Effect of Cobalt content on mechanical properties of Al-Si alloy

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Abstract

This work encompasses studying the effect of different contents of Co on Al-Si alloy with Sb modification prepared by stir casting method. The content of Co is varying from 0 to 1.2wt%, The effect of Cobalt on microstructure, micro hardness, tensile strength and wear rate were studied extensively. The results show that the intermetallic compounds was increased with the increasing of Cobalt content .The Co-bearing compounds presented as small block shape at first and gradually turned into dendrite or fish bone shape. The addition of Co has appositive effect on tensile strength of the Al-Si alloys that used in the current research, the maximum tensile strength was (177MPa) when Co content was 0.9%Co at room temperature as well as wear rate were studied in this paper and noticed that the addition at 0.9%Co had the better effect at low and high load(5N),(10N).

Key words: Aluminum alloy, Cobalt, mechanical properties, stir casting.

تأثير محتوى الكوبلت على الخواص الميكانيكية لسبيكة المنيوم-سليكون

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الخلاصة

البحث الحالي يركز على دراسة تأثير اختلاف محتوى الكوبلت على سبيكة المنيوم –سليكون المحورة بالانتيمون التي تم تحضيرها بطريقة السباكة بالتحريك محتوى الكوبلت تراوح بين 0 و1.2% ، تأثير الكوبلت على التركيب المجهري ، الصلادة،مقاومة الشد ومعدل البلى تم دراسته ، اظهرت النتائج بان المركبات المعدنية الداخلية تزداد بزيادة محتوى الكوبلت . مركبات الكوبلت تمثل كقطع صغيرة الشكل عند البداية وتتحول تدريجياً الى الشكل الشجيري او بشكل عظم السمك . اضافة الكوبلت له تأثير ايجابي على مقاومة الشد لسبائك المنيوم-سليكون المستخدمة في البحث الحالي،أعلى مقاومة شد كانت 177 ميكاباسكال عند اضافة 0.9% من الكوبلت عند درجة حرارة الغرفة علاوة الى دراسة معدل البلى حيث لوحظ ان اضافة 0.9% كوبلت له افضل تأثير عند الحمل الواطئ والعالي (5نيوتن)،(10نيوتن).

1. Introduction:-

Aluminum alloys are widely used in castings because they posses many desirable properties. These include high fluidity, low melting points, lightweight, rapid heat transfer and good surface finish [1]. Alloying additions like Si are used to enhance these properties. Aluminum alloys with silicon as a major alloying element consist of a class of alloys, which provides the most significant part of all shaped castings. This is mainly due to the outstanding effect of silicon on the improvement of casting characteristics, combined with other physical properties, mechanical properties and corrosion resistance [2,3]. Aluminum-silicon castings are excellent candidates for replacing wrought structural components in the aerospace and automobile industries due to increasing requirements to reduce weight, improve energy efficiency, and minimize environmental impact at low cost [4]. New demands of automotive industry for aluminum alloys suitable for high-temperature power train applications require the development of enhancing high temperature performance of cast Al–Si alloys [5].Cobalt is one of the elements that is good for high temperature properties of aluminum alloys [6]. MengShaet.al [6]‹study the effects of Cobalt content on microstructure and mechanical Properties of hypereutectic Al-Si alloy with different Cobalt contents (0.3,0.5,0.7,0.9,1.1,1.5) wt% Co and showed that this addition has a positive effect on tensile strength equal or less than 0.7%Co , After the addition of 1.1-1.5%Co , chines-script $AL_{15}(Fe,Mn,Co)_3Si_2$ and dendrite or fish-bone quaternary phases $AL_9(Fe,Co,Ni)_2$ were formed. MengShaet.al [7]‹study the variation of microstructure of RE-containing $AlSi_{20}Cu_2Ni_1RE_{0.6}$ alloy with different Cobalt contents (0.3,0.5,0.7,o.9,1.1,1.3,1.5) wt% Co and showed that the RE-containing after the addition of cobalt, long acicular intermetallic compounds Al-RE-Co-Ni-Si were formed and this addition has an adverse effect on tensile strength of the$AlSi_{20}Cu_2Ni_1RE_{0.6}Co_x$ alloys.Mengshaet.al [8] study the combined effects of cobalt addition and ultrasonic vibration (USV) on microstructure and mechanical properties of hypereutectic Al-Si alloys with 0.7% Fe, with different cobalt contents (0.3,0.7,0.91,1.05). the results showed that , the Fe-containing compounds changed from long acicular β-$Al_5(Fe,Ni)Si$ phases to Chinese-script or rod-like α-$Al_{15}(Fe,Co,Ni)_3Si_2$ phases with increasing of Co content, the addition of equal or less than 0.91%Co , as well as application of USV has appositive effect on tensile strength of the $AlSi_{20}Cu_2NiFe_{0.7}$ alloys. This research studies the effect of different cobalt content son microstructure and mechanical properties of Al–12.5 %Si alloys with Sb modification.

