EFFECT OF DIFFERENT CADMIUM CONTENT ON MODIFICATION OF SILICON EUTECTIC IN Al-12%Si ALLOYS [+]

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Abstract:

This work is devoted to examine and quantify the expected change in the mechanical properties and microstructure of an Aluminum-Silicon alloy after adding various percentages of cadmium. Two alloys were prepared with adding cadmium (1.5 and 3%wt) to the Al-12%Si base alloy. The new microstructure shows that the addition of (1.5 and3% Cd) resulted in a modification of eutectic Si phase from needle plate form to almost spherical one. The modification in Si eutectic phase could improve the mechanical properties. In specific, the hardness increased from 59 to 69 kg\mm^2, the tensile strength increased from 121 to 140Mpa and the yield strength increased from 31 to51 Map, while ductility decreased from 13 to 8 %.

Keywords: Modification, Al-12%Si alloy, Mechanical properties, Cadmium.

تاثير اختلاف محتوى الكادميوم على تحوير سيليكون اليوتكتك في سبيكة Al-12%Si

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المستخلص:

يتناول هذا البحث دراسة تأثير إضافة الكادميوم على البنية المجهرية والخواص الميكانيكية لسبيكة Al-12%Si .وقد تم تحضير سبيكتين بإضافة عنصر الكادميوم (1.5-3%) بالإضافة إلى السبيكة الأساس. أوضحت نتائج البنية المجهرية إن إضافة الكادميوم بنسبة (1.5-3%) يؤدي إلى تحوير طور السليكون اليوتكتيكي من شكل صفائح أبرية إلى شكل كروي تقريبا. وتتحسن الخواص الميكانيكية بسبب تحوير طور السليكون اليوتكتيكي ، حيث ازدادت الصلادة(من56 إلى69kg\mm^2) ومقاومة الشد(من121إلى140Mpa) ومقاومة الخضوع(من31إلى 51 Mpa) وانخفضت المطيلية (من 13%إلى 8 %).

Introduction:

The agreed advantages of Al-Si alloys have recently expanded their use in a spectrum of engineering applications, including but not limited to building, marine and military. Their key advantages are; high fluidity due to Al-Si eutectic, weld ability, relatively low thermal expansion and also high corrosion resistance [1].

Figure 1 exhibits the simple binary Al-Si system. It is useful to report that the ability of Si to dissolve in Al matrix is relatively limited. At eutectic temperature of 577°C the maximum percentage of Si that can dissolve in Al is about 1.5%; this weight percentage can go up to 1.6 % at 190°C. Additionally, Fig. 1 reveals that there is just one reaction which is invariant; that is the eutectic one L → α + β. Whereas the liquid phase is denoted by L, mainly Al and mainly Si

[+] **Received on 9/9/2015 , Accepted on 24/8/2016 .**
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are denoted by α and β respectively. According to the figure, at temperature of 577°C and Si weight percentage of nearly 12.6 the eutectic reaction has happened.

For commercial purposes, casting alloys such Aluminum-Silicon are typically divided into three different but relevant categories according to Si content - these are; hypoeutectic (5-11)%, eutectic/semi-eutectic (11-13)%, and hypereutectic (13-25)%. According to [Davis, J.R.] each category has its own specific characteristics, for instance, at the eutectic reaction stage the typical characteristics of the hypoeutectic casting alloy is a primary α-aluminum phase that is soft and ductile and a Silicon phase that is hard and brittle.

The impact of coarse silicon particles on the alloy properties was found significant by [3]. They reported that high percentage of such particles can maximize the hardness and minimize the strength to a large extent. As a consequence, this increase in hardness (low ductility) made the application of such alloys quite limited in industry.

Microstructure of this alloy contains plate or needle-like eutectic particles [4]. This plate-like particles would provide abundant stress riser which can limit the maximum strength and ductility. This is because factors such as quantity of modifying elements or rate of solidification can significantly affect alloy microstructure. Modification is one of the most common and effective ways to change the morphology of eutectic silicon from a plate to fine fibrous form. Modification is doneby two different ways: (a) chemical modification (by adding certain elements) and (b) quench modification. Depending on the quantity and technique, eutectic alloy's microstructure can be greatly enhanced after adding specific percentages of stimulating elements such as Ti, Sb, Na and Sr [5].

