

## Investigation of the Properties of Heat Treated Rolled Aluminum Zinc Alloy (7072-T6)

(Ass. Lect.) Kamal Abdulkareem Mohammed

Mechanical Engineering Department, College of Engineering  
Al-Mustaniriya University

E-Mail: kamalabdulkareem@yahoo.com

### ABSTRACT

The effects of heat treatment on the properties of rolled aluminum zinc alloy type 7072-T6 are studied in this work. Representative samples of aluminum zinc alloys were subjected to heat treatment processes which are; Solution heat treatment followed by Artificial Ageing in the different order. The aluminum zinc alloys were heated to the initial temperature of 600 °C and water quenched. The quenched aluminum zinc alloys were subjected to (lamellae formation) by reheating it to the dual-phase region at a temperature of 150°C and then rapidly quenched in water. The (lamellae formation) samples were taken and Artificial Ageing at 400 °C to provide an alloy containing strong, tough and lath  $\alpha - \beta$  phase in a soft and ductile  $\alpha$  - matrix. Mechanical tests were carried out on the samples and the results show that the aluminum zinc alloys developed has excellent combination of tensile strength, hardness and impact strength which is very good for structural applications.

**Keywords:** Aluminum-Zinc alloys (A7072-T6). Heat Treatment. Mechanical Properties.

### الخلاصة

البحث بشكل محدد في دراسة تأثيرات المعاملات الحرارية على خواص سبيكة الألمنيوم - خارصين (7072-T6). أخضعت نماذج السبيكة موضوعة البحث إلى مجموعة من المعاملات الحرارية (التقسية، تشكيل صفائح والمراجعة)، حيث سخنت سبيكة الألمنيوم- خارصين إلى درجة حرارة أولية بمقدار (400 °C) وإجراء التقسية مما أدى إلى تحول الأطوار إلى منطقة ثنائي الطور بدرجة حرارة (150 °C). تم إجراء عملية المراجعة بدرجة (400 °C) لغرض الحصول على الأطوار (ثنائية الطور) ذات المتانة والقوة اللازمة. بينت نتائج الاختبارات الميكانيكية التي أجريت على النماذج المخبرية تحسن سبيكة الألمنيوم- خارصين من حيث قوة الشد والصدمة وكذلك الصلابة وهذا بدوره يزيد من إمكانية استخدام السبيكة في التراكيب الهندسية.

## Introduction

In order to use wrought aluminum alloys for structural components, it is important to improve their mechanical properties on resistance to corrosion and formability as well as strength for high reliability, good design and weight saving. Due to the fact, the grain refinement of aluminum alloy sheets is one useful method to achieve high strength.

In prior studies <sup>[1,2,3]</sup> it was revealed that control of roll temperature and addition of some alloying elements are important to refine microstructures of AA7072 based aluminum alloy sheets after a solution heat treatment.

Heat treatment involves the application of heat to a material in order to bring about changes in the microstructure and, hence, modify the material properties. During the heat treatment process, the material usually undergoes phase microstructural and crystallographic changes <sup>[4,5]</sup>. The purpose of heat treating A7072 is to change the mechanical properties of aluminum, usually ductility, hardness, yield strength tensile strength and impact resistance. The impact strength of the heat-treated specimens are higher than that of the as rolled; This is as a result of the lath microstructure formed during the heat treatment processes which is very strong <sup>[6]</sup>. The electrical, corrosion and thermal conductivity are also slightly altered during heat treatment process.

When A7072 are annealed between the 200<sup>0</sup>C and 400<sup>0</sup>C and then water quenched, due to partial transformation taking place, a dual phase structure, i.e., a mixture embedded islands within the grains of  $\alpha$  is usually obtained <sup>[7,8]</sup>. A uniform microstructure with appropriate volume ratio, geometry and aspect ratio of  $\beta$ - phase islands are often assigned suitable for mechanical properties assessments <sup>[9]</sup>. Dual phase A7072 are preferred in the military application due to their low density and high load bearing capacity <sup>[10]</sup>. There have been many investigations on the microstructural development and mechanical properties of dual phase A7072. It has generally been found that rather than the size, the volume fraction of  $\alpha$ -islands is very effective on tensile properties <sup>[11]</sup>. Increasing the amount of  $\alpha$ -phase reduces the percent elongation considerably. Dual phase A7072 mostly have low yield strength, but on the contrary have high strain hardening rates during deformation <sup>[12]</sup>. It is not possible to find any study focusing on the effects of initial grain sizes on microstructure and mostly on toughness of the A7072. It has been verified that microstructure particularly after an intermediate treatment is different from that after an annealing process <sup>[13]</sup>. Thus, formation of fine grain after intermediate treatments mostly degrades the tensile properties, but the percent

