Journal of Kerbala University , Vol. 6 No.1 Scientific .March. 2008

Effect of Heat Treatments on the Impact Toughness and Hardness of (2024) Aluminum alloy

تأثير المعاملات الحرارية على متانة الصدمة والصلادة لسبيكة الألمنيوم(٢٠٢٤)

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Abstract :

Excellent formability , low weight , Good weldability , Resistance to hot tearing and high tensile and fracture property are among the attractive charactersistics of (2024) aluminum alloy . The effect of solution treatment temperature , Aging time and the aging temperature on the machanical properties have been studied using impact and hardness testing . Microstructural changes were abserved using metallugical microscope .The increase in solution treatment temperature from 525 to 575 Cº resulted in an increase in the hardness and impact toughness was improved from 525 to 550 Cº and decrease at 575 Cº .When the aging time was increased from 3 to 21 hrs. (with an interval of 6 hrs). at 175C , the hardness increased , While the impact toughness decreased . When the aging temperature was increase from 160 to 190 Cº (with an interval of 15Cº) ,The hardness increased , however the impact toughness decreased . The effect of heat treatments investigated in the present study was attributed to the microstractural change during this treatment , in the light of the results of the microstructral examination and concerned published literature .

الخلاصـــة :

سهولة التشغيل والتشكيل وخفة الوزن واللحام الجيد ومقاومة الشد العالية ومستوى جيد لخاصية الكسر هذه سمات تميزت بها سبيكة الألمنيوم (٢٠٢٤) .هذه الدراسة تمثل تأثير درجة الحرارة المعاملة المحلولية ، زمن ودرجة حرارة التعتيق على الخواص الميكانيكية باستخدام اختبار متانة الصدمة وكذلك اختبار الصلادة وتغيرات البنية المجهرية باستعمال المجهر الضوئي . زيادة درجة الحرارة المعاملة المحلوية من ٥٢٥ إلى Cº 575 سبب زيادة في الصلادة وكذلك تحسن في متانة الصدمة من درجة حرارة ٥٢٥ الى Cº 550 يعقبها انخفاض عند درجة حرارة 575Cº . عند زيادة زمن التعتيق من ٣ الى ٢١ ساعة بدرجة حرارة 175Cº فالصلادة قد ازدادت بينما مقاومة الصدمة قلت وعندما ازدادت درجة حرارة التعتيق من ١٦٠ إلى Cº 190 فان الصلادة قد زادت بينما متانة الصدمة قلت أيضا .تأثيرات المعاملة الحرارية التي تم التطرق إليها في هذه الدراسة ساهمت وبشكل كبير في تغيرات البنية المجهرية خلال هذه المعاملات .

Introduction :

The phenomenon of precipitation hardening was first discover in an (Al-Cu) alloys by the Alfred wilm in 1906. One of the most widely used alloys in aeronautical industry is (2024) which was introduced in the 1930 [1] . Precipitation hardening in the most common method to increase the strength of the heat treatable aluminum alloys such as (2024) . This method includes a solution heat treatment at high temperature to maximize solubility , followed by rapid cooling or quenching in water to obtain a solid solution super saturated with both solute elements (Mg and Si) vacancies , followed by aging heat treatment (which may include either natural aging or artificial aging) to produce finely dispersed precipitate at as [2,3] .Solution heat treatment is designed to maximize the solubility of solute elements which are precipitated during subsequent aging . It most effective when carried out near the solid us , where maximum solubility exists and diffusion rates are rapid [4].The transitional (metastable) forms of equilibrium precipitate such as (Mg_2Si) and (Al_2CuMg) and others can be produced by artificial aging at temperature above the room temperature these transitional precipitates remain coherent with solid solution matrix and thus contribute to strengthening . Strength of the aged (2024) is increased with increasing temperature and time of aging until it reaches maximum values . Further heating at higher temperatures and / or time of longer periods can produced equilibrium precipitates , which are coherent and cause softening of the alloys [5] .Intensive research during the past fifty years has resulted in progressive accumulation of knowledge concerning the aging treatment and phases structure changes that occur during precipitation and the mechanisms through which this treatment and structures forms alter alloy properties [6].

