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# Effect of Sodium Chloride on Microstructure and Mechanical Properties of Al-Si alloy

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**ABSTRACT**

In this work, the effect of sodium chloride (NaCl) powder addition with different amounts on microstructure and mechanical properties of Al-12 wt. %Si alloy was investigated. In this technique, modification by NaCl was used because of its availability and low price comparing to other modifiers such as Sr and Sb. A 1000 °C as pouring temperature of molten alloy was used. The present results showed that there is a significant change in the mechanical properties and microstructure compared with unmodified alloy. The optimum properties were found by adding 0.5wt% NaCl to the alloy, and also the modification of microstructure alloy. Mechanical properties and microstructure of Al-12wt. %Si alloys that poured from 1000 °C with NaCl additives were compared with the corresponding alloys but at 800 °C pouring temperature, it is found that alloys poured from 1000 °C have best properties as compared with the same alloys poured from 800 °C.

**Keyword:** Al-Si alloy, Microstructure, Tensile Test, Hardness, NaCl.

## تأثير كلوريد الصوديوم على البنية المجهرية والخواص الميكانيكية لسبيكة Al-Si.

**الخلاصة:**

في هذا البحث تم دراسة تأثير إضافة كميات مختلفة من مسحوق كلوريد الصوديوم (NaCl) على البنية المجهرية والخواص الميكانيكية لسبيكة Al-12wt.%Si. في هذه الطريقة تم اجراء عملية التحوير بواسطة كلوريد الصوديوم وذلك لوفرته ولرخص ثمنه بالمقارنة مع المحورات الاخرى مثل السترونشيوم و الانتيمون. استخدمت درجة حرارة 1000 درجة مئوية لعملية الصهر وصب المنصهر من هذه الدرجة وذلك بسبب حدوث ذوبان المادة المضافة الى المنصهر والتي يعتقد ان الكلور سوف يتطاير كغاز تاركاً الصوديوم في السبيكة المذابة ليؤدي عمله. اظهرت النتائج المستحصلة بان هنالك تغييراً في الخواص الميكانيكية والبنية المجهرية بالمقارنة مع السبيكة غيرالمحورة. تم تحديد الاضافة التي تعطي خواص اعلى والتي كانت عند اضافة نسبة 0.5% من كلوريد الصوديوم الى السبيكة وكذلك تحوير البنية المجهرية. تم مقارنة الخواص الميكانيكية والبنية المجهرية لسبائك Al-12wt.%Si المصوبة من درجة حرارة 1000



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درجة مئوية والمضافة اليها كلوريد الصوديوم بنفس السبيكة ولكن بدرجة حرارة صب مقدارها 800 درجة مئوية, حيث وجد ان صب السبائك من درجة حرارة 1000 درجة مئوية تعطي خواص افضل من صب السبائك نفسها من درجة حرارة 800 درجة مئوية.

## INTRODUCTION

Aluminum alloys offer an extremely wide range of capability and applicability, with a unique combination of advantages that make it the material of choice for numerous products and markets. Aluminum – Silicon casting alloys are essential to the automotive, aerospace and engineering sectors, these applications in automotive and other industries increases because they are lightweight, low costs production, easy to machine and have good recycling possibilities [1]. Aluminum – Silicon alloys are widely used for shape casting due to their high fluidity, ease of casting low density and controlled of mechanical properties. Mechanical properties of Al-Si alloys are related to the morphology of silicon particles (amount, size, shape and distribution), Al grain size, shape, and dendrite parameters [1, 2]. These properties can be easily achieved by modification of the eutectic silicon either by rapid solidification or by the introduction of modifiers to the melt [3, 4]. Modification with Na, Sr and Sb changes the silicon morphology. Na, Sr and Sb are commonly used for chemical modification and addition of small amounts of these elements to the melt changes the coarse and large needles of silicon into a fine and well-rounded form [1, 3, 5-7].