In comparison, other elements such as cadmium (Cd) is not widely used in Al-based alloys due their low melting property. The addition of 0.3 wt% of cadmium can lead to maximize strength, enhance corrosion resistance and also speeding up age hardening. Regarding other alloys such as Al-Z-Mg alloys, (0.005–0.5)% of cadmium can lead to decrease the aging time.

The main objective of the research is to investigate the possibility of reducing the effect of eutectic on the mechanical properties of Al-12% Si alloy. This has been done by adding two percentages of cadmium (1.5 and 3) % as an element for eutectic modification and silicon refining.

Several related research have been found during the review of previous studies; following are the most relevant of them.

In their study, **K. Nogita, and A.K. Dahle [6]** examined experimentally to what extent the added boron to an Al-8.7-10% Si hypoeutectic alloy can influence its solidification and modification characteristics. Two percentages of boron have been examined (3% and 8%) to form two alloys. Three eutectic characteristics have been investigated; these are solidification, Si morphology and arrest thermal characteristics. Their reported results revealed that both percentages of boron have no considerable impacts on any of the above three eutectic characteristics.**Qinglin Li et al. [7]** recently studied the possible impacts of adding several percentages of rare earth cerium on the mechanical characteristics and microstructure patterns of AlSi20 hypereutectic alloy. The weight percentages of Ce tested are (0, 0.3, 0.5, 0.8 and 1.0). Regarding silicon crystal geometrical shape, their findings confirmed that the adding Cerium led to refine the primary silicon crystals considerably. The star-like and polygonal crystal shape have become finer and smoother. Additionally, they found that as the percentage of added cerium goes up, the needle-like and platelet-like pattern of eutectic Si phases structure can be modified to more discrete and finer particles. In contrast, their results proved that mechanicalcharacteristics are dependent on the size and microstructure of both primary and eutectic silicon particles. Specifically, the reduction in size of particles and alteration in their distribution pattern have led to maximize the elongation and ultimate tensile strength. The potential effects of adding slight quantity of Ti on A356 aluminum-silicon casting alloy was examined by **Ghomashchi [8]**. The resulting metal composite is an intermetallic (AlTiSi) with significant microstructure mainly composed of particles with blocky and flaky shapes. The results stated that on the contrary of blocks, flaky particles are formed when Ti percentage is low and cooling rate is high.**Adnan Ibrahim Mohammed et al [9]** investigated the effects of adding Na on the microstructure and wear rate of hypereutectic Al-14 wt% Si alloy. They found that the presence of Na has an important effect on shifting the eutectic composition of Al-Si alloys from approximately 12 wt% to 14 wt% Si; shifting the unmodified alloy from hypereutectic to eutectic alloys for the modified alloys. The modified alloys have eutectic composition with fine needle at lower Na content (0.05%). Increasing the percentage of Na to 0.12 wt% resulted in producing a lamellar Si structure compared with acicular structure for unmodified alloy. The wear rate of modified alloys is lower than the hypereutectic alloy. Wear rates observed were in the range of 10-9 to 10-11 which is fully identified in the mild wear rate regime. They also found that the percentage of porosity increased with increasing the Na addition.

Experimental Work:

Preparation of alloys:

The Al-12%Si alloy of 550 gm are cut, and then charged in 1kg graphite crucible in electrical resistance furnace, and then it was kept it in crucible until furnace temperature reached to 750 $^{\circ}$Cto ensure the full fusion. After reaching full fusion condition,part of the molten was poured into a preheated open-top permanent iron die of 0.1m in diameter and 1m in height.Thereafter, the two percentages (1.5 and 3 wt %) of modifier (Cd) are wrapped in an aluminum foil and plunged into the molten as a powder. The molten was stirred for10 minutes with graphite rod before pouring into the preheated permanent iron die. Table 1 lists the chemical composition analysis of initial materials. The analysis was performed using spectrometer max device and by the staff of the general company for testing and engineering rehabilitation in Baghdad.