Experimental work :

The aim of this experimental work is to study the mechanical properties of (2024) aluminum alloy under different condition of heat treatment . the program of experimental was divided as follows :.

- Heat treatment include solid solution heat treatment and artificial aging at different times and temperature .
- Study of the effect of heat treatment upon the charpy impact and Vickers hardness properties .
- Micro structure

1- Material

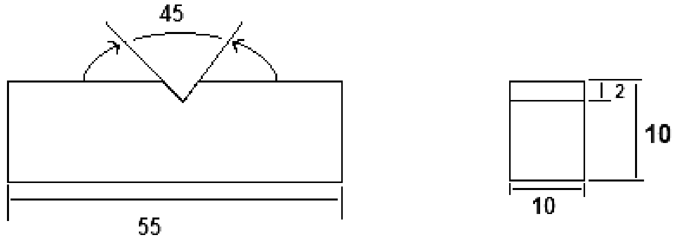
The material under study is (2024) aluminum alloy at annealed condition . The chemical composition of this alloy is given in table (1).

Table (1) Chemical Composition of (2024) alloy

Element	Si	Fe	Cu	Mn	Zn	Mg	Al
Wt %	0.30	0.23	4.27	0.74	0.20	0.38	Bal .

2- Specimen preparation

After solid solution heat treatment , the sub size standard (55 *10*10 mm) impact test specimens had been prepared using milling machine . The specimens were cat from the plate according to the ASTM standard B557M-94 from aluminum alloys .Figure (1) Shows the Charpy impact test specimen.



Dimensions in mm .

Fig (1) Impact Test Specimen

3- Heat Treatment Apparatus

An electrically heated furnace (Heraeus) has been used for heat treatment of the specimens . It was used for solid solution heat treatment and also the artificial aging .

Quenching of the specimens was perfumed by immersion in water at room temperature , maximum delay time was 10 sec., from furnace to water tank.

4- Testing Machine

An instrumented impact testing machine 300 joule has been used to carry out the Charpy impact test . The hammer velocity 5.2 m/s . Each reported of impact test is the average result of separate measurements on three specimens .

The shape and dimensions of specimens used for hardness are one half of the pre-tested impact specimens .load of (100g) for constant duration of 30 sec. was used in all tests .Each value was obtained from the average of at least three measurements.

5- Heat treatment and Aging Process

The heat treatment process for the specimens under includes solid solution heat treatment at 525,550 and 575 Cº respectively for 1 hrs . and then were quenched in water at room temperature , after that artificial aging treatment for different time from 3 hrs to 21 hrs with interval time for 6 hrs. at temperatures 160,175 and 190 Cº.

6- Microstructure Examination

For optical microscopy , cubic specimens of (10*10*10 mm) were used polishing papers to prevent particles of polishing paper from getting embedded in the soft aluminum matrix . After this , the lapping clothes were used .The aluminum suspension were used with (6 µm) suspension . The specimens were etched by using kellers reagent of chemical composition (1 cm^3 Hf , 1.5 cm^3 Hcl , 2.5 cm^3 HNO3 and 95 cm^3 H2O) .

Results and discussion

The mechanical properties of aluminum alloy of various heat treatments and aging conditions were investigated . The study of the mechanical properties includes the charpy impact toughness and Vickers hardness .

The heat treatment carried out involved several stages [7]:

1.Solution at treatment carried at relatively high temperature within the single-phase region at about 525 Cº or more , to dissolve the alloying elements .

2.Quenching in water , to obtain a super saturated solid solution of alloying elements in aluminum .

3.Controlled decomposition super saturated solid solution to from a finely dispersed precipitate .

The complete decomposition of (2024) super saturated solid solution involves several stages . Guniner-Preston zone (GPZ) and an intermediate precipitates of (Al2CuMg) in the form of S and equilibrium phase in the form of (Mg2Si) .

