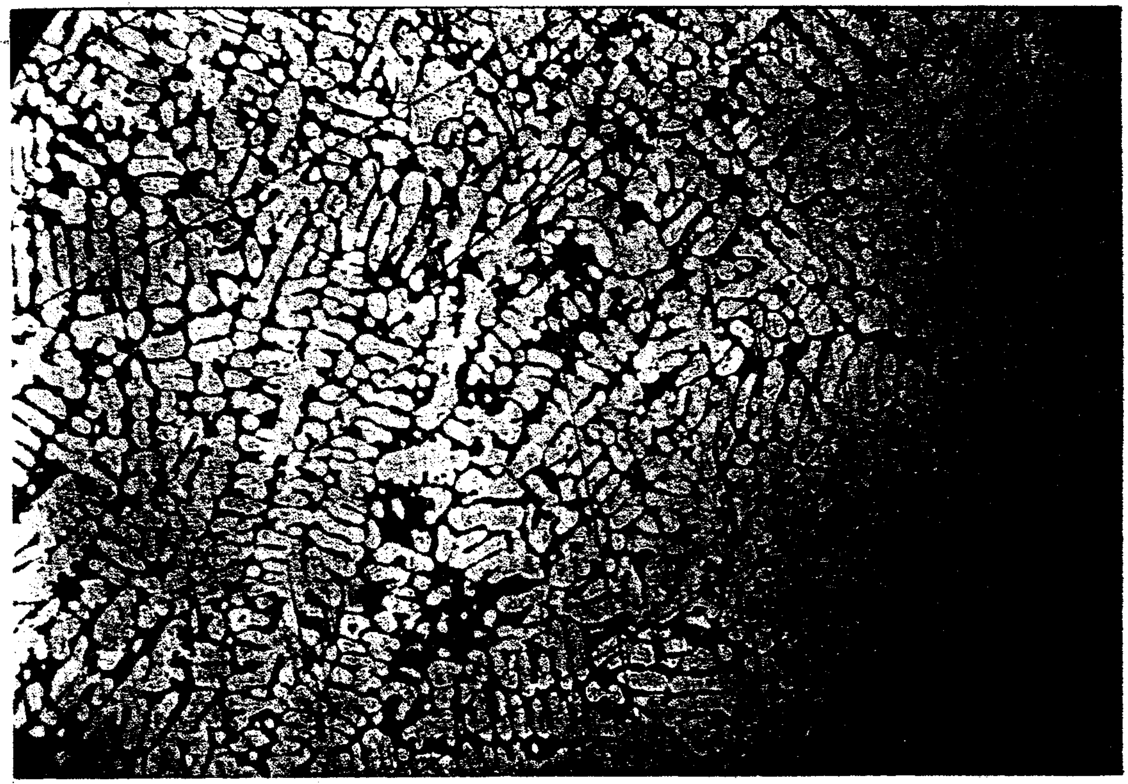

Figure (8b) × 100 [exp.4]

