EFFECT OF QUENCHING BY 30% POLYETHYLENE GLYCOL ON PROPERTIES OF Al-4.3%Cu-0.7%Fe-0.6%Mg ALLOY

Dr. Khadim F. Al-Sultani
Ass. Prof.
University of Babylon

Mohammed Salih Faris
Ass. Lect.
Al-Suwaira Technical Institute

Shymaa Abbas Abd Alsada
Ass. Lect.
University of Babylon

ABSTRACT

The Al-Cu aluminum alloys are primarily used in the aerospace industry as structural components. This study aim to improve properties of Al-4.3%, Cu-0.7%, Fe-0.6%, Mg alloy such as compression resistance, thermal stability and microstructure by quenching in 30% polyethylene glycol. Results showed that compression resistance improved by (10%) when quenching in 30% polyethylene glycol corresponding to the base alloy (quenching in water) when aging at 175 ºC for 3 hour. Also results showed that the thermal stability improved when quenching in polyethylene glycol.

KEYWORDS: Effect of Quenching, Polyethylene Glycol (PAG), Aluminum Alloy.

تأثير الاخماد في ٣٠% بولي-اثيلي كلايكول على خواص سبيكة -(Al-4.3%Cu-0.7%Fe-0.6%Mg)

د.كاظم فنطيل السلطاني
أستاذ مساعد

محمد صالح فارس
مدرس مساعد

شيماء عباس عبد الساده
مدرس مساعد

الخلاصة

إن سبيكة (Al-Cu) مِنْ سبائكِ الألمنيومِ التي تستعملُ في صناعة المركبات الفضائيةِ كمكوّنات هيكلية . إن الهدف من هذه الدراسةِ هو تَحسين خواص سبيكة (Al-4.3%Cu-0.7%Fe-0.6%Mg) مثل مقاومة الانضغاط ، الاستقرارية الحرارية من خلال استخدام الإخماد في البولي اثيلين كلايكول لهذه السبيكةِ. أظهرت النتائج إن السبيكة يحدث فيها تحسنا كبيرا في الاستقرارية الحرارية وكذلك تحسن في مقاومة الانضغاط بنسبة (10%) عند الإخماد في (30%) من البولي اثيلين كلايكول بالمقارنة عند الإخماد عند إجراء التعتيق في درجة 175 ºC .

INTRODUCYION

The 2xxx series age-hardenable aluminum alloys are extensively used in aircraft structures owing to their good specific strength and light weight **[Özbec,2007 ; Xie, et. al. 1998; Huda, 2006].** The 2017 aluminum alloy, n the as-rolled condition, is unsuitable for aerospace application since it lacks strength and ductility owing to elongated grains, regions of high energy, and absence of dispersed second-phase particles in its microstructure. These micro structural features require proper precipitation-strengthening or age-hardening heat treatment to be given to the alloy for aerospace application [**Kacer, 2003; DeGarmo, 2003],**

The metallurgically important feature of 2xxx series aluminum alloys is the ability to improve mechanical properties when suitably heat treated. Aluminum–copper alloys (for aerospace applications) are usually given special heat treatments, called age-hardening which are process of strengthening metals based on θ-particles strengthening. For the process to occur, it requires certain phase transformations resulting from either precipitation strengthening or age hardening heat treatment involving solution treatment, quenching and tempering **[John, 1990]**

The aluminum rich portion of Al-Cu equilibrium phase diagram enables us to determine solution treatment temperature for age hardening of the Al-Cu aerospace aluminum alloy. If the Al-Cu alloy (containing less then 5.7%Cu) is slowly heated at above-solvus temperature (and below liquid us temperature), the particles of $CuAl_2$ are absorbed until a single-phase solid solution comprising of α-phase is obtained. On quenching the alloy, It's retain the copper in solution, and in fact, produce a supersaturated solution of copper in aluminum at room temperature, it is found that strength and hardness gradually increases and reaches a maximum in several days. The completely α-phase structure obtained by quenching is not the equilibrium structure at room temperature. It is in fact supersaturated with copper, so copper atoms diffuse out according to the following phase transformation:

$$\longrightarrow Cu + 2Al \qquad \theta` \qquad (1)$$

where: θ`: Intermediate coherent precipitates of $CuAl_2$.

The precipitation of θ` (see Eq.1) in the microstructure of the 2xxx series Al-Cu alloy greatly increases strength renders the materials suitable for aerospace applications **[Askland and Phule, 2003]**. Quenching of aluminum alloys includes heating to **465- 565** ºC and rapid cooling in order to obtain a supersaturated solid solution. Then the alloys are subjected to aging at different temperatures in order to obtain the requisite strength and plasticity. Minimum warping and minimum internal stresses are obtained by changing the cooling rate in quenching. It is known that well-mixed cold water is a good quenching medium that provides high strength characteristics for the alloys. Unfortunately, high cooling rates in cold water cause a considerable temperature gradient that leads to the appearance of residual stresses, warping and quite often the initiation of cracks.