elongation of the A7072 increases gradually. This has been attributed to an increase in the density of mobile dislocations in  $\alpha$ - islands, while the mean grain size and the inter-particle distance between fines  $\alpha$ - islands becomes smaller <sup>[14]</sup>. This research work was carried out to determine the effect of heat treatment processes on locally hot / or cold rolled aluminum alloys type 7072-T6 and evaluate the

effect of the heat treatment processes (annealing) on the mechanical properties at the dual-phase region.

Therefore, the mechanical properties of AL-Zn alloys under such conditions should be investigated for mechanical applications.

In this study, a new type of roll embedded cylindrical heaters was used and prevented reduction of sample temperature in the rolling process. Having all into consideration, the aim of the present work is to investigate the effect of the heat treatments on rolled A7072 and rolling reduction on the room temperature mechanical properties of the heat treated A7072 with emphasizing on microstructural evolution during rolling such as (lamellae formation).

## Materials and Experimental Methods

### Materials

The material used in this study was 12 mm strip of A7072 –T6 alloys. Samples of the A7072 -T6 were collected and prepared into tensile, impact, hardness, and metallographic examination specimens. The spectrometric analysis of the Aluminum alloy was carried out to determine its chemical composition. The result is shown in Table 1.

Alloy elements		Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Standard <sup>[6,11]</sup>	Mass %	≤0.35	≤0.4	≤0.2	0.05-0.5	1-1.5	4.5	≤0.08	0.1-0.35	Balance
Measured		0.24	0.27	0.1	0.08	1.23	4.16	0.03	0.15	Balance

### Methods

#### Determination of **Annealing** Temperatures

The lower temperature and upper annealing temperature were determined by phase diagram <sup>[15]</sup> as presented below; Figure 1 phase

diagram for Al-Zn alloy, The temperatures range is between 150<sup>0</sup>C and 450<sup>0</sup>C .

## Heat Treatment Processes

Figure 1, show that  $\alpha$ -phase only exist within (Zn=4.16%) at (200 °C) and (550 °C), this was used as the lamellae formation temperatures. Experimental samples of as-rolled A7072-T6 were subjected to three sets of different heat treatment processes in the following order;

### 1. Quenching and Artificial Ageing (QAA).

The A7072 specimens were heated to the temperature of 500 °C, as annealing temperature soaked for 20 minutes and quenched in water; the specimens were finally artificial ageing at a temperature of 400 °C for 30 minutes ( sample A<sub>3</sub>). The same process was also repeated where artificial ageing was carried out at 200 °C, soaked for 20 minutes and quenched in water (sample A<sub>4</sub>).

### 2. Lamellae Formation and Artificial Ageing (LAA).

The specimens were subjected to lamellae formation by heating them to the  $\alpha$ -phase region at a temperature of 500 °C, soaked for 20 minutes and quenched in water. The specimens were finally artificial ageing at a temperature of 300 °C for 30 minutes (sample A<sub>5</sub>). The same process was also repeated where lamellae formation was carried out at 400 °C, soaked for 20 minutes and quenched in water which (sample A<sub>6</sub>).

### 3. Quenching, Lamellae Formation and Artificial Ageing(QLAA).

The A7072-T6 specimens were heated to the temperature of 500 °C, soaked for 20 minutes and quenched in water; this process was repeated again before the specimens were thereafter subjected to lamellae formation by heating them to the dual-phase region at a temperature of 150°C, soaked for 20 minutes and quenched in water. The specimens were finally artificial ageing at a temperature of 400 °C for 30 minutes (sample A<sub>7</sub> ). The same process was also repeated where lamellae formation was carried out at 300 °C, soaked for 20 minutes and quenched in water which (sample A<sub>8</sub>).

