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The effect of adding different percentages of Copper on corrosion of pure Aluminum

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Abstract

Aluminum and its alloys normally solidify in a columnar structure according to directionally slow cooling rate which results in decreasing the mechanical strength. Aluminum has a huge tendency to unite with oxygen to form oxide film on its surface, offers of it excellent resistance to corrosion and provides years of maintenance-free service and offered it excellent corrosion resistance and spare a lot of years without maintenance. Because of the aluminum and its alloys in fact work applications. Study was carried out on the coppers impact in addition to pure aluminum were six different Al-Cu alloys of (1, 2, 3, 4, 5 and 6) wt% Cu content were prepared and experimentally tested in acidic and alkaline medium. As in general the increase in the percentages of copper led to increased total corrosion rates of the samples submerged in corrosive medium. From obtained results has been reached that the corrosion rate of the alloy which 6%Cu content was (0.02585MPY) higher than the corrosion rate of the alloy of the 1%Cu content where it was (0.00081MPY) were the two alloys submerged in acidic medium, while the corrosion of the alloy 6%Cu was (0.505414MPY) higher than the from the corrosion rate of 1%Cu which it was (0.433369MPY) were the two alloys submerged in alkali medium. As was attained that the corrosion rates in the alkaline medium were higher in acidic medium corrosion rates.

Introduction

The high strength of Aluminum which possess in his property made this material to be used in vast and wide advanced application, moreover the demanded features such as, availability, low cost, durability and low density made this material compete and exceed all the other alloying elements in the nature, such as Magnesium, Copper, Silicon, ……etc[1]. Despite of the variation of the alloying elements composition impact weakened the alloy, beside this negative feature; those alloys are affected by the manufacturing and heat treatment process [2]. Despite of the light weight and highly corrosion resistances Aluminum alloys possess, its used widely in engineering structure [3]. This highly corrosion resistance is affected and weaken if copper exist even in a small rate with Aluminum alloy. Copper has tend to precipitate at grain boundaries, making the metal very susceptible to pitting, intergranular corrosion and stress corrosion. The copper rich zones are more noble/cathodic, therefore copper is very bad for anodizing than the surrounding aluminum anode matrix and act as preferred sites for corrosion through galvanic coupling. Copper precipitates dissolve in the anodizing electrolytes leaving holes in the oxide, and solute copper migrates under the high electric field towards the aluminum oxide interface compromising the anodic film properties [3 ,4]. Copper is added to aluminum and making alloys, the first and most widely used aluminum alloys were those containing (2-10) wt.%Cu. The Al-Cu alloys have the lowest negative potential of corrosion [4]. For the increasing the rigidity of the Aluminum and for highly strength structure copper material has chosen because of the high solubility with the Aluminum and better physical properties [5]. All metals and alloys will corroded, the corrosion is known as the environmental chemical process attack and the corrosion is defined as the metal chemical reaction with its environment, resulting deterioration of metal physical and chemical properties. [6,7].

Literature review

The researcher Hind Ati Al-Malki (2007), was studied the effect of temperature on the corrosion process and then evaluation of some thermodynamic

parameters using weight losses method and the effect of different concentrations of HCl, H_3PO_4, H_2SO_4 and NaOH acidic solutions on Al-Cu alloy. The results were obtained that the corrosion rate of Al-Cu alloy increases with increasing the concentrations of corrosion media , and the corrosion rate increase in the order : HCl < NaOH < H_3PO_4 < H_2SO_4 [8].

 Wislei R. Osório & etal (2011): were studied the effect of solidification thermal parameters on the microstructural array of Al 5 wt.% Cu and Al 9 wt.% Si alloys castings with a view to developing correlations between the as-cast dendritic microstructure, the electrochemical corrosion resistance. Considering the as-cast Al 5 wt.% Cu alloy, it was found that smaller secondary dendrite arm increase the corrosion resistance. For the Al 9 wt. % Si alloy, it is found the corrosion resistance decreases [9].