Several studies of Al-Si casting alloy have different factors that affect on microstructure and chemical properties, S. A.Jenabali etc. 2004, were studied the effect of Sr and Sb on silicon modification were investigated. The optimum amount of Sr content for achieving a modified fibrous structure in a sand mould is 0.013% Sr (by weight), whereas the amount for Sb is around 0.1%. Mechanical properties of the modified A356 alloy were superior to the unmodified alloy. Solution heat treatment at 540 $^{o}$C for 6 hours, water quenching and aging at 150 $^{o}$C for 3 hours significantly enhance these properties. D. G. Mallapur, etc. 2010 investigations were carried out to find the effect of grain refinement (by Al- 3Ti and Al-3B) and modification (by Al-10Sr) of A356 alloy. The effect was studied on the microstructure and mechanical properties of A356 alloy. The present result shows that a reduction in the size of α-Al dendrites, modification of eutectic Si and improvement in the mechanical properties were observed with the addition of grain refiner and modifier either individual addition or in combination. Witthaya Eidhed 2008, studied the effects of Sr, Mg, Cr, Sr/Mg and Sr/Cr combined additions on the Fe-containing intermetallic phase in a recycled Al-Si-Fe cast alloy. The experimental results show that the additions of Cr and Sr/Cr successfully modified the platelet and flake-like $\beta$-Al5FeSi phases ($\beta$-compound) into the fibrous $\alpha$-Al8Fe2Si ($\alpha$-compound). V. Maksimović etc. studied the microstructural analysis of a commercial 2219 alloy modified with a small (Si+Ge) addition was carried out using different analytical techniques. The presence of $CuAl_2$ phase, which cannot be dissolved during solution treatment and various phases containing Cu, Mn, Fe and Si in overaged microstructure indicates that more Cu was removed from the solid solution and did not contribute to hardening.

The present research focused on evaluating the effects of the addition of different amounts of NaCl on the microstructure of eutectic Al-Si and mechanical properties (tensile strength, yield strength, hardness) by comparing their effects with traditional modifiers such as Sr and Sb in a eutectic Al-Si alloy. The Na is usually added to eutectic or hypoeutectic aluminum silicon casting alloys to modify the morphology of the silicon phase. Without the benefit of a modifying treatment, eutectic silicon solidifies in a relatively coarse continuous network of thin platelets.

## Experimental work

The materials used in this work was Al – 12wt%Si alloy (chemical composition of the alloy is shown in Table 1) the chemical composition analysis was carried out using (dissolution spectrometer) at a State Company for Examination Engineering and Qualification (Specialist Institute for Mechanical Industry, previously). Al – 12wt%Si alloy was cut and melted using graphite crucible in an electrical furnace at 800 °C as shown in figure (1). After melting process, different weight percentage (0.05, 0.1,0.2, 0.3, 0.5, 1wt.) of NaCl were added to the melt in the form of pure powder of sodium chloride (supplied by Iraqi market with 99% purity) and wrappers with aluminum foil, the molten of alloy was stirred for 30 seconds using a silicon carbide rod to homogenize the molten metal, After which the stirring, temperature of the furnace was raised to 1000 °C for 10 min to ensure the interchange of Na to molten alloy. The homogeneous melt was poured in a preheated stainless steel die with dimensions of (17 mm) diameter and (120 mm) length. All the processes were made at the same manner and withholding time of 10 minutes at 1000 °C. Melting process done at high temperature laboratory in Production Eng. and Metallurgical Department.

**Table (1). Chemical composition of the Al-12 wt% Si alloy.**

| Si | p | Mn | Mg | Zn | Fe | Cu | Al |
|---|---|---|---|---|---|---|---|
| 12.06 | 0.001 | 0.1 | 0.13 | 0.09 | 0.12 | 0.32 | Balance |

**Figure (1) electrical furnace.**

## Tensile Test

The tensile specimens were prepared according to ASTM-E8 as shown in figure (2). The tests were done by using an Instron machine with a (20) ton capacity and (1 cm/min) cross head speed. All tests were performed at ambient temperature.

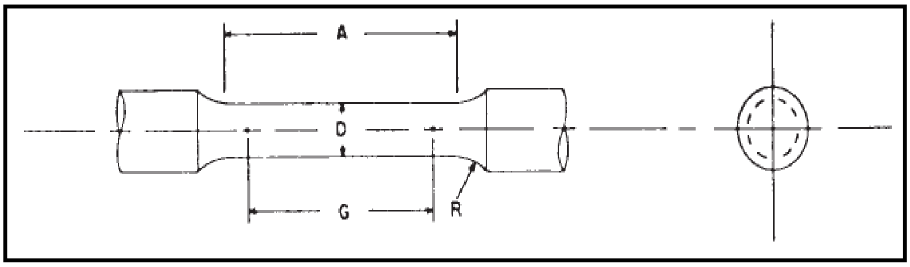


**Figure (2) shows the standard ASTM-E8 of tensile specimens.**

Where:
G: Gage length = 45mm.
D: Diameter = 9 mm
R: Radius of fillet = 8
A: Length of reduced section = 54mm.