The intermediate precipitates and equilibrium are much larger in size then the (GPZ) and are only coherent with the lattice plants of the matrix . This is due to that the intermediate precipitate differs then the matrix structure . Whereas the (GPZ) are formed within the matrix . The intermediate precipitate may be nucleated from , or at , the sites of the stable (GPZ) . However can be nucleated heterogeneously at lattice defects such as dislocation and vacancies [8,9].

1- Effect of Solid Solution Temperature .

Specimens were heat treated a different solid solution temperatures (525,550 and 575 Cº) followed by water quenching and artificial aging at 175Cº .

Figure (2) shows the absorbed energy by impact toughness as a function of solution treatment temperature . with the solution temperature being increase from 525 to 550 Cº , The absorbed energy increases from 18.2 to 20.4 joule , When solution treated at 575 Cº the absorbed energy decreases to 19.6 joule .

Figure (3) shows the microhardness (HV) as a function of solution treatment temperature , with the solution temperature increase from 525 to 575 Cº the Vickers hardness increase almost linearly from 90 to 115 HV .

Increasing the solid solution heat treatment temperature has both positive and negative effect of the fracture toughness , this treatment reduced the volume fraction of both insoluble and soluble inclusion , these effect are expected to increase with solution treatment temperature will also result in a higher number of quenched – invacancies , which will lead to a smaller average size of precipitates as discussed above . These effect of increasing the solid solution treatment temperature on the inclusions and precipitates enhance the fracture toughness [10]

On the other hand increasing the solid solution treatment temperature may have negative effect on fracture toughness . The increase in the number of the fine precipitates would increase the possible sites for void initiation in the void sheets between the large voids initiated a round the inclusion , as discussed above . Also , the will serve to active smaller and smaller particles as void nucleating agent . In addition ,the grain size increases with increasing the solid solution temperature . All these changes are expected to reduce the fracture toughness [8,10] .