2. Experimental work:

2.1preparing the specimen

The alloys with different amount of Cobalt (0.3,0.6,0.9,1.2) used for this research were synthesized by stir casting method. The chemical composition of the alloy used in the present investigation is given in table (1), which conducted at ministry of science and technology labs in Baghdad :

Table (1): (Chemical composition of Al-Si alloy in weight %)

Element	Si	Zn	Mg	Fe	Mo	Mn	Al
Wt%	12.5	4.37	0.91	0.61	0.05	0.01	balance

The alloy was melted in electrical resistance melting furnace with maximum temperature of the furnace 1200˚C$\pm$2˚C under argon gas with flaw rate 50 cm^3/min as shown in the Fig. (1). During melting 0.2 wt% Sb was added as modifier [9] and stirring the molten alloy in the furnace for 10 minutes using an electrical stirrer at speed (600 rpm) then close the cover of the melting furnace to increase the temperature to 850˚C .

The cobalt was wrapped firstly in a very thin foils and heated to 200˚C for 1 hrthen restirring for10 minutes to enhance mixing and homogeneity, close the melting furnace for increasing the temperature to 850 ˚C , then stirring the molten alloy again for 10 min, After that the produced alloy was poured into the tool die steel with dimension(12mm) in diameter and (100mm) in height as shown in Fig.(2) which preheated at 300˚C for 30 min. The samples were heated to 250 ˚C for one hour then cooled inside the furnace .This annealing process will remove the residual stress resulting from the casting process and also to achieve the homogeneity of the mixture.

Fig. (1) The electrical furnace

Fig. (2) The die used in casting

2.2 Microstructure test

In order to perform the microstructure test for the specimens, they were cut from the center, wet, polished and grinding. The grinding was conducted with silicon carbide papers (350, 500, 1000) grit using grinding machine (struers DAP-5, Denmark). The specimens were then polished using a diamond with particle size 7µm.Each specimen was then etched by 0.5% HF [9].These samples were then washed in water and alcohol and then dried in hot air. The microstructure was examined by an optical microscope with digital camera.

2.3 X-Ray Diffraction (XRD) Test

In order to obtain a relation between diffraction angle (2θ) and relative intensity (I), XRD specimens (12*2.5) mm were cut and prepared by the same method that is used to prepare the microstructure specimens. XRD analysis was conducted at ministry of science and technology labs in Baghdad. The apparatus used is SHIMADZU XRD-6000 to identify the resulting phases in the Al-Si alloy with minimum and maximum amount of cobalt with Cu target (λ=1.5406 A˚) and a scan speed of (5 ˚/min).

2.4 Micro hardness test

The micro hardness of the specimens was measured by using Digital Micro Vickers Hardness Tester (TH714), made in china. The following formula is used:

$Hv = 1.8544\ (F/ d_{av}^2)$ …………..(1)

Where:-
Hv: Vickers's hardness (kg/mm^2).
F: The applied load 200gm.
d_{av} : The diameter of the rhombus indentation in (mm) .

2.5 Tensile test

The tensile tests were made on the specimens with the dimensions shown in Fig (3) (ASTM E8) by using the Instron machine type 1195.