**Hardness Test**

Vickers macrohardness was measured using diamond pyramid indenter with applied load of 200 gm. for 15 seconds to measure samples hardness. Three values for specimens were taken.

**Microstructure examining**

The samples were prepared with diameter of 10 mm and a height of 5 mm for the purpose of studying the microstructure. Grinding process was conducted for samples on grinding device by using silicon carbide papers (320, 500, 800 and 1000) with the presence of liquid water cooling, with increasing softness to remove any scratches provided through cutting operations. After the completion of the grinding process, conducted on samples using a polishing process refinement which consists of a rotating disk prove the polishing cloth and used polished diamonds paste of 1μm particle size with polishing liquid as a cooling lubricant, as well as the alcohol to clean the samples to be obtained on the surface of the mirror-free. The polished samples were etched using Keller's reagent (190ml $H_2O$ + 5ml $HNO_3$+ 3ml HCl + 2ml HF) for about 30-50s in order to develop microstructure with grain boundaries and finally, the polished specimens were taken for optical microscopy. The microstructure of the test samples was examined by optical microscope (100W Carlzeiss Jane, Germany, EP. Type 2) connected to digital camera.

**X-Ray Diffraction (XRD) Test.**

X-Ray Diffractometer SHIMATZO 6000X was used to study the phase composition of the Al-12wt%Si alloy, with measuring condition as below. This test was done at a State Company for Examination Engineering and Qualification.
Target: Cu, Wave length= 1.5406 A, 2Theta range= 0-80 deg.

**Results and Discussions:**

**Mechanical properties**

Table (2) illustrates the mechanical properties of Al-12wt%Si alloy with different additions of sodium chloride powder. It is clear that the added sodium chloride into Al-12wt%Si alloy leads to increase the tensile, yield strength and hardness up to 0.5wt% NaCl.

**Table (2) the effect of different additions of sodium chloride powder on mechanical properties of Al-12%Si alloy at pouring temperature 1000 °C.**

| Alloy No. | Alloy type | Tensile strength (MPa) | Yield strength (MPa) | Strain | Hardness HV | Elongation % | Reduction Area % |
|---|---|---|---|---|---|---|---|
| 1 | Al-12%Si | 160 | 33 | 0.062 | 68 | 6.2 | 5.8 |
| 2 | Al-12%Si+0.05%NaCl | 190 | 44 | 0.091 | 81 | 9.1 | 8.3 |
| 3 | Al-12%Si+0.1%NaCl | 233 | 61 | 0.197 | 87 | 19.7 | 16.4 |
| 4 | Al-12%Si+0.2%NaCl | 235 | 57 | 0.148 | 91 | 14.8 | 12.8 |
| 5 | Al-12%Si+0.3%NaCl | 219 | 71 | 0.077 | 82 | 7.7 | 7.1 |
| 6 | Al-12%Si+0.5%NaCl | 237 | 77 | 0.088 | 94 | 8.8 | 8.1 |
| 7 | Al-12%Si+1%NaCl | 214 | 63 | 0.151 | 74 | 15.1 | 13.1 |

Figures (3-7) show the influence of the different NaCl additions on the mechanical properties of Al-12wt%Si alloy. From the figures, it is clear that there is an improvement in the mechanical properties such as tensile strength, yield strength, hardness, increased with addition of NaCl due to the change in the morphology as compared with unmodified alloy. These results as better comparing with [S. A.Jenabali Jahromi, et al.] whom modified A356 alloy by Sr, Sb it is clear that the tensile and yield strength increase to 165 and 162 MPa respectively as compared with unmodified alloy.

From the figures (3, 4 and 5) find that the alloy with additives 0.5 sodium chloride have the maximum tensile strength, yield strength and hardness compared with the rest of the alloy additions and without additions alloy. It is believed that the optimum structure modification is 0.5% NaCl addition (as is seen from the results). For less than this amount, the addition is not enough to make a complete modification. While for more than this ratio, some of the NaCl particles (after solidification) coexist in the structure, and since this brittle material will affect the mechanical properties of the alloy to some extent.

