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Effect of Cooling Rates and Rapidly Quenched on Al-Si Alloy

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ABSTRACT

Due to its unique properties, the material could be applicable in the automotive industry for the manufacture of exhaust valves, for wear parts, and probably as a material for selected aggressive chemical environments. The solidification behavior of the Al-80.5 % Si-19.5 (A), Al-79% Si21% (B) and Al-77.5 % Si-22.5 % (C) alloys at slowly cooling and Rapidly quenched are reported and discussed. The samples were characterized by X-ray diffraction to calculated lattice constant, optical microscopy and mechanically by (Tensile test, and Hardness) in order to evaluate the response of the heat treatment on the different starting microstructures and mechanical properties. It was found that the lattice parameters for all Si contents decreases with increasing Si content in the solid solution. All mineral compounds formed during hardening were examined by optical microscopy. The highest maximum tensile strength was 120 MPa in the sample Al-22.5Si (Slowly cooled) and 126MPa in the sample Al-22.5Si (rapidly quenched) in the same weight, and highest hardness was 77 HB in the sample Al-22.5Si (Slowly cooled), and 81 HB in the sample Al-22.5Si (rapidly quenched).

KEYWORDS: Casting; Aluminum alloys; Microstructure; XRD and Mechanical properties.

الخلاصة

يمكن إستغلال هذه المواد في صناعة السيارات نظراً لخواصها الفريدة حيث يمكن استعمالها في صناعة السيارات لتصنيع صمامات العوادم والأجزاء المعرضة للتآكل وربما يمكن إستعمالها كمادة لبعض البيئات السريعة التأثر الكيميائي. تم مناقشة نتائج عملية التصلب السريع والبطيء لسبيكة أ- (الألمنيوم 80.5%- السيليكون 19.5%) ب- سبيكة (الألمنيوم 79%- السيليكون 21%) جـ- سبيكة (الألمنيوم 77.5% - السيليكون 22.5%). تم فحص العينات بجهاز الـ XRD لحساب ثابت الشبيكة، والفحص المجهري والميكانيكي عن طريق فحص الشد والصلادة وذلك لتقييم إستجابة المعالجة الحرارية على البنى المجهرية والخواص الميكانيكية. وجد أن معاملات الشبيكة تتناقص مع زيادة محتوى السيليكون في المحلول الصلب. تم فحص جميع المركبات المعدنية المتكونة أثناء التصلب بواسطة المجهر الضوئي. كانت أعلى مقاومة شد هي 120 ميجا باسكال في العينة Al-22.5Si (تبريد بطيء) و126 ميجا باسكال في العينة Al-22.5Si (تبريد سريع) بنفس الوزن وكانت أعلى قيمة صلادة 77 HB في العينة Al-22.5Si (تبريد بطيء) و81HB في العينة Al-22.5Si (تبريد سريع).

INTRODUCTION

The modern world requires the use of light structural materials to improve fuel economy, energy consumption and emissions of gas in industrial application. The properties (low density, high strength stiffness to weight ratio, good formability and good corrosion resistance) make aluminum alloys an ideal material for the manufacturing of components for automotive and aerospace applications [1]. Aluminum-silicon base alloys are widely used in aerospace structural application and the automobile industry due to their low thermal expansion coefficient, high wear resistance and good cast ability [2]. Aluminum-Silicon (Al-Si) alloys are the most important of the Al alloys, these are classified in three groups: hypoeutectic (<11 wt. (%) Si), eutectic (11-13 wt. (%) Si), and hypereutectic (>13 wt. (%) Si). The hypereutectic alloys are attractive to the automotive industry and desirable for wear resistant applications, where high strength and low weight ratio are required [3].

The cooling rate during solidification is an important factor that determines the microstructure formation in castings and hence the mechanical properties of foundry alloys. In general, the enhanced cooling rate is used for the microstructure refinement of different foundry alloys, including widely spread Al-Si alloys [4].In addition to chemical composition, the structural and mechanical properties of alloys depend on many factors that act during solidification. Important factors are the structure of the melt, the crystallization rate, and the temperature gradient at the liquid–solid interface. As a rule these factors are varied simultaneously, giving rise to contradictory information on the structure and mechanical properties of Al–Si alloys [5]. The cooling rates for this process were estimated within the range of 105 to 106 Ks^{-1}, much faster than the conventional solidification rates which are 102 Ks^{-1} or less [6]. Since the introduction of rapid quenching of metallic melts by Duwez, a great variety of techniques have been developed to obtain alloys produced by rapid solidification. Although, the effects of rapid solidification vary widely from system to system, the major effects are: (i) Decreased in grain size, (ii) Increased in chemical homogeneity, (iii) Extension of solid solubility limits, (iv) Creation of metastable crystalline phases, and (v) Formation of metallic glasses [7].