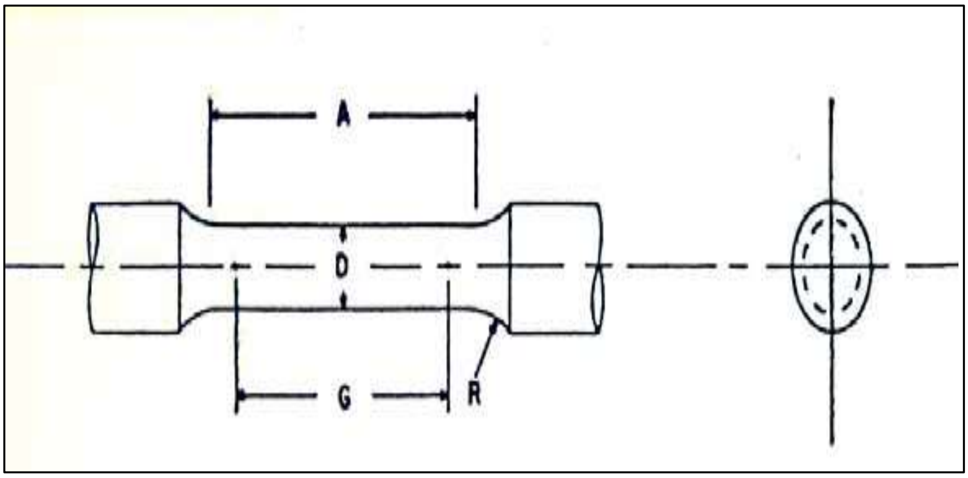


Fig. (3) Tension test specimen

2.6 Wear test

Dry sliding wear tests were conducted on all specimens according to standard test method (ASTM G99) for wear testing with a pin-on-disc apparatus shown in Fig. (4). The wear specimens are cylinder with diameter of 10 mm and a length of 20 mm. The specimen slides on a carbon steel disc with a hardness of 38 HRC at 3.7 m/sec for 20 minutes. Wear rate is calculated from the following formula:

$Wr = \Delta W / \pi DsNt$ (gm/cm) …………… (2)

And

$\Delta w = w1 - w2$ ………………(3)

Where

Wr: wear rate (gm/cm)
w1: specimen weight before the wear test. (gm).
w2: specimen weight after the wear test. (gm).
Ds: the diameter of circles' sliding (100,140,180) mm.

N: the number of cycles for the steel disc = 510 rpm.
T: the sliding time = 20 minutes.

The applied load used in this test was 5 and 10N.

Fig. (4) Wear test apparatus

3. Results and Discussion:-

Fig (5) shows optical photos microscopy of Al-Si alloys with different concentrations of Cobalt (from 0 - 1.2wt%Co). In general the addition of antimony (Sb) in this weight percentage, (0.2wt %) make the structure of crystal surface finer as was mentioned by Saleh [10]. The addition of Cobalt change the microstructure from small block shape to comparatively small dendrite or fish bone structure ,on the other hand Cobalt works as refiners, because that has pinning effect in certain extent on matrix and make a hindering effect on the dislocation of elastic strain field[7].