Mechanical properties of Al-Si casting alloys, especially elongation, depend on the alloy microstructure and distribution the eutectic silicon, which may have an acicular or lamellar shape. It is known that elongation is improved by modifying the alloy by Na to form a fibrous eutectic structure [4, 10]. The mechanical properties of the Al-Si alloy are

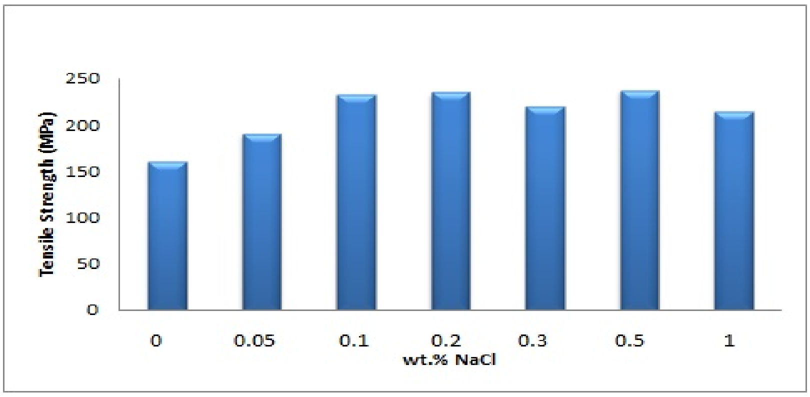


**Figure (3) behavior the tensile strength with different additions of wt.% NaCl.**

related to the size, shape and distribution of the eutectic silicon phase in the microstructure [4, 10].