Macro hardness and microstructure test:

To examine the microstructure of the base and two prepared alloys, the specimens were at first cut from the center of the samples. The silicon carbide papers of three grit sizes (320,500, 1000) were utilized for grinding purposes using the grinding machine. The specimens after that were suitably polished on polishing cloth by the aid of 0.5 μm alumina before being etched with (1,5% HCl, 1% HF, 2.5% HNO_3 and 95% Water) solution. Before drying in hot air, the resulting samples have been washed using water and alcohol. The microstructures of both base alloy and prepared alloys were thoroughly scanned using an optical microscope equipped with digital camera. The micro hardness of the base alloy and prepared alloys were determined by using Vickers hardness apparatus, and calculated by the following formula **[10]**. Hardness values listed in Table (2).

$$HV = 1.8544 * P / dav^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:-

P: The applied load 1 Kg.

dav: The average diameter of the rhombus indentation in(mm) .

HV: Vickers hardness. Kg / mm^2.

Tensile test:

The standard specifications ASTM E-8 is designated to conduct the tensile test on the composite accordingly [11]. The samples for the test were machined to round specimen configuration with 7 mm diameter and 36 mm gauge length. The test was carried out at room temperature using an Instron universal testing machine operated at an extension rate 1mm/min. Two repeat tests were performed for each alloy composition to guarantee reliability of the data generated. The tensile properties evaluated from the stress-strain curves developed from the tension test are the ultimate tensile strength the yield strength , and the elongation . A typical tensile specimen is shown in Fig 2. And results of tensile properties of Al-12%Si and prepared alloys listed in Table (3).

Results And Discussion:

Figure 3 shows the microstructure of AlSi12 alloy with three different percentages of Cd – 0%, 1.5 %, and 3%. The microstructure is found to be composed of three phases; these are primary α-Al, eutectic Si and primary Si. Figure 3a exhibits the microstructure of the base alloy (0% Cd); i.e., without any modifying element. It shows the coarse platelet and needle-like of eutectic silicon in the α-Al matrix which is uniformly distributed. Figures 3b & 3c shows the morphology patterns for alloys with 1.5%Cd and 3%Cd respectively. With the increase in the percent of Cd it is observed that the silicon begins to diffuse out of the silicon eutectic particles and hence changing the microstructure. Where these particles starts fragmentation, spheroidization and finally stabilization, the resulted changing in the silicon needle to small particle is happened and it is attributed to the role of Cd.

According to Figure 4, it is obvious that the sample hardness increased with the rise in percentage of Cd. This is highly expected since the presence of Cd can modify Si eutectic, and therefore help in increasing the hardness of the aluminum alloys. Similar results were reported by study **[12]**.

Figure 5 demonstrates the influence of the different percentages of Cd on the sample's tensile strength. It is obvious that when Cd quantity goes up both the tensile and yield strengths go up accordingly. While the ductility is decreased with the increase in weight percentage of Cd, This may be due to the high hardness of the samples after the addition of Cd.

According to **[13]**, at 700°C the density and viscosity of the melt go up because of the added cadmium in the molten aluminum. The rise in viscosity of solute rich liquid continues as the temperature of the melt goes down. As a consequence, at the temperature of Al-Si eutectic reaction (577°C), there will be impedance to the growing eutectic Si as a result of the friction generated by the viscosity between Cd rich liquid and eutectic. The liquid Cd is reported to be the latest liquid to be solidified because of its relatively low melting point (321°C). The solid front will force this liquid to move up towards inter-dendritic areas. These changes collectively will result in modifying the eutectic Si.

Figure 7 describes the patterns of X-ray diffraction of the Al-12%Si alloy and the other prepared alloys. The figure illustrates that the alloys are composed of Al, Si and SiO_2.It can be seen that there are no other phases, this is probably due to the fact that at room temperature the cadmium is with low solubility in Aluminum or Silicon alike. Therefore, it is not expected to create any componentwith either one of them **[13]**.

Conclosions:

Based on the experimental results, following are the key drawn conclusions:

1. Utilizing Cd, an effective technique for modifying the eutectic Si has been proposed
2. As the weight percentage of Cd goes up (max. 3%), the modification effect goes up too.

3. As Cd percentage increase, tensile strength, yield strength and hardness also increase.
4. The increase in Cd percentage causes a decrease in ductility.