EXPERIMENTAL PROCEDURE:

Six specimens of (Al-Si) alloy were melted in different proportions as shown in table 1 using a crucible made from graphite in gas furnace which was adjusted at 735°C. The obtained material was poured into a preheated to 300°C cast iron metal mold because it has about the best thermal fatigue resistance and that best in aerospace industry, the term vacuum casting likely will be interpreted as the use of a vacuum during the melting of metal material that available because contain low losses of alloying elements by oxidation, very close compositional tolerances, precise temperature control, low level of environmental pollution, removal of undesired trace elements with high vapor pressure and removal of dissolved gasses, such as hydrogen and nitrogen. To study the influences of cooling rate a three different composition samples were quenched in cooled water by ice.

Table 1. Weight fractions associated to different elements present in the Al-Si specimens

Specimen No.	Al%	Si%	
1.	80.5	19.5	Slowly cooled
2.	79	21	Slowly cooled
3.	77.5	22.5	Slowly cooled
4.	80.5	19.5	Rapidly quenched
5.	79	21	Rapidly quenched
6.	77.5	22.5	Rapidly quenched

X-Ray diffraction

X-ray diffraction (XRD) technique was used for additional identification of the phases present in investigated alloys. X-rays produced by Empyrean Cu anode tube operating at 45 kV and 40 mA between 25-100 degrees run at a scan rate of 0.033deg/s.

Optical Microscopy

Microstructural features were observed using Olympus optical microscope at a magnification of 100X and 200X on a polished surface of thealloys. Polishing was performed with graded abrasive (180,220, 320, 400, 600, 800, 1000, 1200, and 1500) grit followed by diamond paste of 1.5 and I micron. Etching was performed with Keller’s solution (1 volume part of hydrofluoric acid (48%), 1.5 volume part of hydrochloric acid, 2.5 volume parts of nitric acid and 95 volume parts of water) for about 30-50s in order to reveal the microstructure with grain boundaries . Photomicrographs were shot by using 5mm Olympus camera. The area of the grey silicon grains before and after annealing were measured using Reichert optical microscope at a magnification of 100X on polished surfaces of the alloys.

Tensile strength Test

The tensile properties of the alloy were studied by performing a test employing the universal testing machine (Model: WP 310 Materials testing, 50kN, Germany). Sample dimensions were taken in accordance with ASTM B-557 [9]. For a uniaxial tensile test, the Young’s modulus (E) is defined as the ratio between stress and strain during the elastic region. For metallic specimens, it is given as:

$$E = \frac{P}{A \times \varepsilon} \qquad (1)$$

Where: P is the load measured during the elastic region through a load cell;A is the cross-sectional area of the specimen; ε is the elastic strain.

The Brinell hardness Test

The Brinell harness number is attained by dividing the applied load by the indentation surface area. When the indentation is drawn, two diameters of the impression, d_1 and d_2, were measured using a special microscope with a calibrated graticule and then the average values were calculated as shown in the following equation (2) and shown in Figure 1.

$$\text{BHN} = \frac{\text{p}}{\frac{\pi \text{D}}{2}[D-\sqrt{D2}-d2]} \qquad (2)$$

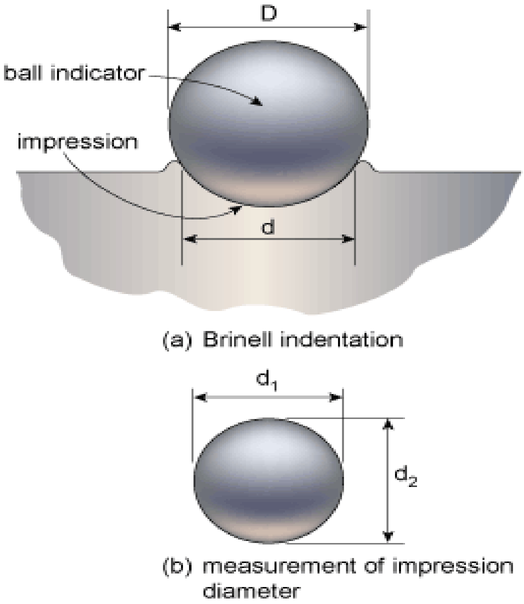

Figure 1. Sample of Brinell hardness Test.

Where:
P is the test load [kg], D is the diameter of the ball [mm], d is the average impression diameter of indentation [mm].