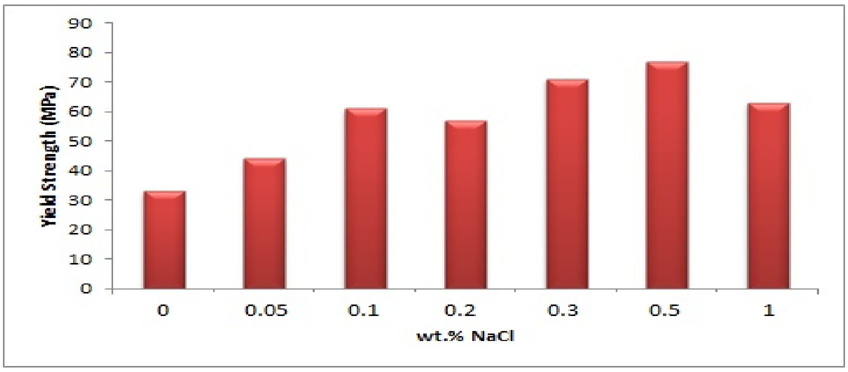


**Figure (4) behavior the yield strength with different additions of wt.% NaCl.**

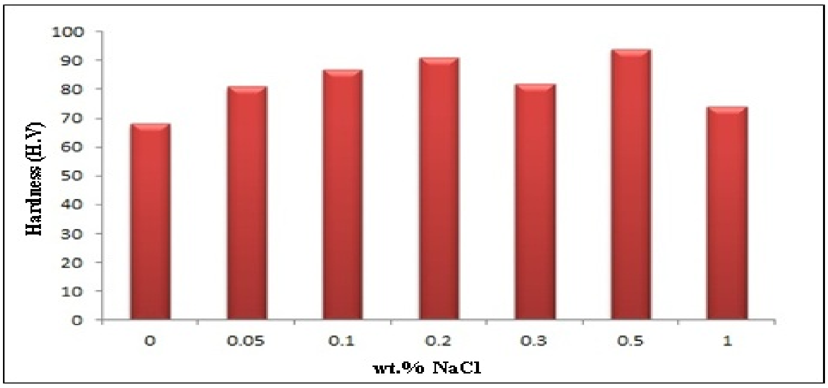


**Figure (5) behavior hardness with different additions of wt.% NaCl.**

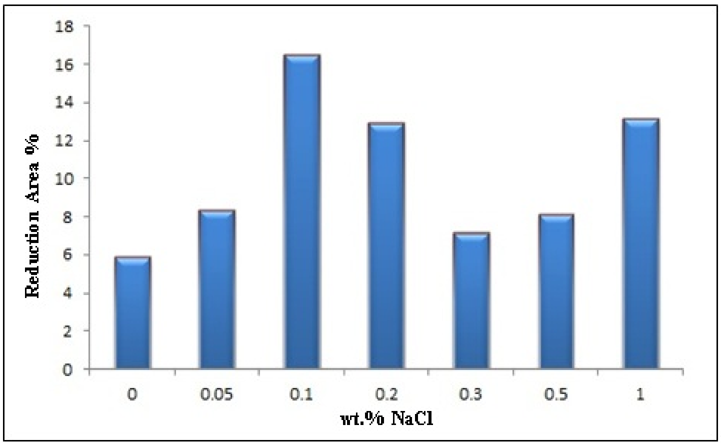


**Figure (6) behavior the reduction area percentage with different additions of wt.% NaCl.**

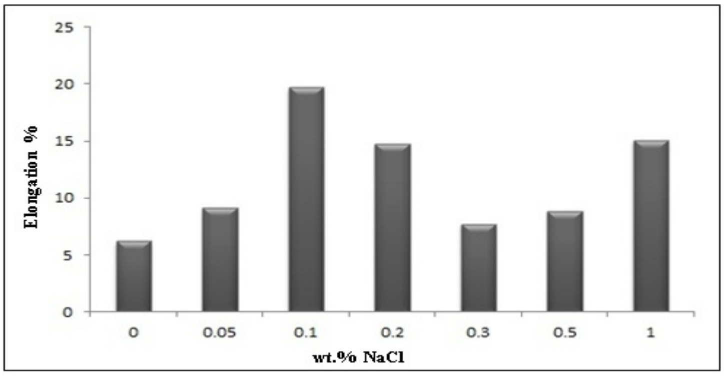


**Figure (7) behavior the elongation percentage with different additions of wt.% NaCl.**

The results are shown in table (2) as comparing with the same sampling (0.1, 0.3, and 0.5 wt% NaCl only) which were melted at 800 °C, as shown in table (3). It is clear that the mechanical properties values of the samples at 1000 °C are highest than the mechanical properties values of the corresponding samples melted at 800 °C. Since NaCl is a crystalline material and its melting point is a bit higher than 800 °C and in case that the furnace temperature is exactly or nearby that, the NaCl will not melt, instead, there will be some solid-solid diffusion process. For that its effectiveness will be lower. 1000 °C was used to be sure that all NaCl particles are melted.

**Table (3) the effect of different additions of sodium chloride powder on mechanical properties of Al-12%Si alloy melted at 800 °C.**

| Alloy No. | Alloy type | Tensile strength (MPa) | Yield strength (MPa) | Strain | Hardness HV | Elongation % | Reduction Area % |
|---|---|---|---|---|---|---|---|
| 1 | Al-12%Si+0.1%NaCl | 170 | 59 | 0.0597 | 86 | 5.97 | 5.63 |
| 2 | Al-12%Si+0.3%NaCl | 180 | 65 | 0.0487 | 90 | 4.87 | 4.64 |
| 3 | Al-12%Si+0.5%NaCl | 195 | 69 | 0.0494 | 91 | 4.94 | 4.71 |

**Microstructure**

The microstructure of the test samples was examined by optical microscopes. Figure (8) is micrograph of unmodified Al-12wt%Si alloy casting in as cast condition showing microstructures in which the eutectic silicon phase is dispersed in the aluminum matrix with needle-like morphology which is actually plate or flake-like in three dimension.

Addition of wt% NaCl to the alloy casting results in slight changes in the microstructure of the alloy (Figure 9-14). It can be observed that most of the eutectic silicon is not able to grow into large plates but seems to have been stunted or broken down into smaller sized particles. Though few still exist as large plates, they are not as many and randomly dispersed as those of the unmodified alloy signifying partial modification of the alloy. Also figure (18) illustrated the XRD pattern of Al-12wt%Si alloy which shows the peaks of Al and Si. In Figure (9), with the addition of 0.05% NaCl, shows the simple change in structure. The addition of 0.1% of NaCl in Figure (10) shows a response towards grain refinement with structural transition from coarse columnar dendritic structure to fine relatively equiaxed structure with smallest silicon crystal. Whereas with the addition of 0.2% of NaCl, Figure (11), the structure changes from columnar to finer equiaxed α-Al dendrites compared to figure (8). While addition of 0.3% of NaCl, the plate like eutectic Si is converted to very fine particles and α-Al dendrites converted to fine dendritic structure. The Figure (12), with 0.5% NaCl addition shows fine α-Al dendrites and Si. Figure (13), with 1% NaCl addition shows a modified structure into fine dendrites structure. All changes in the structures due to the effect of sodium which convert coarse dendrites structure to fine dendrites structure also the silicon particles appear as isolated spherical crystals when observed at low magnification. This observed effect of modification is consistent with the findings of other researchers [11, 12]. Figures (15-17) illustrated that microstructure of Al-12wt%Si alloy from pouring temperature at 800 °C it seen that the structure change from dendritic structure to fine equiaxed structure.