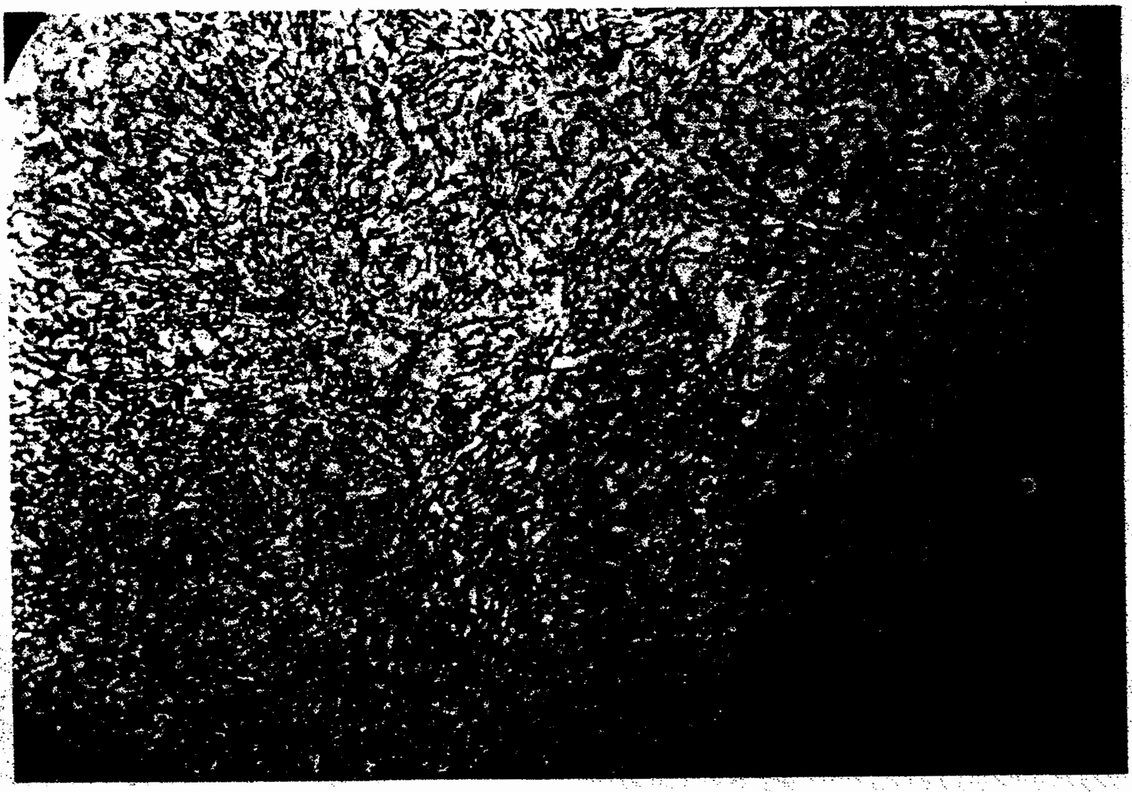

Figure (8c) × 100 [exp.5]

Figure (8d) × 100 [exp.8]

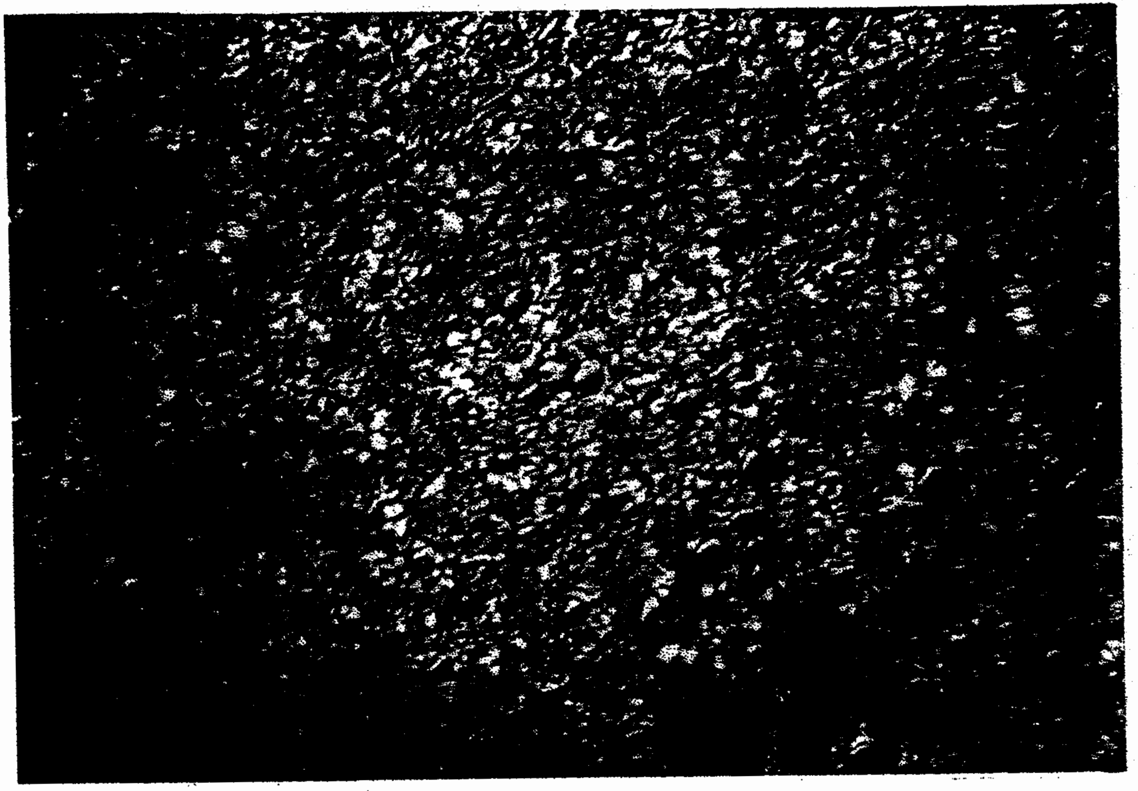

Figure (8e) × 100 [exp.9]