Acknowledgements:

The Author Is Grateful To The Management And Department Of Production And Metallurgy Engineering, University Of Technology,For Assist And Support Of This Work.

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Table 1. The chemical compositions of Al-12%Si and prepared alloys

Alloys	Si	Cd	Fe	Cu	Mg	Ti	Al
Al-12%Si	12.02	0.028	0.266	0.002	0.008	0.004	Bal.
Al-12%Si-1.5Cd	12.07	1.476	0.261	0.002	0.009	0.004	Bal.
Al-12%Si-3Cd	12.08	3.004	0.262	0.002	0.007	0.006	Bal.

Table 2.Hardness value of Al-12%Si and prepared alloys

Alloys	Test1	Test2	Test3	Average Hardness(HV) Kg\mm^2
Al-12%Si	55	57	57	56
Al-12%Si+1.5%Cd	63	67	68	66
Al-12%Si+3%Cd	68	68	71	69

Table 3.Tensile propertiesof Al-12%Si and prepared alloys

Alloys	UTS(Mpa)	YS(Mpa)	Elongation (%)
Al-12%Si	121	31	13
Al-12%Si-1.5%Cd	136	44	11
Al-12%Si-3%Cd	140	51	8

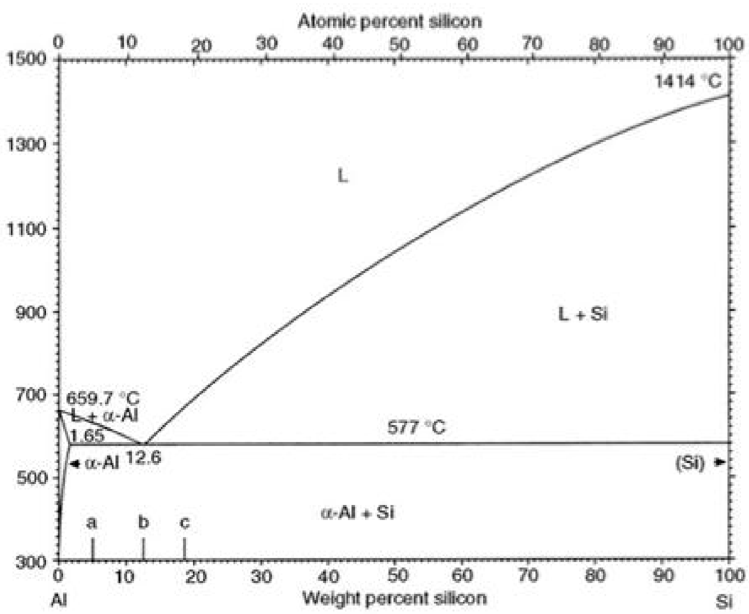


Fig. 1 Phase diagram of Al-Si system

Fig.2 Tensile strength specimen test

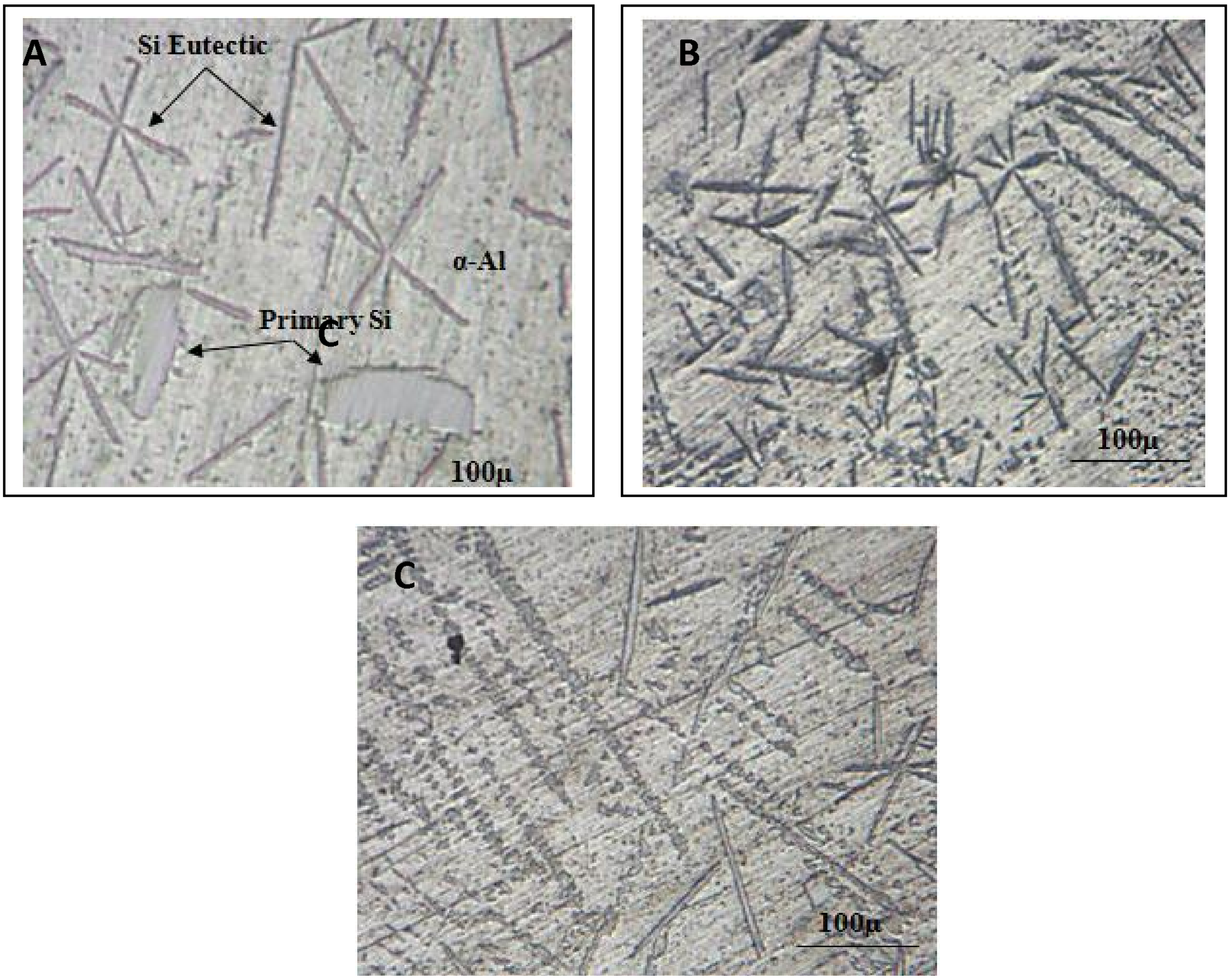


Fig.3 Microstructure of the alloys: (A) Al-12%Si alloy ,(B)Al-12%Si-1.5%Cd, (C) Al-12%Si-3%Cd