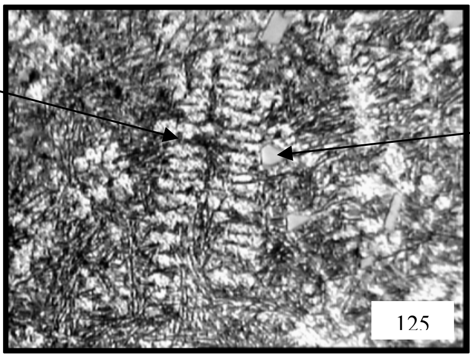


Figure (8) microstructure of Al-12%Si as cast.

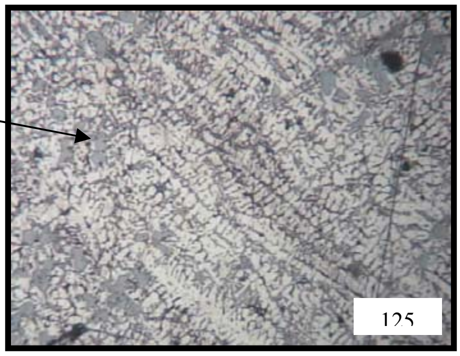


Figure (9) microstructure of Al-12%Si-0.05%NaCl, pouring temp. 1000 °C

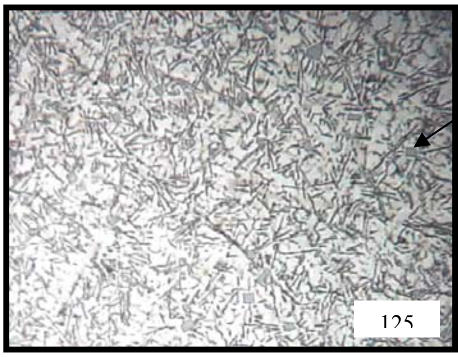


Figure (10) microstructure of Al-12%Si-0.1%NaCl, pouring temp. 1000 °C

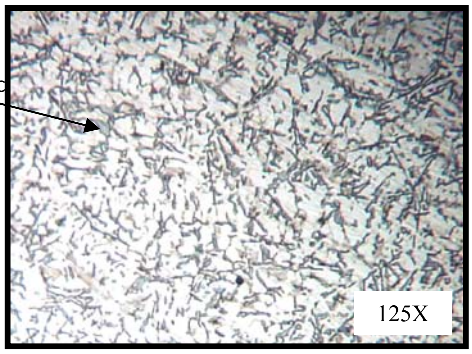


Figure (11) microstructure of Al-12%Si-0.2%NaCl, at pouring temp. 1000 °C

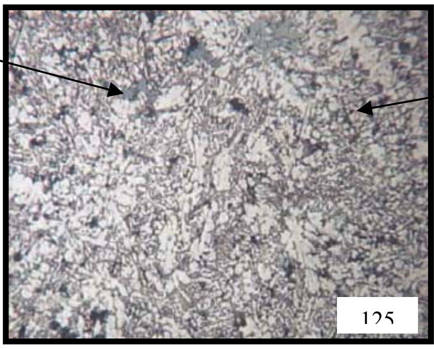


Figure (12) microstructure of Al-12%Si-0.3%NaCl, at pouring temp. 1000 °C

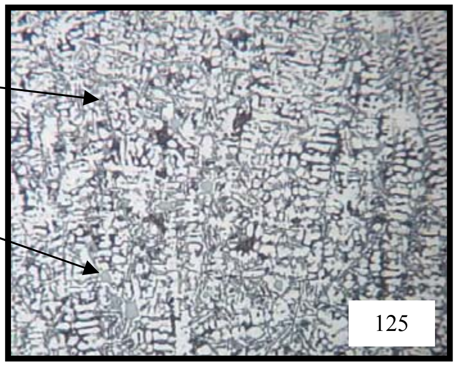


Figure (13) microstructure of Al-12%Si-0.5%NaCl, at pouring temp. 1000 °C

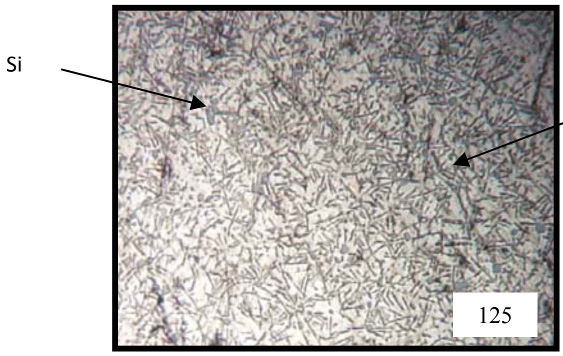


Figure (14) microstructure of Al-12%Si-1%NaCl, at pouring temp. 1000 °C

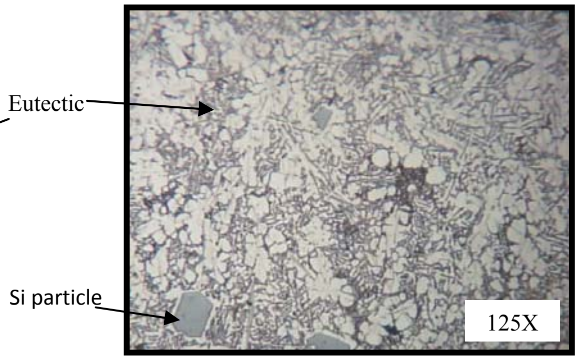


Figure (15) microstructure of Al-12%Si-0.1%NaCl, at pouring temp. 800 °C

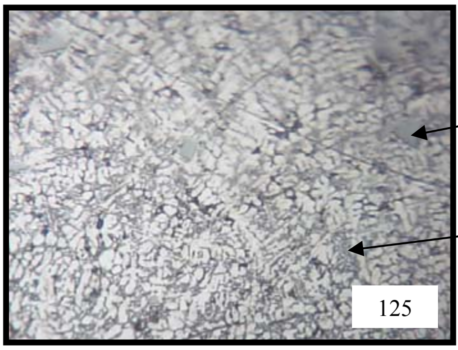


Figure (16) microstructure of Al-12%Si-0.3%NaCl, at pouring temp. 800 °C

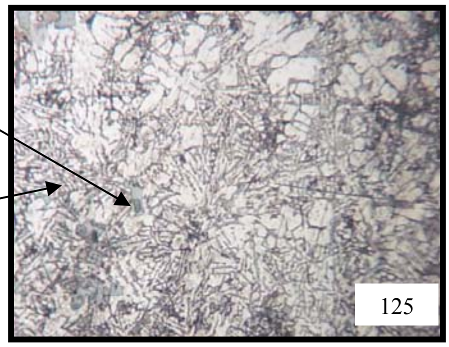


Figure (17) microstructure of Al-12%Si-0.5%NaCl, at pouring temp. 800 °C

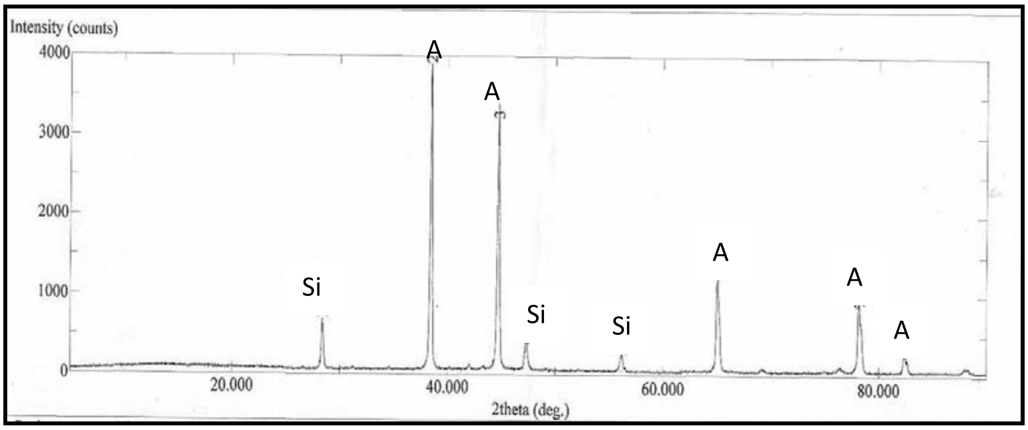


**Figure (18) XRD pattern for Al-12wt%Si alloy**

## CONCLUSION:

1-The tensile, yield strength and hardness increased with increasing the addition of sodium chloride powder in Al-12wt%Si alloy. An alloy with additive 0.5wt%. NaCl poured from 1000 °C have best mechanical properties (tensile strength = 237 MPa, yield strength = 77 MPa and hardness = 94 HV).