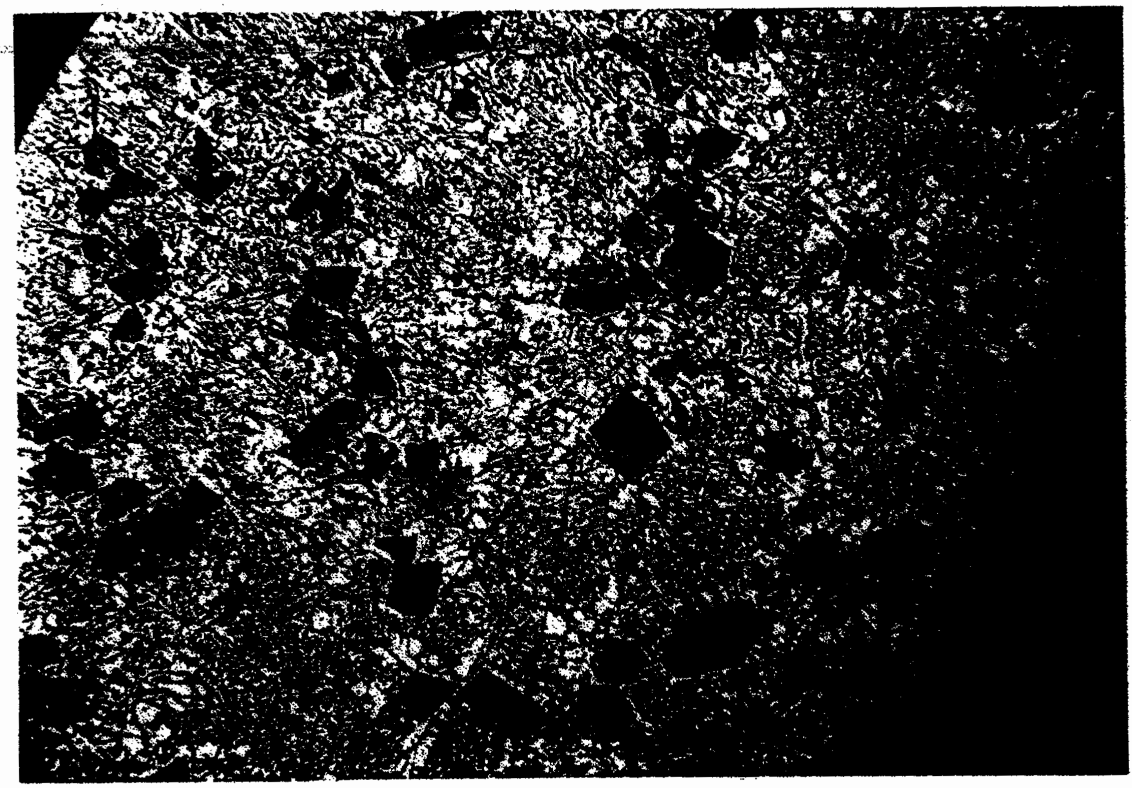

Figure (8f) × 100 [exp.12]

تأثير التسخين الفائق على خواص مسبوكات الألومنيوم سيليكون

ملخص

يدل البحث على أن المتانة والصلادة لسبائك الألومنيوم سيليكون تتأثر قليلاً بالتسخين الفائق ونسبة وجود السيليكون بينما تتأثر المطولية بشكل واضح بالتسخين الفائق ونسبة السيليكون أيضاً ، أما سبائك فوق اليوتكتيك للألومنيوم سيليكون فإن درجة حرارة الصب يجب أن تكون أقل ما يمكن للحصول على أفضل الخواص ، كما أن ترسيبات السيليكون تتأثر بنسبة وجوده.