Rana and Rajesh (2012): the effects of Copper on the corrosion of Aluminum alloys were studied, and they found copper effect generally reduces the corrosion resistance of aluminum and in certain alloys and tempers, it increase stress corrosion susceptibility [10].

Experimental part
A. Methodology
Different Copper percentages samples of Al-Cu Alloys, were used in this work. The commercial pure Aluminum with 99.9%wt purity used as base material in this work and pure copper with 99.9% purity was used as an alloying element, which have melting point temperature (1083ºC) and density of ($8.2g/cm^2$), six alloys with different percentage copper contents were prepared (1,2,3,4.5 and 6) wt% Cu. Manufacturing of Sample was by using the following Gravity Casting procedure:

a) Using an electrical furnace to melt the aluminum by using a graphite crucible which was initially preheated in the furnace until reaching to temperature (700ºC) then adding the copper to the casting.

b) Pouring the molten metal into a carbon steel mold followed by leaving the casting to cool down to room temperature. This step was repeated for the six samples with different percentages used in the study.

B. Equipment
The following equipment's & machines were used:
i) Sensitive balance device four digits.
ii) Carbolite electrical furnace, chamber furnace (CWF) type 11/1, UK.
iii) pH meter.
iv) Grinding & polishing machine.
v) Hand saw.

C. Corrosion tests
1- The preparation of specimens for corrosion test
This process was performed by the following steps:
i) After the casting process, cutting the samples by hand saw with dimensions (5) mm length and 30 mm diameter into(12) samples [11], these enumerated to recognize between them.

ii) Grinding each specimen with SiC emery paper in grade of softness are (400, 600, and 1000).
iii) Washing the specimens by distilled water and ethanol to clean them from the particles which caused by cutting and grinding process, then the specimens where dried by drier.
iv) By using a four digit balance weighing each specimen.
v) The specimens from number (1-6) were immersed in acidic solution (H_2SO_4), and the specimens (7-12) were immersed in alkaline solution (NaOH).
vi) Preparing the chemical solutions (acidic & alkaline) mediums using pH meter.

2- Corrosion mediums
After prepare the specimens, the following mediums were used to test in this work:
1- Acidic Mediums: six sample with different percentages of copper were immersion in (H_2SO_4) medium with pH=2 by dilution it with distilled water.
2- Alkaline Mediums: six sample with different percentages of copper were immersion in (NaOH) media with pH=12 by dilution it with distilled water.
• The PH meter was used to setting in wanted level.
3- Intervals of corrosion test
 The Corrosion test were done in 13 days (316 hours):
4- Calculation of corrosion rates
i) The corrosion tests finished and the samples taken from the corrosion mediums and cleaned from the oxidation layers and the time of immersion was due to the standard in [12] which causes from the corrosion and by using smooth brush and then immersed in (HNO_3) for (1-5) minutes at room temperature[12], then washed and dried and weighing the samples. These steps were followed at the end of each interval for corrosion to know the weight difference before and after the test. The losses in weight method was used to know the corrosion, and the formula for calculating the corrosion rate is [13]:

Miles per year = KW / DAT -------(1)

Where K: 534
W: losses in weight by g.
D: The specimens density in g/cm^3 = 2.7 g/cm^3
A: surface area of specimen in cm^2.
T: exposure time hr.

ii) The total corrosion rates found by using the formula in equation one only the difference is in submitted of values weight losses which will be the difference in weight between the initial weight and final weight, and the value of time will be the total exposures to the corrosive mediums.