2-The ductility decreased with increased the addition of sodium chloride powder in Al-12wt%Si alloy.

3-There is some change in mechanical properties of Al-12wt%Si alloy with changing pouring temperature from 800 °C to 1000 °C.

4-Sodium chloride powder could be used as refinement agent for the structure of Al-12wt%Si alloy.

5-From a compromise between tensile strength, yield strength and hardness from one hand and elongation from other hand a percentage of 0.1% NaCl could be used.

6-Sodium chloride has decreased number of Si particles and changed its morphology.

**REFERENCES**

[1] D. G. Mallapur, K. Rajendra Udupa, S. A. Kori. “Influence of Grain Refiner and Modifier on the Microstructure and Mechanical Properties of A356 Alloy”, International Journal of Engineering Science and Technology, Vol. 2(9), 2010, pp. 4487-4493.

[2] “Aluminum Foundry Products,” Metals Handbook, 9th ed., Vol. 2, 1993, p. 145.

[3] Haitham Razouqi Saleh, “Mechanical Properties of the Modified Al-12%Si Alloy Reinforced by Ceramic Particles”, Eng. & Tech. Journal, Vol.28, No.2, 2010,pp.289-300.

[4] S.A.Jenabali Jahromi,A.De Hghan and S.Malekjani,“Effects of Optimum Amount of Sr and Sb Modifiers on Tensile, Impact and Fatigue Properties of A356 Aluminum Alloy”, Iranian Journal of Science & Technology,Transaction B,Vol.28,No.B2.2004, Shiraz University.