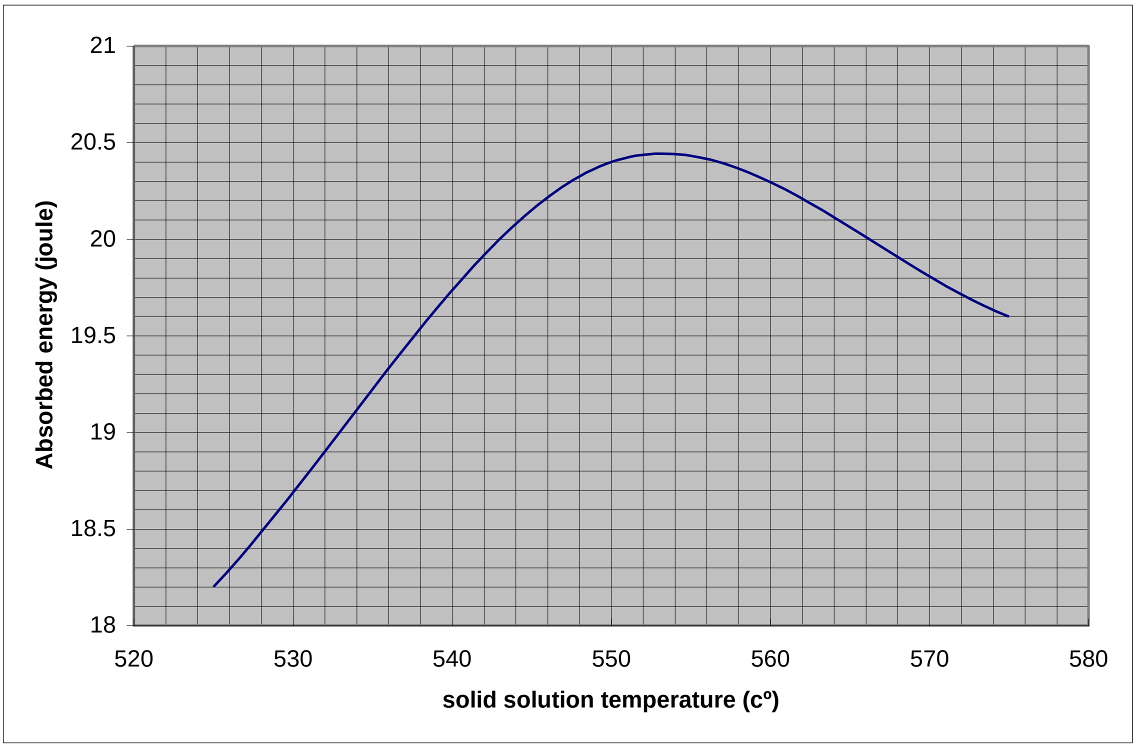


Fig.(2) Effect of Solid Solution Temperature on the Charpy Impact Toughness.

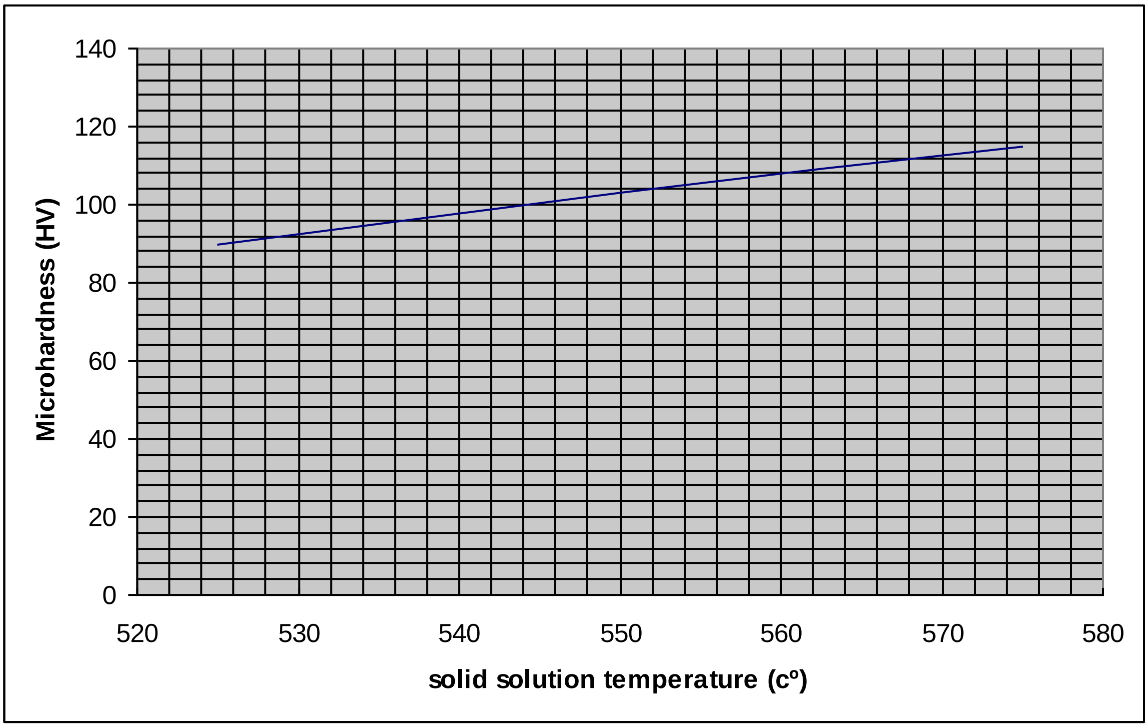


Fig. (3) Effect of Solid Solution Temperature On the Vickers Hardness

2- Effect of Artificial Aging Time

Figure (4) shows the absorbed energy as a function of the artificial aging . When the aging increase from 3 to 21 hrs , the absorbed energy decreases from 38 to15 joule .