Results and discussion
The general Corrosion behavior for Al-Cu alloys with different percentage of copper content was:
D. In sulfuric acid medium
After the corrosion intervals for the wet test we found the corrosion rates differs between the alloys due to the corrosion mediums. The figure (1a, 1b, 1c, 1d, 1e & 1f) with fitting curves illustrated the relation

between the time in hour and the corrosion rates of different percentages of Cu contents alloys with using of H_2SO_4 mediums, and the behavior of alloys with different percentages of copper. Aluminum is solid metal and convert to Ions with available of acidic mediums decays according to the chemical equation:

$$Cu + H_2SO_4 \rightarrow Cu\,SO_4 + H_2\uparrow$$
$$2Al + 3\,H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2\uparrow$$
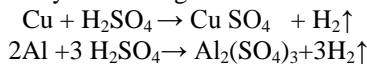
The maximum total corrosion rate done in specimen no.(6) with 6%Cu content equal to (0.02585MPY), and minimum total corrosion rate was done in specimen no.(1) with 1%Cu content which equal to (0.00081MPY) as shown in figure (2), this is illustrated that increases copper content tends to precipitate at grain boundaries, making the metal very susceptible to corrosion, therefore where the copper percentages increase in alloys the total corrosion rates increase ,referring to studies and researches [4,8 & 9].
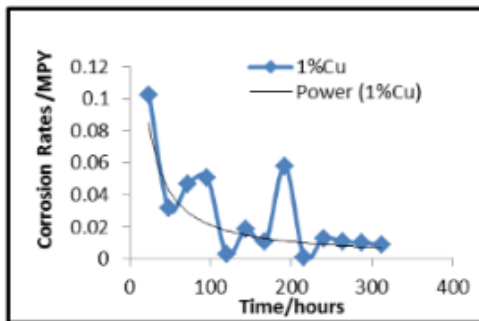
Fig. 1a The relation between the corrosion rates and time exposure to corrosion for (1%Cu) in acidic mediums
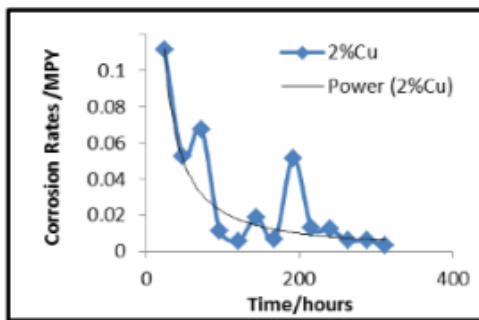

Fig. 1b The relation between the corrosion rates and time exposure to corrosion for (2%Cu) in acidic mediums
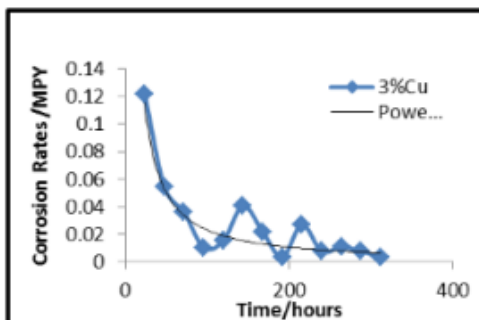

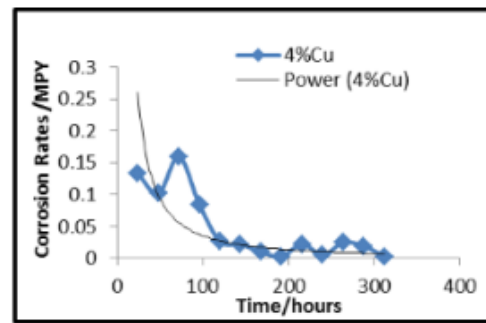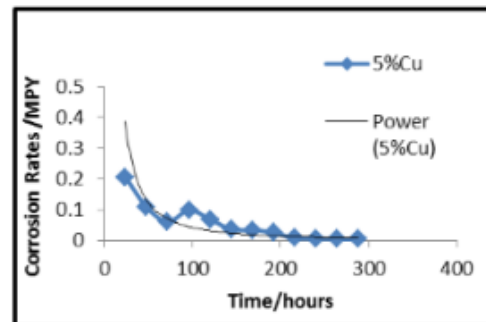**Fig. 1c The relation between the corrosion rates and time exposure to corrosion for (3%Cu) in acidic mediums**