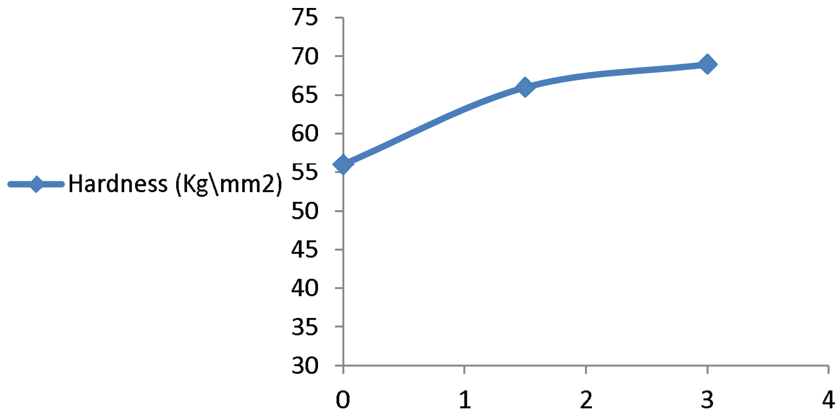


Fig.4 Variation of hardness with cadmium content

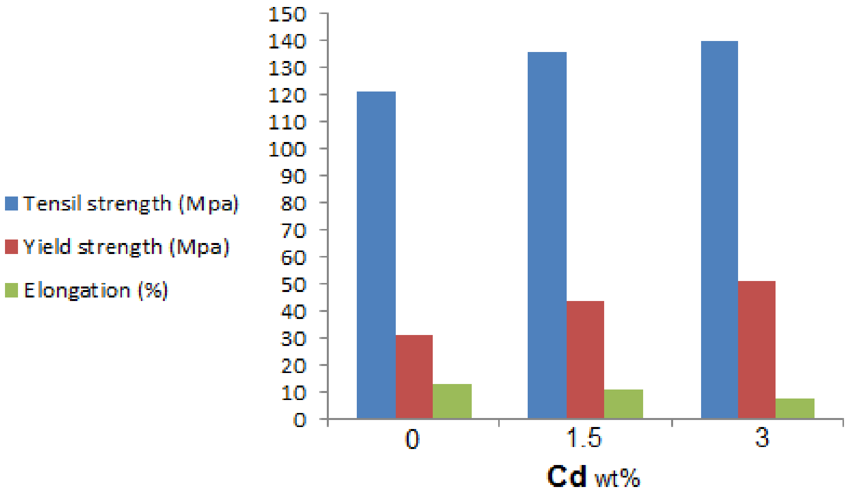
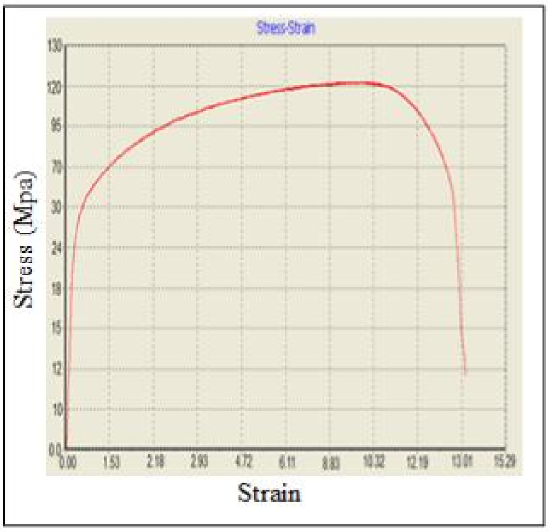
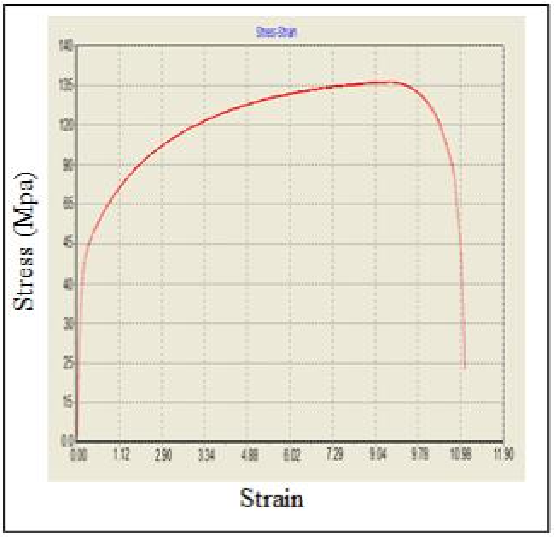


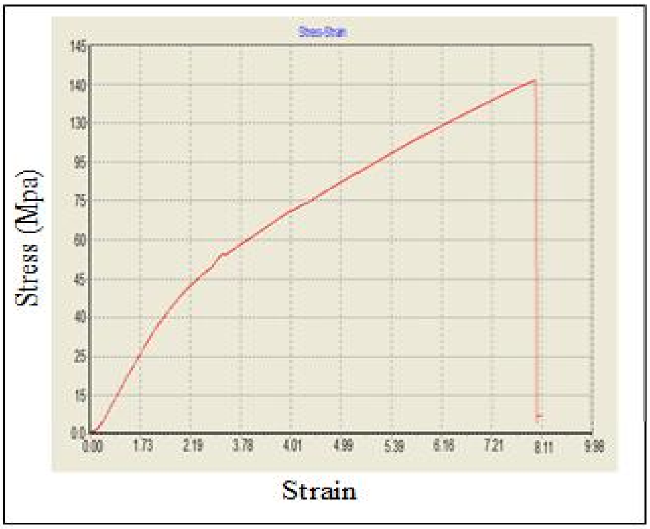
Fig.5Changes of tensile properties *vs.*Cd content



0%Cd



1.5%Cd



3%Cd

Fig.6 Stress- strain curves with different Cd content.