[5] Liao. H, Sun. Y and Sun. G, “Correlation between mechanical properties and amount of dendritic α-Al phase in as-cast near-eutectic Al–11.6%Si alloys modified with strontium”, Materials Science and Engineering, Vol. 335, 2002, pp. 62-66.

[6] Xiufang B, Weimin W and Jingyu Q, Mater. Character, Vol. 46, 2001, p. 25.

[7] Sigworth. GK, “Theoretical and practical aspects of the modification of Al-Si Alloys”, AFS Trans. Vol. 91, 1983, pp. 7-16.

[8] Witthaya Eidhed, “Modification of β-Al5FeSi Compound in Recycled Al-Si-Fe Cast Alloy by Using Sr, Mg and Cr Additions”, Department of Production Technology, Faculty of Engineering, King Mongkut0s Institute of Technology North Bangkok, Thailand, 10800 J. Mater. Sci. Technol., Vol.24, No.1, 2008.

[9] V. Maksimović, Z. Cvijović and V. Radmilović, “Microstructural Characterization of Modified Commercial 2219 Aluminum Alloy”, Association of Metallurgical Engineers Serbia and Montenegro, Scientific paper AME., 2005, pp. 225-230.

[10] Closset, B. & Gruzleski, G. “Mechanical properties of 356.0 alloys modified with pure strontium”. AFS, 1982, pp. 453-463.

[11] M.M.Makhlouf and H. V. Guthy, “The Aluminum-Silicon Eutectic Reaction: Mechanisms and Crystallography,” Journal of Light Metals,Vol.1,No.4,2001,pp.199-218.

[12] E. Martínez, D. M. Cisneros, G. S. Valtierra and J. Lacaze, “Effect of Strontium and Cooling Rate upon Eutectic Temperatures of A319 Aluminum Alloy,” Scripta Material, Vol. 52, No. 6, 2005, pp. 439-443.