Fig. 1d The relation between the corrosion rates and time exposure to corrosion for (4%Cu) in acidic mediums

Fig.1e The relation between the corrosion rates and time exposure to corrosion for (5%Cu) in acidic mediums
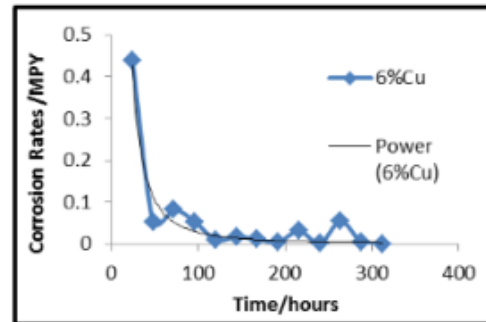

Fig, 1f The relation between the corrosion rates and time exposure to corrosion for (6%Cu) in acidic mediums
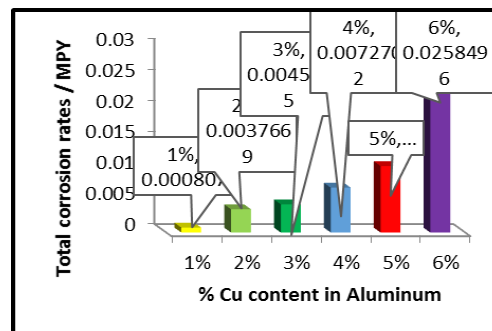

Fig. 2 The total corrosion rates for the six specimens immersed in concentrated acidic medium.

E. In alkaline media
After the corrosion intervals for the wet test we found the corrosion rates differs between the alloys due to the corrosion mediums. The figure (3a,3b,3c,3d,3e & 3f) illustrated with fitting curves the relation between the time in hour and the corrosion rates of different percentages of Cu contents alloys with using of

NaOH mediums, and the behavior of alloys with different percentages of copper. Aluminum is solid metal and convert to Ions with available of acidic mediums decays according to the chemical equation:

$$Cu + 2NaOH \rightarrow Cu(OH)_2 + 2Na$$
$$Al + 3NaOH \rightarrow Al(OH)_3 + 3Na$$

The maximum total corrosion rate done in specimen no.(12) with 6%Cu content equal to (0.505414MPY), meanwhile the minimum total corrosion rate was done in specimen no.(7) with 1%Cu content which equal to (0.433369MPY) referring to studies and researches in [4,8 & 9] , all these obviously shown in figure (4).
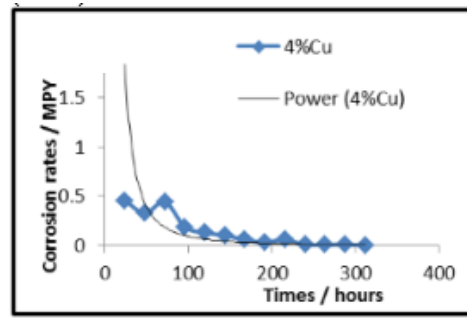

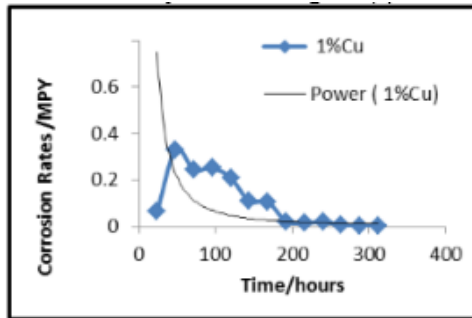**Fig. 3a The relation between the corrosion rates and time exposure to corrosion for (1%Cu) in alkali mediums**