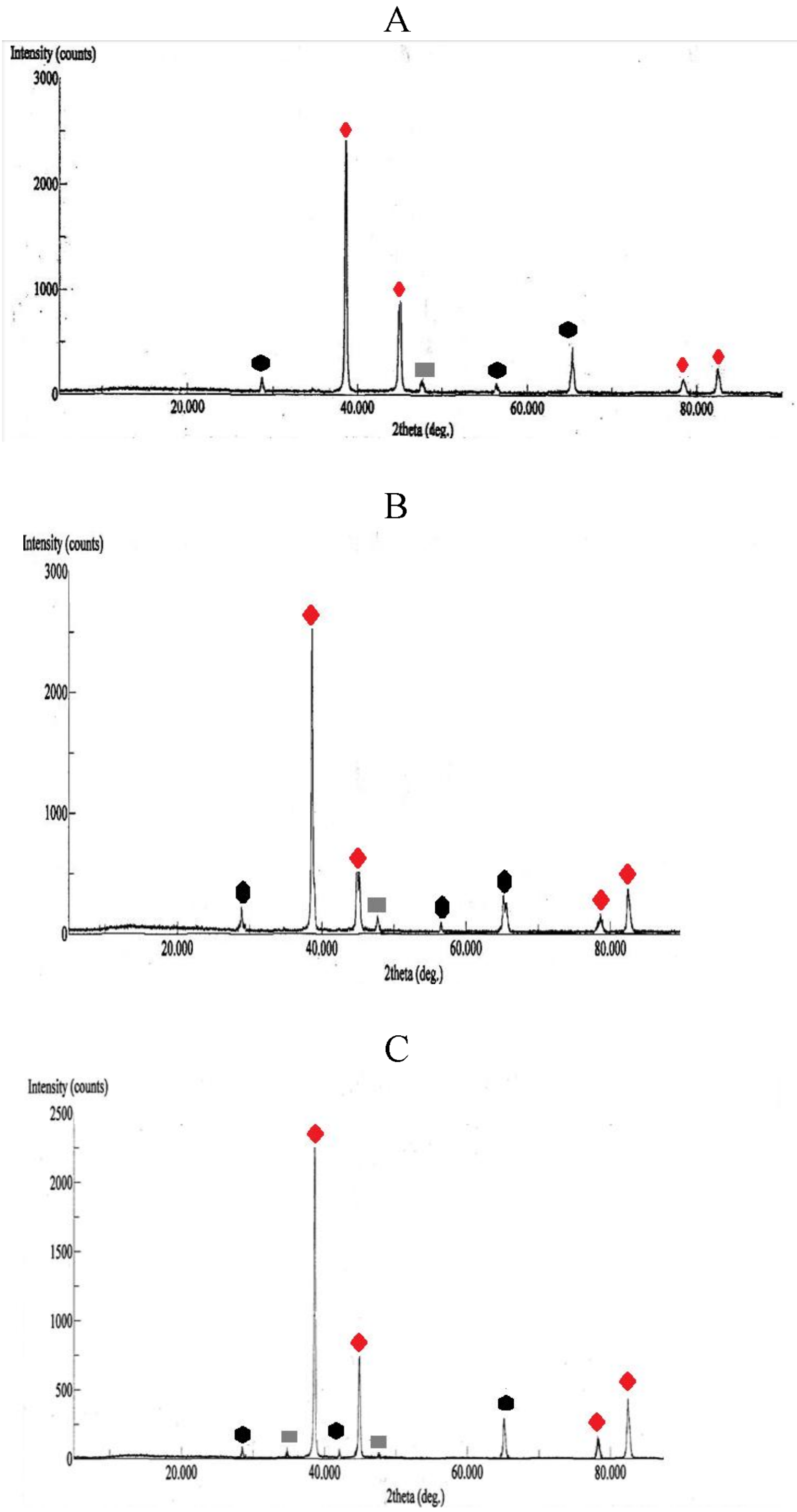


Fig.7 XRD pattern of : (A) Al-12%Si,(B)Al-12%Si+1.5%Cd, (C)Al-12%Si+3%Cd.

Al Si SiO_2