Figure (5) shows the microhardness (HV) as a function of the Artificial aging time . when the aging increases from 3hrs to 9 hrs , the Vickers hardness increased almost linearly from 72 to 88 HV, When the aging time increases from 9 hrs to 15hrs , the Vickers hardness increases from 88 to 93 HV. When the aging time increases from 15 hrs to 21hrs, the Vickers hardness increases from 93 to 102 HV.

The second phase particles present in such heat treatable Al alloy are (i) The constituent particles , which are coarse intermetallic compound , (ii)The dispersions , and (iii)The hardening precipitates . The first two formed before the aging treatment are not affected by the aging temperature on the aging time . The hardening precipitates are formed during the aging process and are affected by both the aging temperature and time [11] .

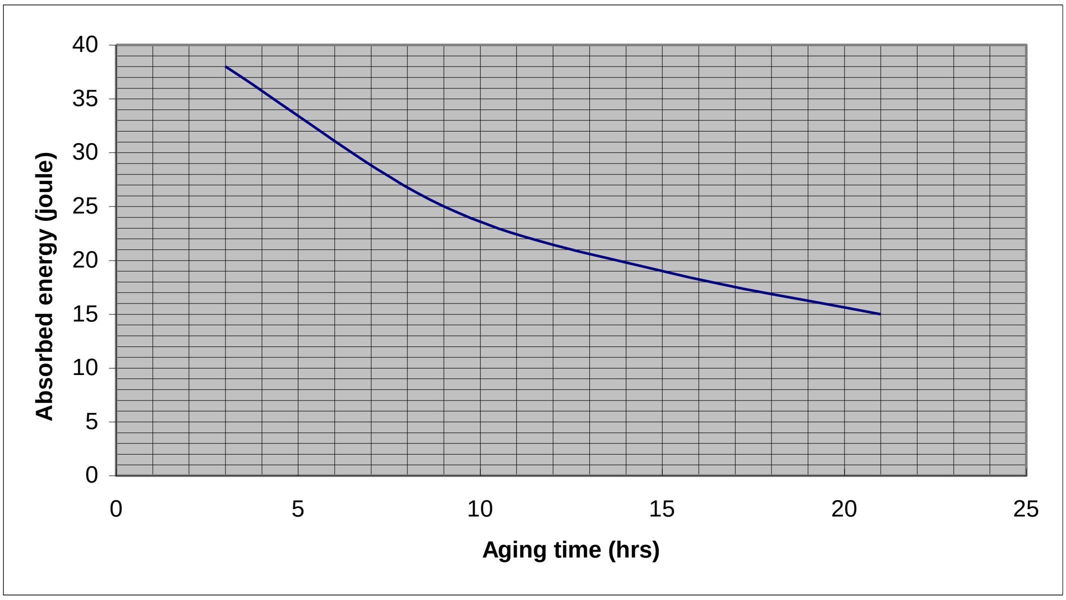


Fig.(4) Effect of Aging Time on Charpy Impact Toughness .