Fig. 3b The relation between the corrosion rates and time exposure to corrosion for (2%Cu) in alkali mediums
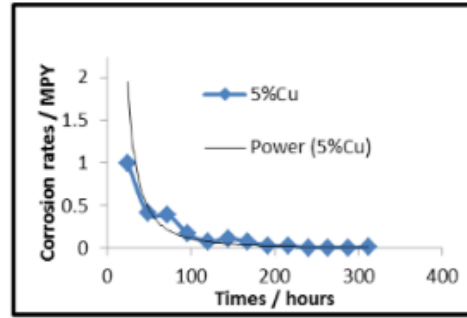

Fig. 3c The relation between the corrosion rates and time exposure to corrosion for (3%Cu) in alkali mediums

Fig. 3d The relation between the corrosion rates and time exposure to corrosion for (4%Cu) in alkali mediums

Fig. 3e The relation between the corrosion rates and time exposure to corrosion for (5%Cu) in alkali mediums
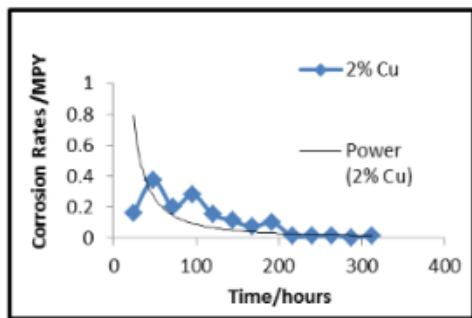

Fig. 3f The relation between the corrosion rates and time exposure to corrosion for (6%Cu) in alkali mediums
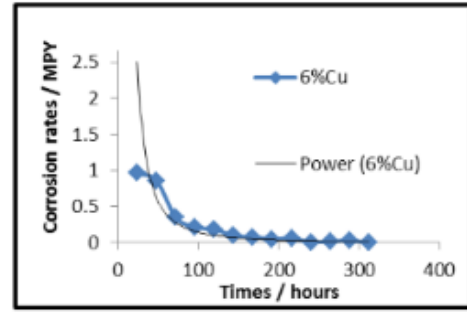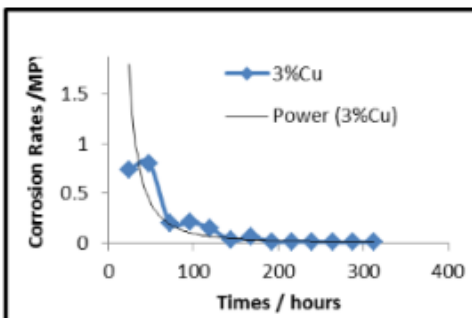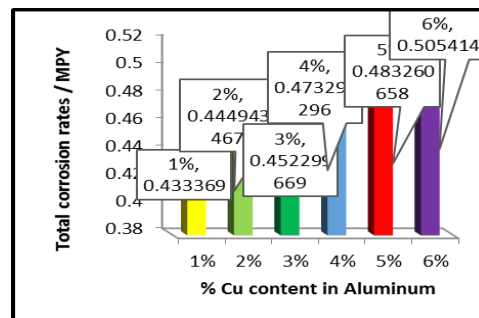

Fig. 4 The total corrosion rates for the six specimens immersed in concentrated alkaline medium

C. Aluminum is active and corrosive resistance, but it is also a passive metal which has electrode potential (-1.662V). This unpleasant nature is explainable because new Aluminum surface react with oxygen or water and forms a coherent surface oxide which obstacles Aluminum reaction with the environment. The presence of Cu is noble and with electrode potential equal to (+0.337V) viewed as detrimental to

corrosion due to the formation of cathodic particles capable of sustaining the cathodic reaction locally and efficiently, such as Al_2Cu as in reference [14].