By increasing the temperature of the quenching medium the temperature gradient in the quenched parts can be decreased while decreasing or eliminating the warping. It should be noted that parts produced from aluminum alloys often have a complex geometry **[Sverdlin and Totten, 1996].** One of the ways to decrease warping while preserving the requisite mechanical characteristics consists in using aqueous solutions of polymers as a quenching liquid. In this case the coefficient of convective (film) heat exchange between the part and the quenching medium is decreased, which decreases the rate of heat removal from the surface of the part and improves the uniformity of the temperature distribution in the volume of massive parts with a variable cross section. Estimated the possibility of using well-known (PAG polymer) for quenching aluminum alloys for the aircraft industry **[Sverdlin and Totten, 1996]**

Aqueous solutions of poly alkylene glycol (PAG) are used to improve the cooling characteristics of the quenching medium and to reduce the machining requirements after the heat treatment. PAG concentrations vary from 4 to 30%, depending on the type of product being processed. For the heat treatment of aluminum alloys, such polymeric solutions have been widely applied during more than 30 years **[Sarmiento and Coscia, 2000]**

The objective of the research reported in the paper aims at studying difference between quenching ways (water and 30%polyethylene glycol) on properties such as micro hardness, microstructure and compression resistance.

EXPERIMSNTAL WORK

Chemical Composition of the Alloy

The Al-based alloys used in this research are shown in **Table 1**.

Sample Preparation

Specimens were prepared firstly, by casting process and then machined to the required dimensions. These ingots were prepared as follows:

Casting Process

Casting process includes die designing and manufacturing. Ingots as shown in **Figure 1** were prepared by melting aluminum at 675 ºC then remain for 5 minutes after each element addition and then cast in especially design. Steel die which is designed and manufactured with dimension and tolerance with respect to the required ingot as shown in **Fig. 2**.

Specimen Machining

Heat Treatment of Specimens

Heat treatment usually includes three main stages namely:

Solution Heat Treatment

Heating alloys into solid solution at 510 ºC (ASM, Aerospace Specification Metals), for tow hours, then the specimens quenched by different ways of cooling.

Quenching

Water, and polymer solutions are common quenching mediums for aluminum alloy are used in this studied. The mediums differ in the rate at which they dissipate heat out of a quenched part. Medium of polyethylene glycol have [30%PAG + 70% water].

Aging

The final stage to optimize properties in the heat treatable aluminum alloys was aging. Artificial aging at temperature 175 ºC for 5 hour is used only.

Mechanical Testing

Many mechanical testing have been done.

Hardness Test

Appropriate grinding and polishing were done before subject specimens to hardness tests.

A Vickers micro hardness testing machine type [**TH-717**, **Digital Micro Vickers Hardness Tester**] used to conduct the test with a load of 100g for 20 sec. as shown in **Fig. 3.**

Compression Resistance Test

Specimens for compression resistance have diameter (d=12mm) and length (L=10mm) are used.

Specimen Preparation for Microscopic Analysis

The specimens were prepared in consistent with the standard metallographic techniques. The ultimate objective of such a process was to obtain a flat scratch free, mirror like surface.

Standard metallographic examinations using optical microscopy type (**Union/ME-3154**) was used to reveal the specimens structures **Fig. 4.**

RESULTS AND DISCUSSION

The results are presented and discussed under various aspects difference between quenching in two mediums (polyethylene glycol and water) and note the difference by compared the results obtained in each parts of work microstructure, and mechanical properties such as (compression resistance and micro hardness properties).

Thermal Stability Test

The little change in hardness at 175 ºC with aging time indicate to thermal stability at these temperatures. The relationship between Vickers hardness and exposure time at temperature 175 ºC appears in **Fig. 5**.

From **Fig. 5** concluded alloy (quenched in 30% PAG) has maximum value of hardness (at aging time 3 hr.) was 150 kg/mm^2, and the same alloy (quenched in water) have maximum value of hardness (at aging time 3 hr.) was 170 kg/mm^2 because the medium of water was faster quenching than PAG, and grain size in alloy (quenched in water) become very small, these reasons cause high hardness.

Figure 5 appears that alloy (quenched in 30% PAG) have stability in values of hardness in a most of aging time than same alloy (quenched in water) because the following reasons: first, the quenching in pure water originates the very high residual stresses, which lowered by addition of PAG polymer quench ant to the bath, and second, the quenching with a concentration of 30% of this polymer gives a product free from residual stresses.