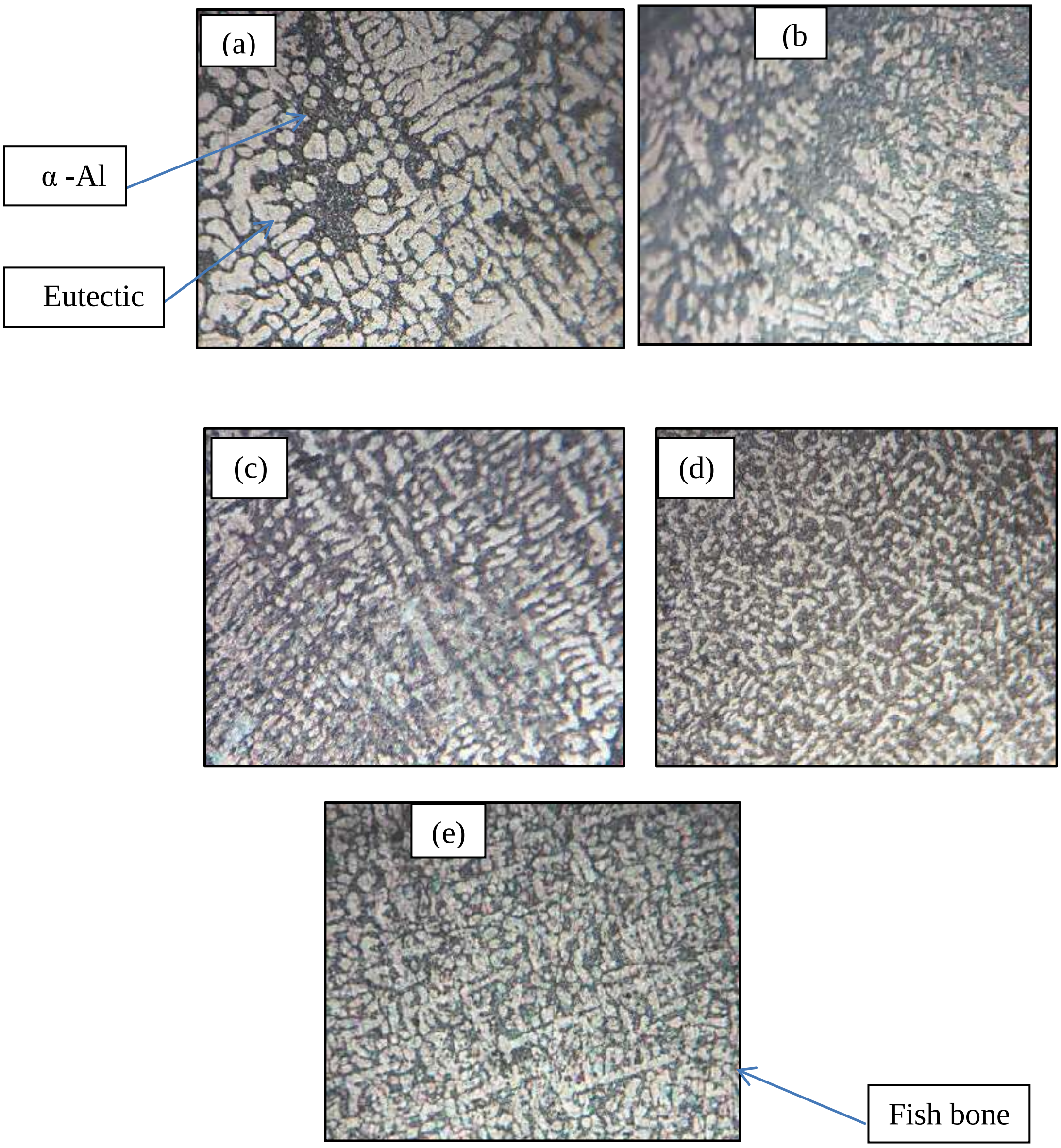


Fig.(5) optical photos microscopy at X 125 of Al-Si alloy with different concentration of Co (a) 0wt%Co (b) 0.3wt%Co (c) 0.6wt%Co (d) 0.9wt%Co (e) 1.2wt%Co

Fig. (6) shows the XRD chart of Al-12.5Si-4Zn-0.9Mg-0.6Fe, The peaks are matched with ASTM (**American Society for Testing and Materials)** card No. 04-0787 for aluminum and 27-1402 for silicon as shown in the table (2).Fig (7) and (8) shows the XRD peaks for the base alloy with minimum and maximum Cobalt contents 0.3wt% and 1.2wt% respectively as shown from the table (3).at minimum content of cobalt , there is no effect appear on the location of the diffraction angle or on the intensity . when the content was increased ,there is obvious effect occurs as a result of constructive interference in phase for cobalt which has chart No. 15-0806 and aluminum chart ,where the maximum intensity of cobalt at (2θ) equal to 44.216 near the intensity of aluminum 44.788. So, lead to reinforcing and strengthening of this peak [11].

Table (2)

XRD Characterization of Al-12.5Si-4.37Zn-0.91Mg-0.61Fe-OCO

Type	2θ (ASTM)	2θ(Measured)	I (ASTM)%	I(Measured)%	hkl
Si	28.442	28.697	100%	6%	111
Al	38.472	38.767	100%	100%	111
Al	44.788	45.013	47%	92%	200
Si	47.302	47.546	55%	4%	220

Table (3)

XRD Characterization of Al-12.5Si-4.37Zn-0.91Mg-0.61Fe at 0.3 wt% Co and 1.2 wt%Co

Type	2θ ASTM	0.3wt%Co 2θMeasured	1.2wt%Co 2θMeasured	I ASTM%	0.3wt%Co I(Measured)%	1.2wt%Co I(Measured)%	hkl
Si	28.442	28.694	28.580	100%	11%	11%	111
Al	38.472	38.757	38.637	100%	100%	85%	111
Al	44.788	44.991	44.885	47%	28%	100%	200
Si	47.302	47.558	47.422	55%	6%	5%	220