## Mechanical Testing of Specimens

### Tensile test

Tensile test was carried out on the heat-treated and as-rolled aluminum zinc alloys for cold and hot rolled specimens using Universal Tensile Tester. The initial gauge length and thickness were measured before and after subjecting them to the test. The yield and maximum loads

were recorded directly from the resulted graph. The readings that were obtained were used in the determination of the yield strength ( $\sigma_y$ ), ultimate tensile strength ( $\sigma_u$ ), percentage elongation (%E) and Yield Ratio (YR). Table 2 Shows the mechanical properties of experimental specimens.

Figures show the tensile test curves

### Impact test

Representative samples of as-rolled (cold and hot rolled) and heat-treated specimens were subjected to impact test on an Izod V-Notch impact testing machine. The pendulum of the machine is allowed to swing freely through a known angle while energy was introduced to break the specimen. The energy was recorded directly on the scale attached to the machine.

### Hardness test

The hardness of as-rolled (cold and hot rolled) and heat-treated specimens were measured with the aid of Rockwell hardness tester Indented 2007 model. This machine measures the resistance to penetration by measuring the depth of impression and the hardness is indicated directly on the scale attached to the machine.

### Microstructural examination

Samples of as-rolled (cold and hot rolled) and heat-treated specimens were mounted on hot phenolic powder and ground with hand grinding set-up of abrasive papers (240, 320, 400 and 600 grades) that progress from coarsest to finest grit sizes using water as lubricant. Polishing was carried out on a rotating disc of a synthetic velvet polishing cloth impregnated with micron alumina paste. Final polishing was carried out with diamond paste. The specimens were then etched as given by the standard so as to reveal the microstructure grain boundaries. The optical microscopic examinations were carried out on a metallurgical microscope at a magnification of 200X. The specimens were illuminated with 100 kW detachable quartz iodine lamps.

### Results and Discussion

The tensile, hardness and impact energy results of the Al-Zn alloy specimens after various heat treatment processes are shown in fig 2 and 7.

### Mechanical properties

Figures 2,3 and 4 present the stress-strain curve of the heat treated specimens and as-rolled (cold and hot rolled). From the results in 2, it was

observed that, the ultimate tensile strength ( $\sigma_u$ ) and the percentage elongation of the aluminum zinc alloys developed by the heat treatment processes are higher than that of the as-rolled aluminum zinc alloys. The results show that sample **A<sub>7</sub>** with UTS of 620 MPa followed by sample **A<sub>6</sub>** with UTS of 610 MPa and sample **A<sub>8</sub>** with UTS of 600 MPa has the best ultimate tensile strengths respectively. It was observed that the yield strength of as-rolled is higher than that of the heat treated processes in the following order; the as-rolled has 580 MPa, sample **A<sub>1</sub>**, sample **A<sub>2</sub>** of 565 MPa and sample **A<sub>1</sub>**, **A<sub>2</sub>** of 500, 484 MPa respectively (Yield stress). The result shows that lamellae formation at 400 °C gives the best tensile properties. This was as a result of the strong deformable second phase structure formed during the heat treatment processes which consist of  $\alpha$  and  $\beta$  laminar. The strong second phase is dispersed in a soft ductile  $\alpha$  matrix.  $\alpha$  and  $\beta$  provides the strength in the AL-Zn alloys whereas the  $\alpha$  phase provides the ductility. The increase in ductility and the tensile strength leads to better formability and makes the AL-Zn alloys very attractive for use in cold-formed high strength components.