D. In general the avarage of corrosion rate in alkai mediums for six alloys used in this work is higher than from average of corrosion rates in acidic mediums for another six alloys used in this work referring to studies and researches in [8], all of these behaviors clearly shown in figure (5).
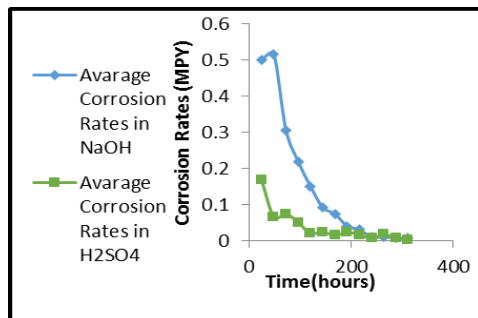

Fig. 5 The average of corrosion rates in acidic & alkali mediums

E. The resistivity of the corrosive mediums by increases the electrical conductivity of the mediums to be more aggressive on the alloys by reduces its corrosion resistance by spreaded the interaction of electrochemical on possible large areas of surface, can be seen from the results that each mediums of

corrosion has its own impact of the corrosion rates, and its varies from the mediums to another depending on the nature mediums and the severity of the impact as in reference [15].

F. In general the corrosion rates for all alloys used in this work have maximum value at the beginning of the corrosion intervals and gradually decreases with increases the time of corrosion interval due to reduce the corrosion mediums dissolve oxygen. And also slow or weakness the speed of the electrochemical interaction with the continuation of exposure of time from the start of the reaction the reason for this is due to membrane or remnants from corrosion test which hinder the continuously of electrochemical corrosion as in reference [15].

Conclusion

i. The corrosion resistance is proportion inversely with copper content.

ii. The maximum corrosion rate was occurred in 6%wt Cu in both medium's acidic & alkaline meanwhile the minimum corrosion rate was occurred in 1%wt Cu in both medium's acidic & alkaline.

iii. The average of corrosion rates in alkaline medium were higher than the average of corrosion rates in acidic medium.

iv. The corrosion rates decrease with increasing the time of exposure to the corrosive medium.

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تأثير اضافة نسب مختلفة من النحاس على تآكل الالمنيوم النقي

نوزاد جلال محمود

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الملخص

يتجمد الألمنيوم وسبائكه على شكل بنية مجهرية عمودية من الحبيبات وذلك بسبب التبريد الاتجاهي البطيء مما يؤدي إلى تقليل القوة الميكانيكية. ان للالمنيوم قابلية جيدة للاتحاد مع الاوكسجين لتشكيل طبقة أكسيد على سطحه، ويقدم لها مقاومة ممتازة للتآكل ويوفر سنوات من الخدمة الخالية من الصيانة. بسبب تطبيق الألمنيوم وسبائكه على نطاق واسع في العمل، تمت دراسة تأثير النحاس بالإضافة إلى الألمنيوم النقي تجاريا على مقاومة التآكل. تم إعداد ستة سبائك مختلفة من النحاس من 1، 2، 3، 4، 5 و6٪ محتوى النحاس واختبارها تجريبيا في وسط حمضي وقلوي. وبشكل عام فان الزيادة في نسب النحاس أدت إلى زيادة مجموع معدلات التآكل من العينات المغمورة في وسط تآكل. من النتائج التي تم التوصل اليها تبين ان معدل التآكل للسبائك الذي كان محتوى النحاس 6٪ (0.02585 ميل/سنة) اعلى من معدل التآكل للسبائك من محتوى النحاس 1٪ حيث كان (0.00081 ميل/سنة) هما السبائك المغمورة في الوسط الحامضي في حين كان تآكل سبيكة النحاس 6٪ (0.505414 ميل/سنة) أعلى من نسبة التآكل من النحاس 1٪ الذي كان (0.433369 ميل/ سنة) كانت السبائك الاثنين مغمورة في وسط القلويات. كما تم التوصل إلى أن معدلات التآكل في الوسط القلوي كانت أعلى من معدلات التآكل في الوسط الحمضي.

الكلمات المفتاحية: سبائك الالمنيوم–النحاس, التاكل, وسط حامضي, وسط قاعدي.