Compression Resistance Test

The relationship between force and deflection at temperature 175ºC with aging time 3 hour appears in **Fig. 6.** From **Fig. 6** that the deflection of alloy (quenching in 30% polyethylene glycol) improved comparison to the alloy (quenching in water) because when quenching alloy in polyethylene glycol that cause to reducing residual stresses and producing uniform in precipitate along grain size.

Optical Microscope Testing

The microstructure of as cast alloys that used in this study shown in **Fig. 7**.

This structure was obtained from the ingot which has been cooled quickly to obtain equi-axed network structure. This network structure is made up of particles of several intermetallic compounds formed by combinations of the alloying elements in this alloy. Some of these compounds are soluble while others have slight or practically insolubility. In cast condition, this alloy contains grain boundary precipitate phases along the grain boundary and near the grain boundary as shown in **Figure 7**.

The following **Figure 8** appear microstructure of alloy sample that quenching in two different mediums (water and 30% polyethylene glycol) with aging temperature at 175 °C .

From **Fig. 8** It can be seen that alloy (quenched in 30% polyethelene glycol) have precipitates in structure, the grains sizes homogenizing.

Generally when these figures are compared it can be obtained that the microstructure of alloys consists of shape, size and uniform distributing for grains.

The effect of aging on alloys are not appeared in optical microscopy because magnification and resolution not enough to photo and analysis the results

CONCLUSION

According to results of present work, the following can be concluded:

1- Quenching in medium of 30% polyethylene glycol improves most of properties of alloy that used in this study such as compression resistance, microstructure and thermal stability for alloy at the most aging times especially at 175 ºC.

2- Thermal stability improved when quenching alloy in 30% PAG at aging temperature 175ºC in comparison to the base alloy when quenching in water.

3- Deflection of alloy that quenching alloy in 30% PAG less comparison to the base alloy when quenching in water.

REFERENCES

[1]Özbec İ, " Materials Characterization ", 2007.

[2]Xie C. Y, Schaller R, and Jaquerod , " Materials Sc and Eng. ", 1998.

[3]Huda Z, Saufi M, Shaifulazuar J. , " Industrial Technology ", Vol. 15, No.2, pp.127, 2006.

[4]Kacer H, Atik E and Meric C, " Materials Processing Tech. ", Vol. 142, No. 3, pp. 762, 2003.

[5]Degarmo P., Black J. T., and Kohser R.A., "Materials and Processing in Manufacturing ", John Wiley Publications, 2003.

[6]John V.B., " Engineering Materials ", MacMillan Press, London, 1990.

[7]Askland D.R, and Phule P.P," The Science and Engineering of Materials," Thomson Books Inc USA, 2003.

[8]Sverdlin, A., and Totten, G.,"Cooling Media ", Metal Sience and Heat treatment, Vol. 38, No. 6, pp. 14-17, June 1996.

[9]Sarmiento, Coscia, Jouglard, Totten, Webster and Vega, " Residual stresses, distortion and heat transfer coefficients of 7075 aluminum alloy probs quenched in water and polyalkylene glycol solutions ", ASM International, Materials Park, Ohio, pp. 1118-1124, October, 2000.

[10]ASM Aerospace Specification Metals Inc., " ASM Material Data Sheet ", on the web:
http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA7075T6

Table 1 The composition of Al-base alloy used in research

Element / Wt%	Cu	Fe	Mg	Al
Stand.	4.1	0.7	0.8	Bal
Exp.	4.3	0.7	0.6	Bal.

Figure 1 Rod ingots.

Figure 2 Steel die.

Figure 3 The digital micro Vickers hardness tester was used to conduct the test with a load of 100g for 20 sec.

Figure 4 Optical microscopy used to reveal the specimens structures.

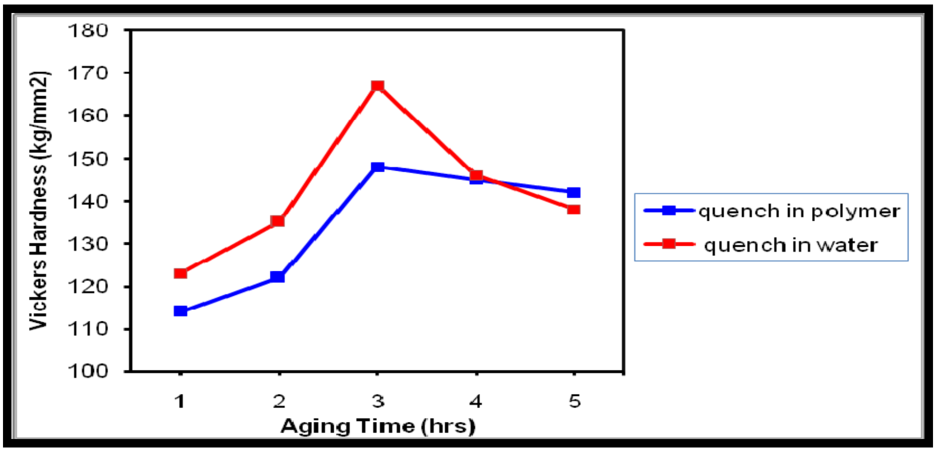


Figure 5 Variation of hardness of alloy sample (quenching in a: water medium, b: 30% polyethylene glycol medium) with ageing temperature at 175°C.