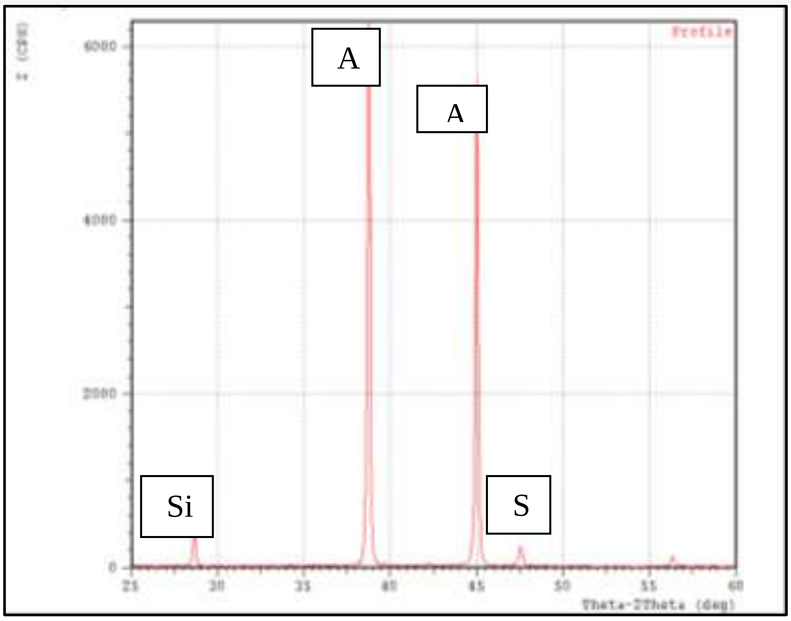


Fig. (6)XRD for Al-12.5Si-4.37Zn-0.91Mg-0.61Fe-OCO.