RESULTS AND DISCUSSION

X- Ray diffraction

X-ray diffraction (XRD) is widely used to examine the, lattice constant (a) of various alloy appears in Table 1, Figure 2 that determine the amount of retained-Si upon rapid quenching, the lattice parameter of α-Al phase was determined using Bragg’s formula for both slowly cooling and rapidly quenched. The lattice parameters for all Si contents are given in table 1. The lattice parameter of α-Al phase decreases with increasing Si content in the solid solution. The quantity of decrease has been detected via the closest distance of approach of the constitutional atoms that agree with Farah Tariq [8] and Orhan UZUN *et al*. [9] that mean all added Si amount were nearly solved in α-Al for each melt-spun Al-Si alloys. However, because of the very weak and broad Si reflections in the melt-spun ribbons, a certain Si amount could be lost in the background.

Table 1. The lattice constant of Al-Si alloy at (a) slowly cooled and (b) rapidly quenched.

Al-Si Slowly cooled		
Lattice constants		
Sample	a (Al)	a (Si)
A	5.4265	4.0469
B	5.4249	4.0474
C	5.4230	4.0469

Al-Si Rapidly quenched		
Lattice constants		
Sample	a (Al)	a (Si)
A	5.4249	4.0462
B	5.4235	4.0468
C	5.4198	4.0456

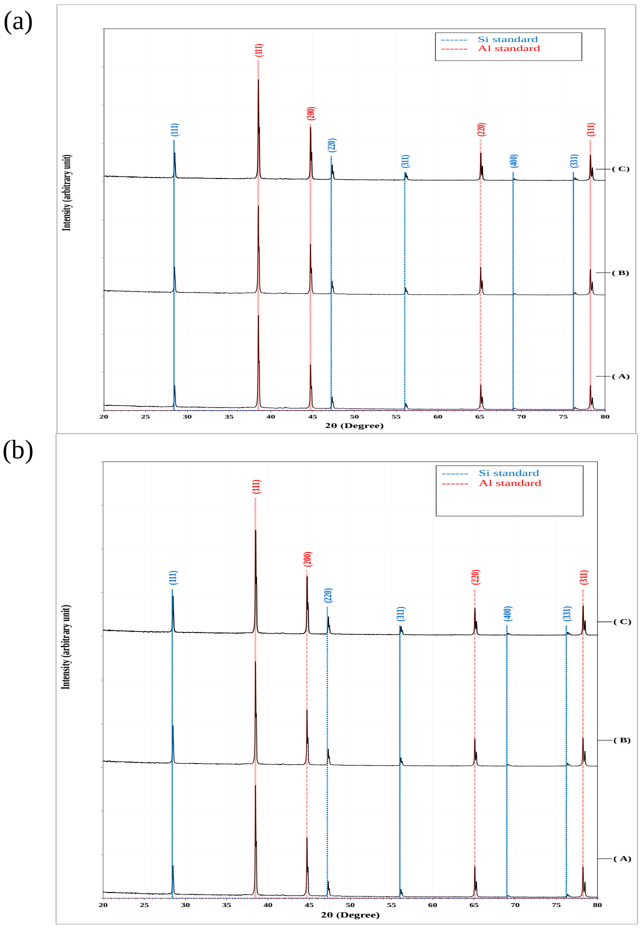

Figure 2. XRD pattern for (a) Al-Si alloy with slowly cooled, (b) Al-Si alloy with rapidly quenched.

Optical microscopy

Figure 3 shows the images taken by the optical microscopy of Al–Si alloys obtained by casting of levitated melts for 20.5 wt. %. The 20.5 wt. % Si alloy has an anomalous finest-grain eutectic structure and also that Si wt.

percentage in the Aluminum-Silicon alloys can be classified into three main classifications: - Hypoeutectic (<12 wt. % Si), Eutectic (12-13 wt % Si), and Hypereutectic (14-25 wt. % Si) [3].