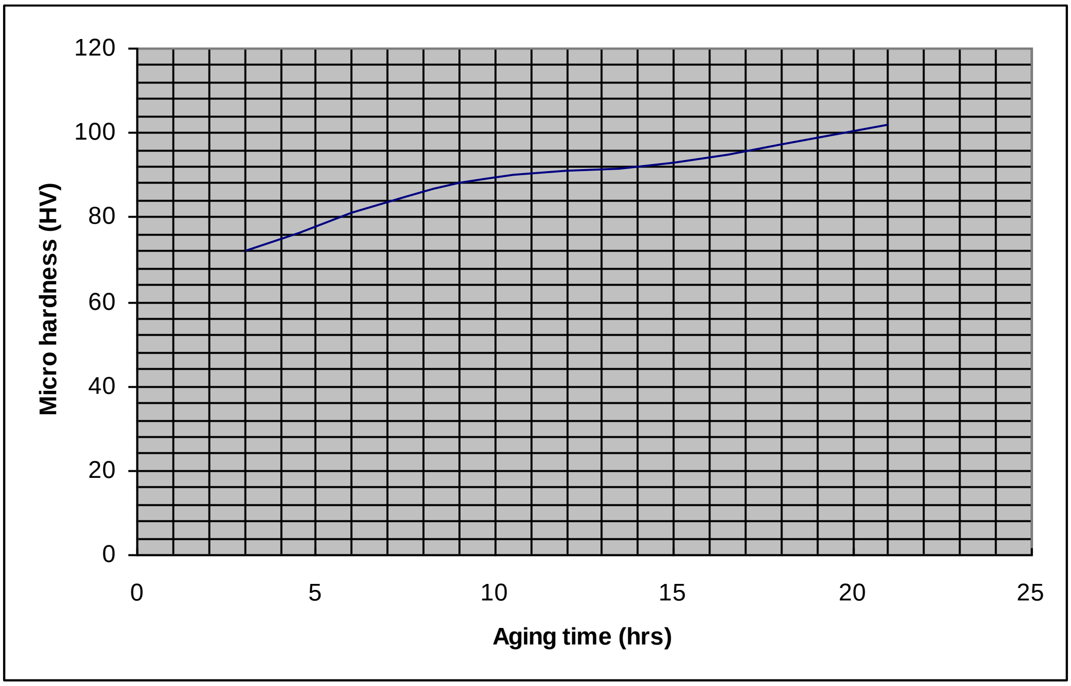


Fig. (5) Effect of Aging Time on Vickers Hardness.

3- Effect of Aging Temperature

Figure (6) shows the absorbed energy as a function of the aging temperature . When the aging temperature increased from 160 to 190 C º , the absorbed impact energy decreased from 28 to 17 joule

Figure (7) shows the microhardness (HV) as a function of the artificial aging temperature . When the aging temperature increase from 160 to 190 C º , the Vickers hardness increased from 85 to 105 HV .

According to the nucleation theories of the age hardening precipitates , the precipitates in the (2024) alloy nucleate homogenously below the aging temperature of 200 C º as shown by Murakami[12]. The homogenous nucleation theories based on the critical temperature (Tc) of the GP zone solves were discussed in detail by Loimer and Nicholson [13] and Pashely[14] raising the aging temperature in coarsening and high volume fraction of precipitates , this explain the increase in strength and hardness with the aging temperature .