Figures 5 present the changes in the hardness values of the specimens. The Rockwell hardness values of the heat treated AL-Zn alloys are higher than that of the as-rolled AL-Zn alloys. From the results, it was observed that, sample **A<sub>7</sub>** has the best value of 62HRA followed by sample **A<sub>6</sub>** with a value of 61.5HRA and sample **A<sub>4</sub>**, **A<sub>6</sub>** with a value of 58HRA which was closely followed by sample **A<sub>3</sub>** with a value of 57.5HRA. This was probably due to the higher volume fraction of the harder  $\alpha$  -  $\beta$  matrix in the developed alloy. The transformation of  $\alpha$ - phase to  $\alpha$ - $\beta$  matrix by a diffusionless shear type transformation in quenching is also responsible for higher hardness obtained and this property is attributed to the effectiveness of the interstitial zinc in hindering the dislocation motion<sup>[16]</sup>.

Figures 6 present the impact energy of the heat treated specimens and as-rolled AL-Zn alloys. The impact strength of the heat-treated specimens is higher than that of the as-rolled. The result showed that sample **A<sub>5</sub>** has the highest value of 59.4J followed by sample **A<sub>6</sub>** with a value of 58.5J and sample **A<sub>7</sub>** with a value of 57.1J which was closely followed by sample **A<sub>3</sub>**, **A<sub>8</sub>** with a value of 56.6J. This is as a result of the lath  $\alpha$ - $\beta$  alloy formed during the heat treatment processes which is very strong and tough<sup>[17]</sup>.

## Microstructures

The microstructures obtained are shown in Figures 7a-e. The microstructure produced by the as-rolled (cold and hot rolled) consists of  $\alpha$  and  $\alpha$ - $\beta$  structure while the microstructures produced by the processes consist of a duplex  $\alpha$ - $\beta$  microstructure. The strong deformable second phase consists predominantly  $\beta$ - laminar with some  $\alpha$ - $\beta$  matrix and retained  $\alpha$ -phase. Laminar  $\beta$  provides the strength in the AL-Zn alloys whereas  $\alpha$ - phase provides the ductility. The strong second phase is dispersed in a soft ductile  $\alpha$ - matrix. From the lamellae formation and artificial aging and quenching, lamellae formation and artificial aging processes, it was observed that,  $\alpha$ - phase volume fraction was high resulting in lower yield strength. Also, the volume fraction of the second phase was observed to be low but the zinc content enhances the hardness, which in turn produce good tensile strength. This mechanism made the processes to produce low yield-to-tensile strength ratio of 80 to 70% when compares with that of the as-rolled sample with a ratio of 85 to 80%.

## Conclusion

The results from the research have shown that, the mechanical properties of rolled AL- Zn alloys type (7072 -T6) can be improved by these heat treatment processes. It was noticed that as the heat treatment processes increases from lamellae formation and artificial aging to quenching, lamellae formation and artificial aging, the improvement in the properties are enhanced. Also, lamellae formation at 400 °C tends to give best results in all the processes. It was observed that, the AL-Zn sample **A<sub>8</sub>** developed by quenching, lamellae formation and artificial aging processed at a lamellae formation temperature of 400 °C has the best ultimate tensile strength of 620 N.mm<sup>-2</sup>, yield ratio of 70%, hardness value of 61.50 HRA with excellent combination of impact strength of 56.6J which are very attractive for structural applications. This was followed by AL-Zn sample **A<sub>6</sub>** developed by lamellae formation and artificial aging processed at a lamellae formation temperature of 400 °C with ultimate tensile strength of 610 N.mm<sup>-2</sup>, yield ratio of 67%, hardness value of 58HRA with excellent combination of impact strength of 58.5J which are also very attractive for structural and military applications.

Table (2): Mechanical properties – Reduction in area, yield and tensile strength, hardness and impact properties of as – rolled (AA 7020-T6) Specimens