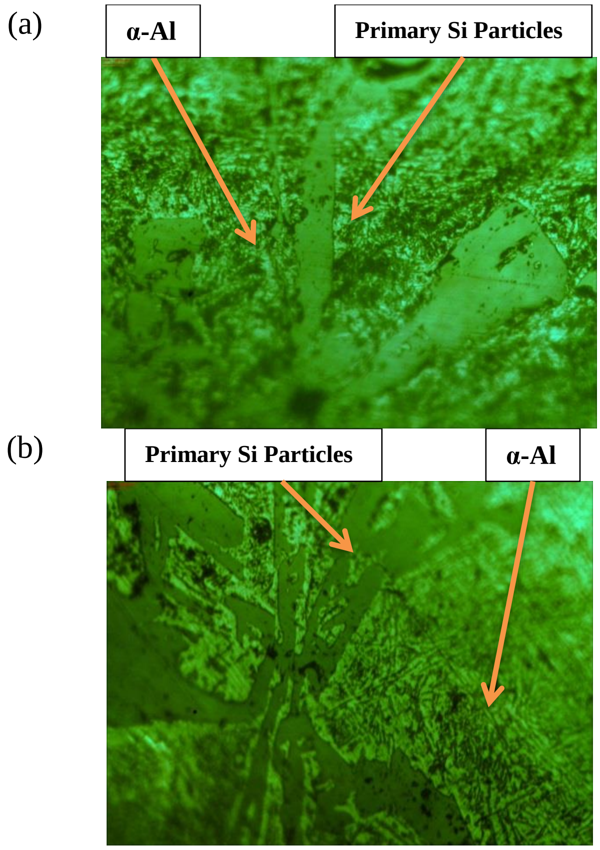

Figure 3. As received microstructure, (a) Al-Si alloy with slowly cooled, (b) Al-Si alloy with rapidly quenched.

Tensile Test

The results of the tensile strength are shown in Table 2, Figure 4 seen that the tensile strength increases proportionally. The highest UTS was 126 MPa, in sample 6 (Si content was 22.5% Si), this is due to the rapid cooling of the samples that agree with Suk Bong Kang *et.al* [2].

Table 2. Tensile Strength [Al-Si] of alloys at slowly cooled (S.c.) and rapidly quenched (R.q.).

Specimen No.	Al%	Si%		Tensile Strength (MPa)	E. %
1	80.5	19.5	S.c.	90	4.5
2	79	21	S.c.	104	5.2
3	77.5	22.5	S.c.	120	5.6
4	80.5	19.5	R.q.	95	5.4
5	79	21	R.q.	110	5.8
6	77.5	22.5	R.q.	126	6.5

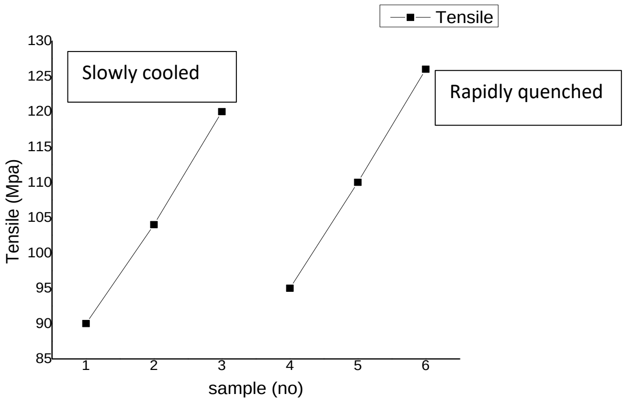

Figure 4. Curves are showing variation of Tensile Strength with sample no.

The Brinell hardness Test

The Hardness results shown in Table 3 and Figure 5, it increased proportionately with the increase in Si contents. The highest hardness value was 81 HB, in sample 3 (Si content was 22.5% Si) this may be due to increment of silicon amount which is hard precipitates which increased hardness of Al-Si alloy that agree with Farah Tariq [8] .

Table 3. Hardness test outcome.

Specimen No.	Al%	Si%		Hardness (HB)
1	80.5	19.5	S.c.	60
2	79	21	S.c.	67
3	77.5	22.5	S.c.	77
4	80.5	19.5	R.q.	64
5	79	21	R.q.	72
6	77.5	22.5	R.q.	81

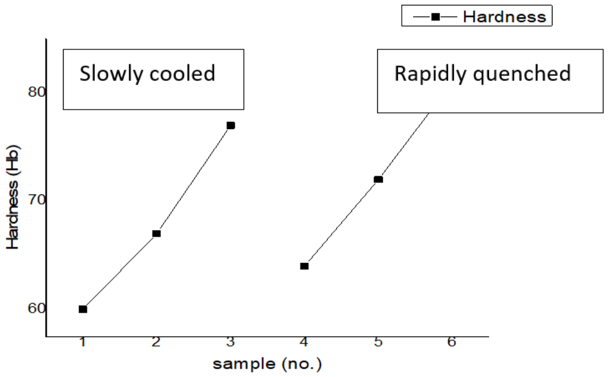

Figure 5. Curve showing variation of Hardness with sample no.

CONCLUSIONS

1. In this work, the Al-Si alloy (in wt %) was prepared at slowly cooling and rapidly quenched are reported.
2. The lattice parameters for all Si contents decreases with increasing Si content in the solid solution.
3. The highest maximum tensile strength (UTS) was 120 MPa in the sample Al-22.5Si (Slowly cooled) and 126MPa in the sample Al-22.5Si (rapidly quenched) in the same weight, and highest hardness was 77 HB in the sample Al-22.5Si, and 81 HB in the sample Al-22.5Si.

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