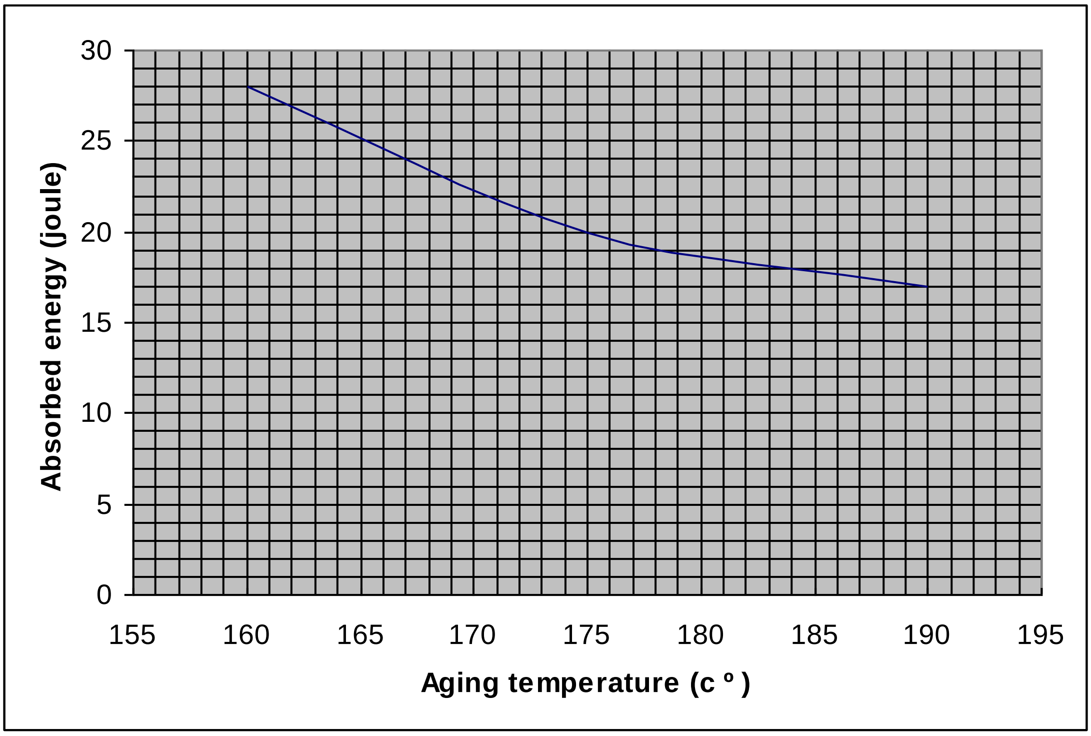


Fig.(6) Effect of Aging Temperature on the Impact Toughness

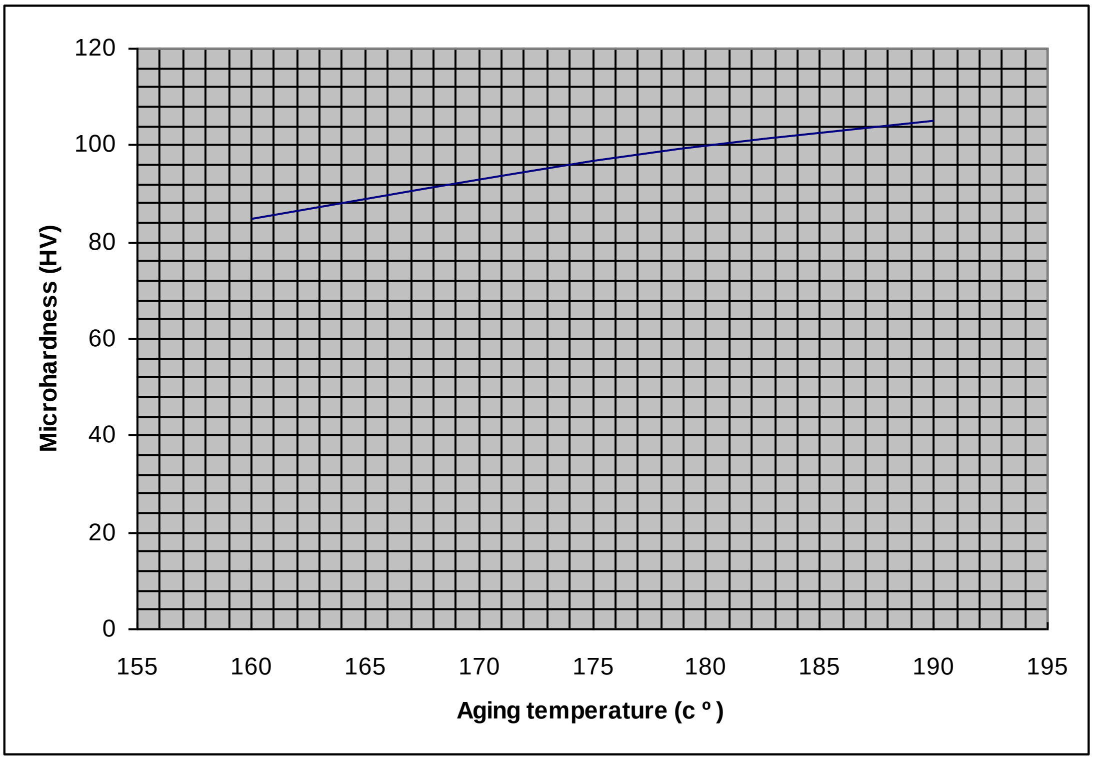


Fig.(7) Effect of Aging Temperature On Vickers Hardness

4- Metallography

Figure (8) show 2024 aluminum alloy in the as received (annealed)
Figure (9) show the same alloy at 575C° solution heat treatment for 1 hr.
Figure (10) show 2024 aluminum alloy in T6 condition small precipitates uniformly distributed at grain and grain boundaries