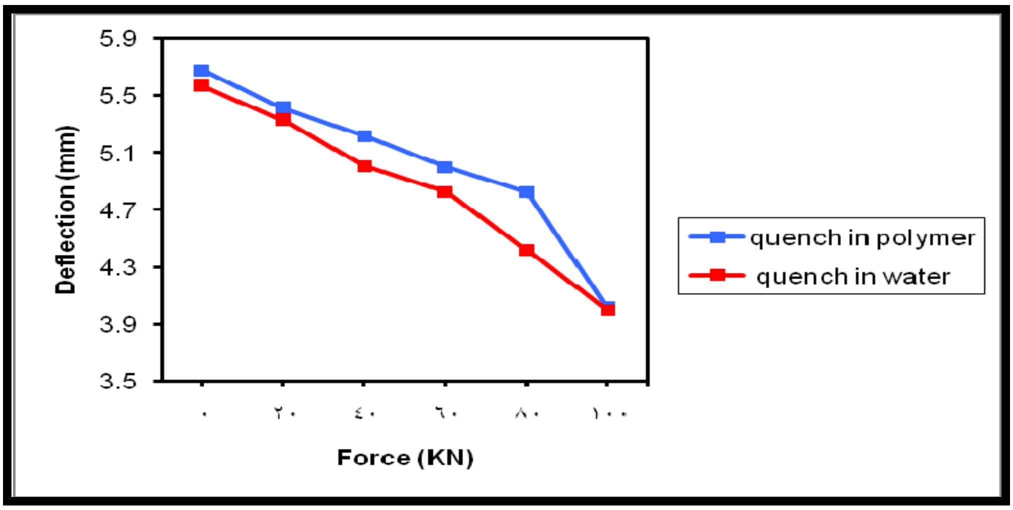


Figure 6 Variation of deflection of alloy sample (quenching in a: water medium, b: 30% polyethylene glycol medium) with ageing temperature at 175°C.

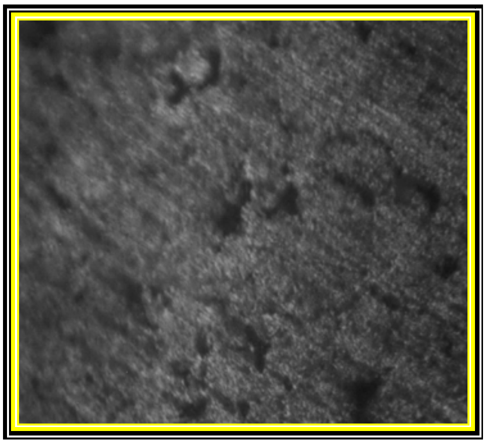
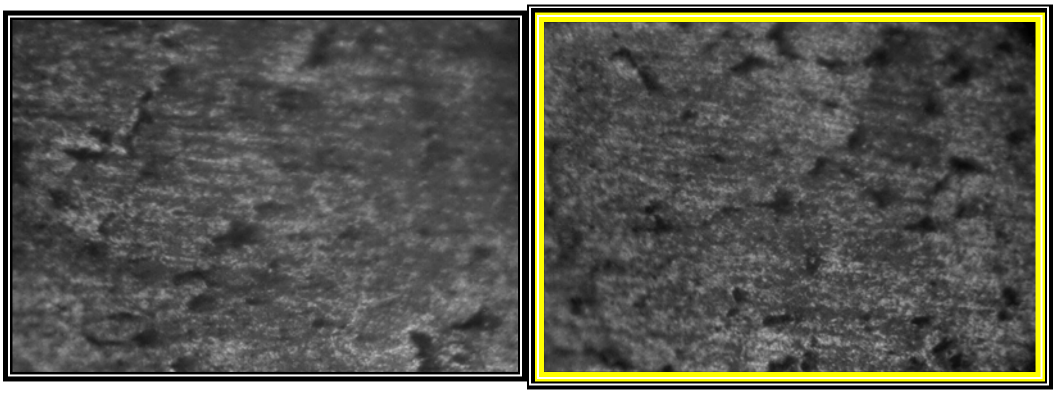


Figure 7 Microstructure of cast alloy, 150 X.



- a - - b -

Figure 8 Microstructure of alloy sample: a – quenching in water, b- quenching in 30% polyethylene glycol. (Ageing time at 175 °C), 150X.