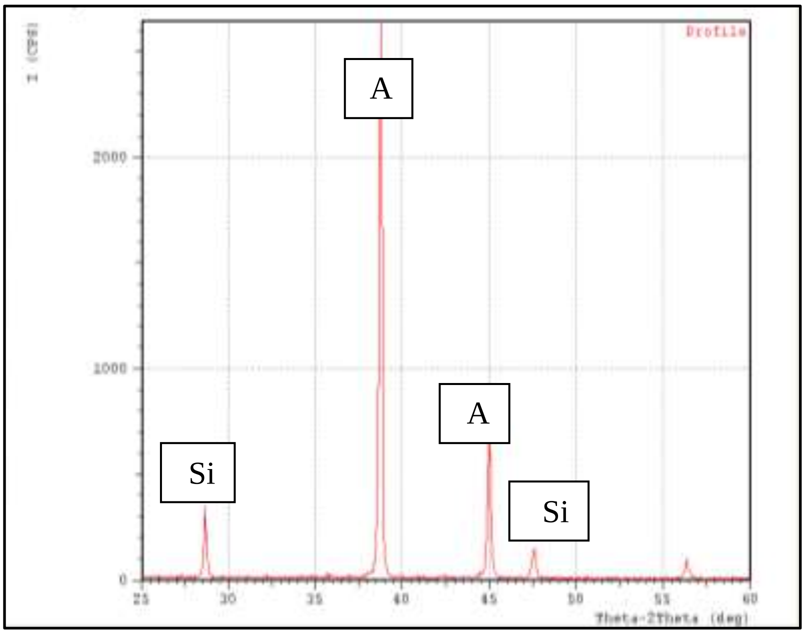


Fig. (7)XRD for Al-12.5Si-4.37Zn-0.91Mg-0.61Fe-0.3Co

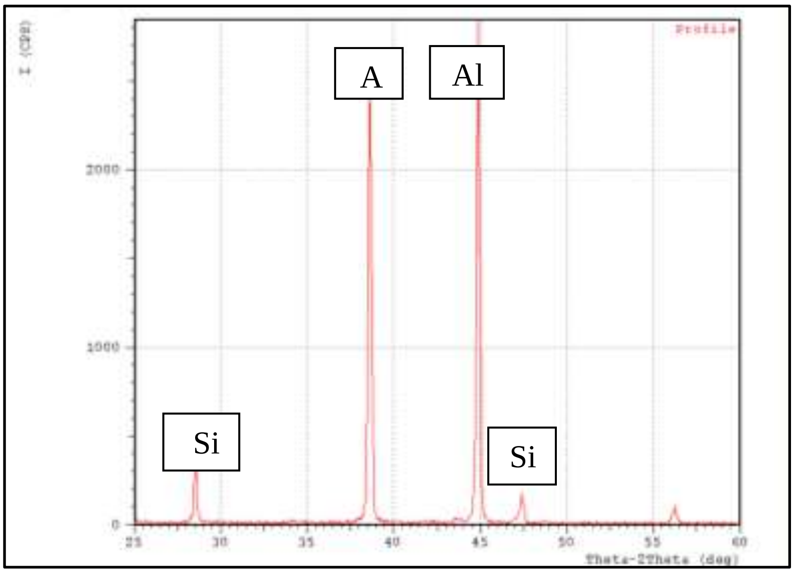


Fig. (8) XRD for Al-12.5Si-4.37Zn-0.91Mg-0.61Fe-1.2Co

Table (4) shows micro hardness for alloys with different concentrations of cobalt, It is observed that the values of the base alloy with 0%Co was 60Hv and decreased when the addition was (0.3-0.6)%Co then increased at the addition 0.9%Co to reach to 72Hv ,that's attribute to fine equated grain structure as show in Fig (5) as well as to the role of cobalt in reducing the particle size and hindering of crystal growth[7] .After that the Micro hardness decrease to 59Hv at 1.2%Co because the fish bone structure.

Table (4) Effect of Co content on micro hardness

Co wt%	Vickers micro hardness
0	60.06
0.3	50.25
0.6	53.95
0.9	73.68
1.2	59.27

As shown in the table. (5), the tensile strength increased when Co content increased from 0% to 0.9%, while they reduced when Co was equal to 1.2%. The tensile strength values of samples significantly increased from 115Mpa (0%Co) to 177Mpa (0.9%Co), Mg play an important role in tensile strength at room temperature improvement by solid solution strengthening and precipitation hardening of Mg_2Si phase[7], then tensile strength decreased to 165Mpa at (1.2%Co).the tensile strength of the Al-12.5Si-4Zn-0.9Mg-0.6Fe-xCo alloys changed in accordance with the effect of Co content on microstructure and inter metallic. The small block shape and dispersible Co-bearing inter metallic compounds formed when Co was under o.9% had positive effect on tensile strength while the dendrites that generated when Co was equal to 1.2% had unfavorable influence because the dendrite or fish-bone compounds act as stress raisers which contribute to the brittleness of the material. Therefore, the properties of the alloy would be severely decreased [7].

Table (5) Effect of Co content on tensile strength

Co wt%	U.T.St (mpa)
0	115
0.3	148
0.6	152
0.9	177
1.2	165

The values of wear rate calculated under dry sliding wear conditions for the Al-Si alloys with different concentrations of Cobalt ,table (6)and (7) shows Wear rate under load 5N,10N and sliding speed 3.7m/sec , Note that the wear rate for each of the base alloy and alloys with different concentrations of Cobalt increases with increasing load hanging in general from $81.55*10^{-6}gm/cm^3$at 5N to $18.71*10^{-5}gm/cm^3$at 10N for base alloy .The reason for this is due to that increasing the load increase plastic deformation winning tops surface outcrops of the sample, which leads to an increase in density of dislocations with increasing deformation, when you increase the load as shown in table (7) hanging metal connection gets strong force between them makes the force necessary to cut surface outcrops relating higher than the strength of the interdependence metal atoms of the sample itself, which will lead to dislocation and separation of metal particles from the surface of the sample, leading consequently to increase the rate of wear at (10N) than (5N),but in general the addition of Cobalt at different concentration decrease the wear rate . This corresponds with hardness valuesas shown in table (4) where the hardness is inversely proportional to the rate of wear.