In general , the Metallography of aluminum and its alloys is a hard job in that aluminum alloys represent a great variety of chemical composition and thus a wide range of hardness and different chemical properties . Therefore the techniques required for metallographic examination may very considerably between soft and hard alloys . More over , one specific alloy can contain several microstructural features , Like matrix second phases , dispersions, grains, sub-grains and grain boundaries or sub – boundaries according to the type of alloy used [7,10].

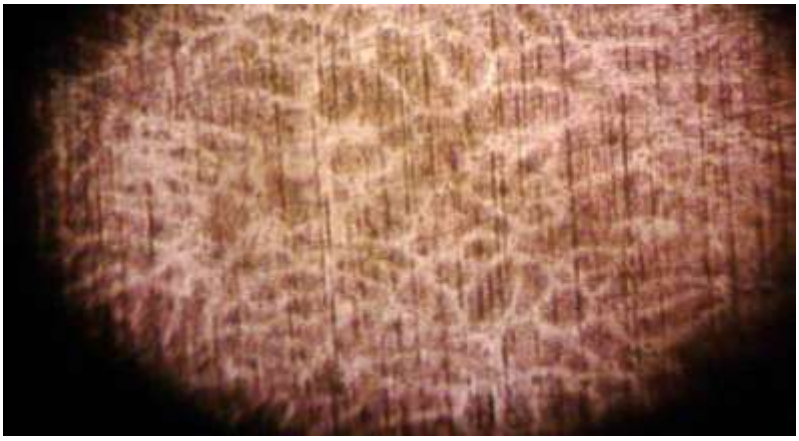


Fig. (8) Aluminum alloy (2024)

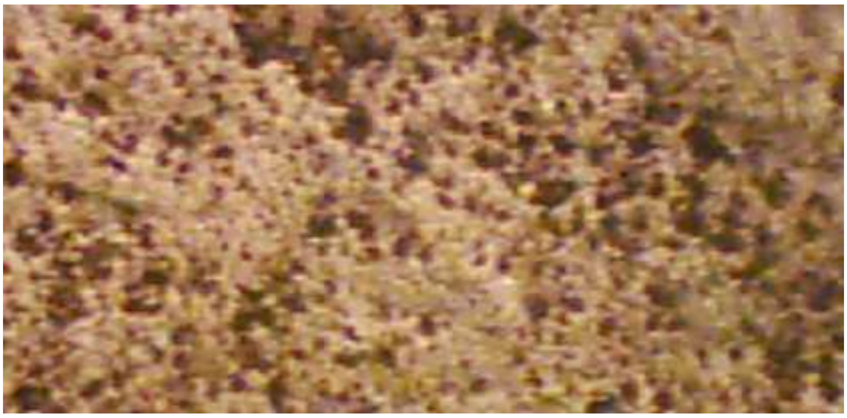


Fig.(9) Aluminum alloy (2024) at 575C Solution Heat Treatment

Fig.(10)Aluminum alloy (2024) at T6 condition

Conclusion

1. A charge in solution treatment temperature from 525 to 575 Cº resulted in hardness from 90 to 115 HV .
2. The Charpy impact toughness is improved by increasing the solid solution heat treatment temperature from 525 to 550 Cº, then decreases at 575 Cº.
3. The increase of aging time from 3 to 21 hrs (with interval of 6 hrs) at 175 Cº resulted in increasing the hardness . on the other hand the Chapy impact toughness decrease from 38 to 15 joule.
4. The increase of aging temperature from 160 to 190 Cº (with interval 15Cº) resulted in increasing hardness from 85 to 115 HV . on other hand the Charpy impact decrease from 28 to 17 joule .

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