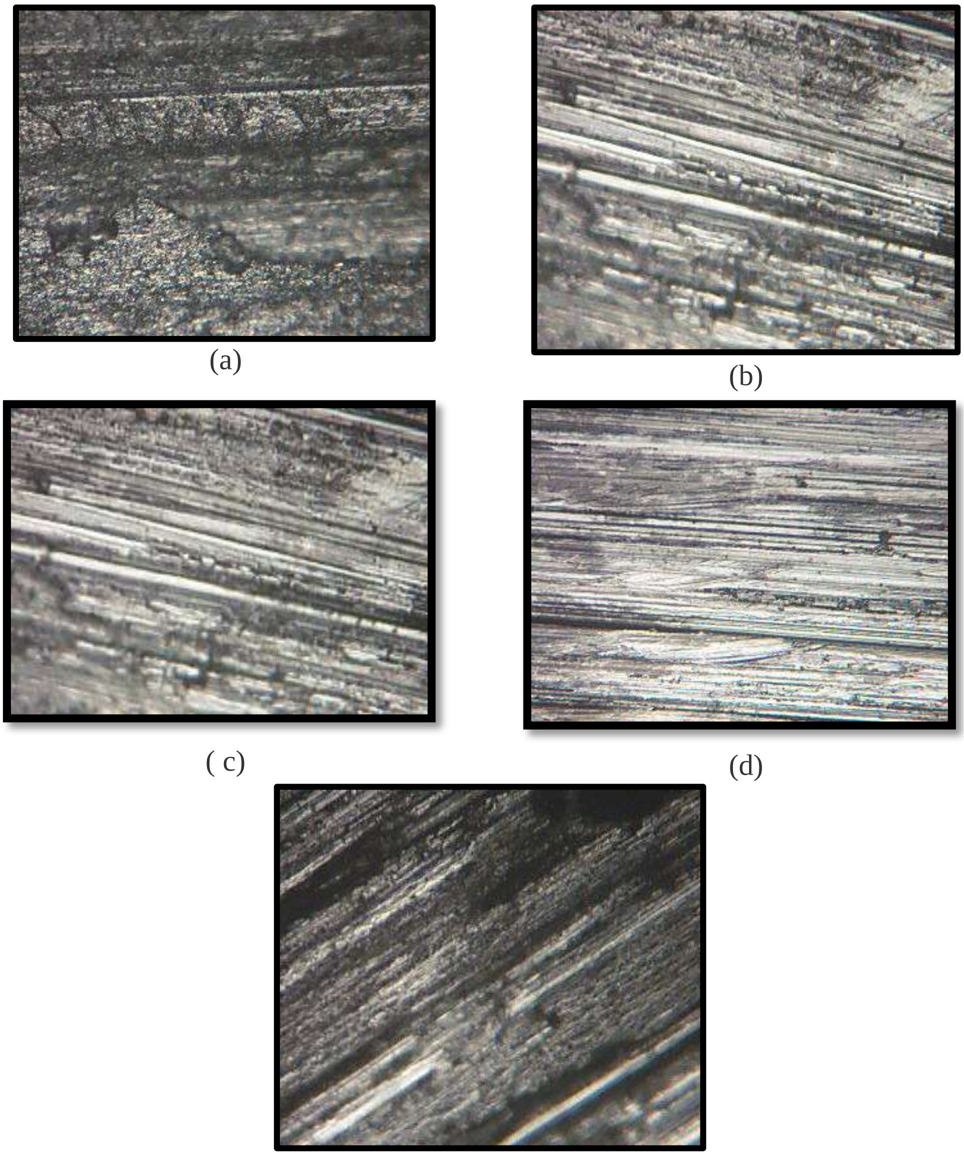
Table (6) Effect of applied load on wear rate for the Al- alloy at 3.7 m/sec sliding speed and 5N load

Co wt%	Wear rate $*10^{-6}$gm/cm
0	81.55
0.3	57.48
0.6	41.44
0.9	16.04
1.2	38.77

Table (7) Effect of applied load on wear rate for the Al- alloy at 3.7 m/sec sliding speed and 10N load

Co wt%	Wear rate $*10^{-5}$gm/cm
0	18.71
0.3	21.25
0.6	17.37
0.9	16.45
1.2	19.21

The resulting specimen surface after wear was studied .When using different loads5and10N with constantslidingspeed3.7m / spy optical microscope. Fig. (9) Shows path slide and the effects of wear formed, showing clearly easy deformation surface alloy foundation through the process of slip and get severe deformation, leading to a removal of the metal plow surface and the formation of grooves minutes and soft when load little as increasingly deep grooves Further more formation crack son both sides of the grooves sin Fig. (10) At10Nload, it could be notice that the evidence of extensive plastic flow and cracking. It is also possible that the hard dispersion particles or fractured pieces are mechanically dislodged during wear. The pinholes so formed act as potential sites for nucleation and growth of cracks. When cracks grow and get interconnected, a layer of metal gets removed [12].



(a) (b) (c) (d) (e)

Fig. (9) Optical micrograph of worn surface at sliding speed 3.7 m/sec, Load 5 N. X 125.

for the alloy with different concentration of Cobalt (a) 0wt% Co (b) 0.3wt% Co (c) 0.6wt% Co (d) 0.9wt%Co (e) 1.2wt%Co .

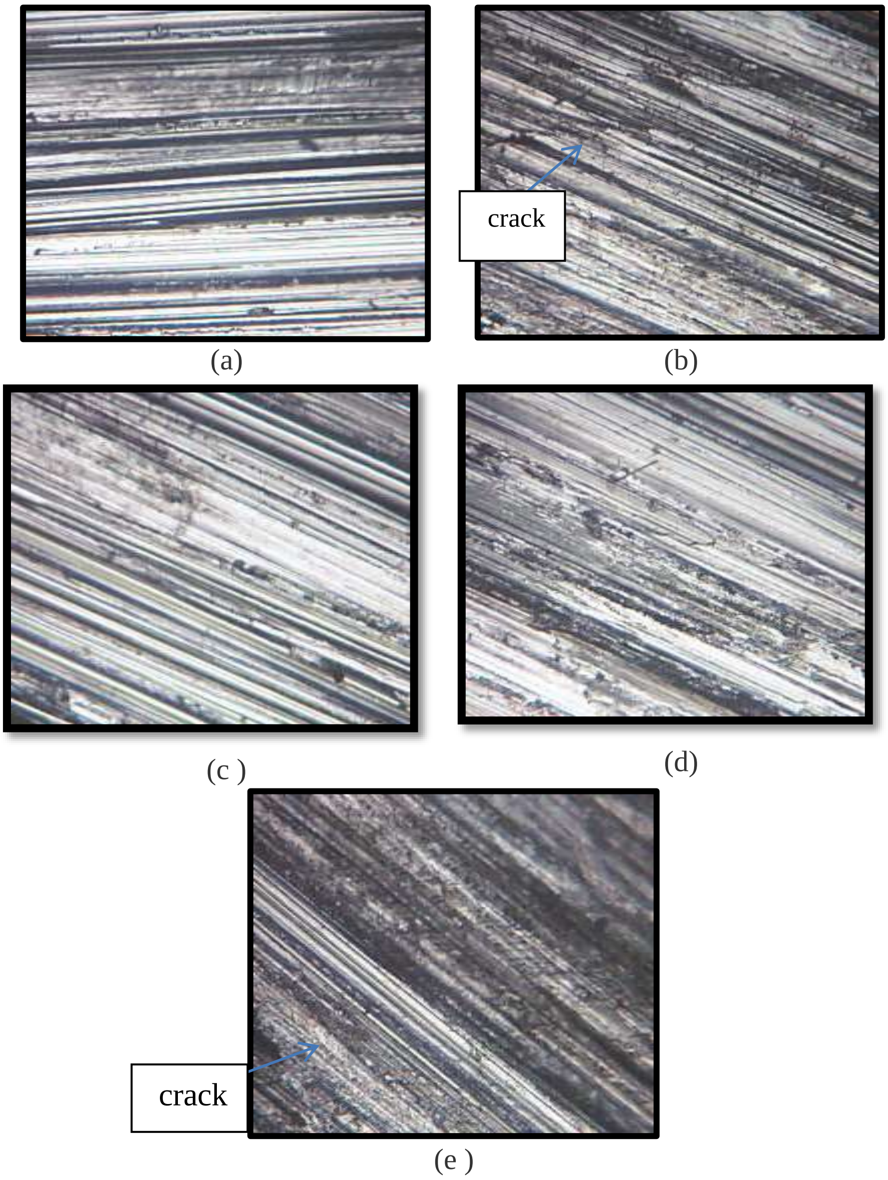


Fig. (10)Optical micrograph of worn surface at sliding speed 3.7 m/sec, Load 10 N. X 125.

for the alloy with different concentration of Cobalt (a) 0%wt Co (b) 0.3wt% Co (c) 0.6wt% Co (d) 0.9wt% (e)1.2wt% .

4. Conclusions:-

1- After the addition of Co contents, the microstructure was changed from coarse columnar grain structure to dendrite or fish-bone structure.

2- The micro hardness decrease when the addition was (0.3-0.6) % Co then increased at the addition 0.9%Co to reach to max hardness of 72 H.V.

3- The addition of Co has appositive effect on tensile strength of the Al-12.5Si-4.37Zn-0.91Mg-0.61Fe alloys. the maximum tensile strength was (177Mpa) when Co content was 0.9%Co at room temperature.
4- The wear rate decrease by the cobalt content addition to Al-Si alloy at low load (5N) and (10N).

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