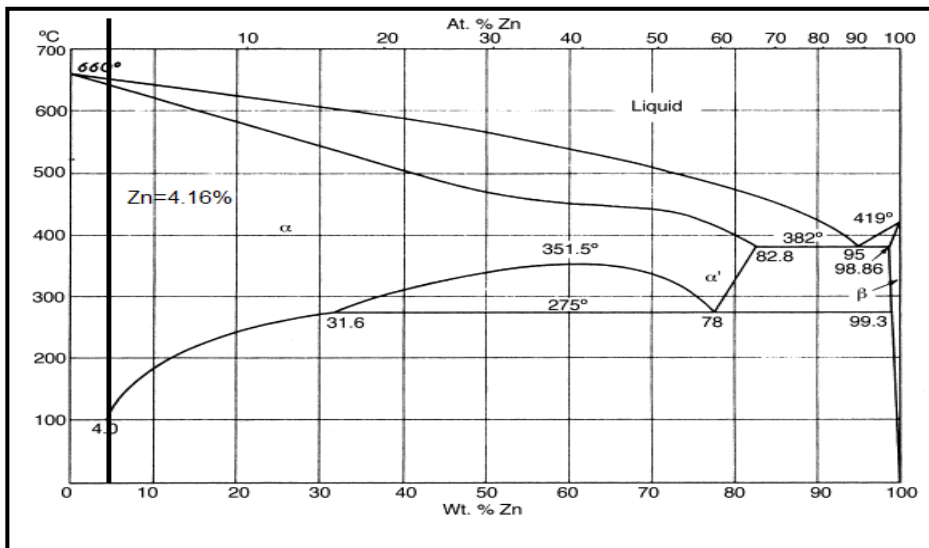


Figure (1): Phase Diagram for Aluminum Zinc alloy <sup>[2]</sup>

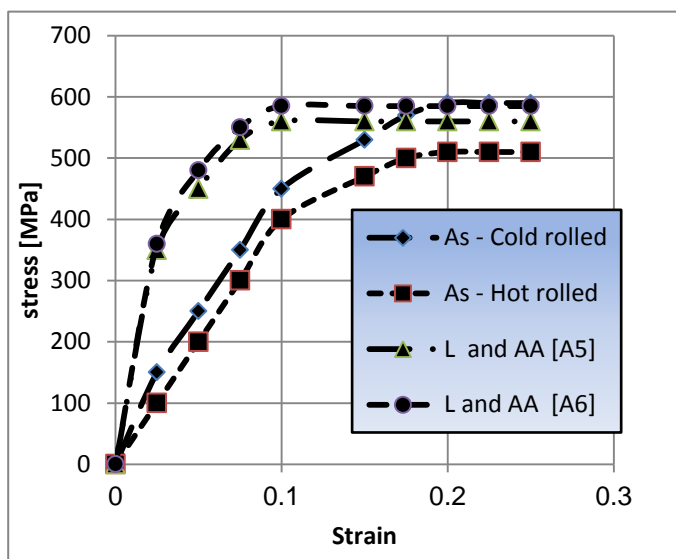


Figure (2): Stress - Strain curves for As-Rolled (Cold /Hot ) laminar , **artificial aging** heat treatment Specimens



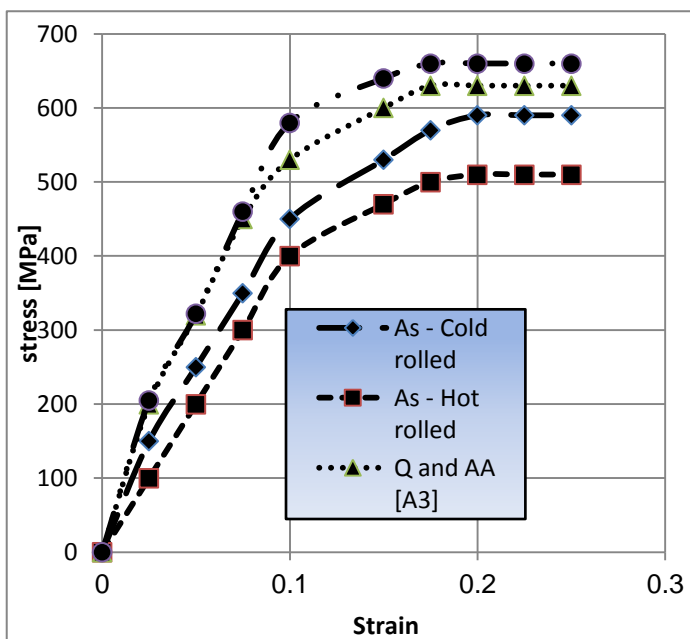


Figure (3): Stress - Strain curves for As-Rolled (Cold /Hot ) quenching and **artificial aging** heat treatment Specimens

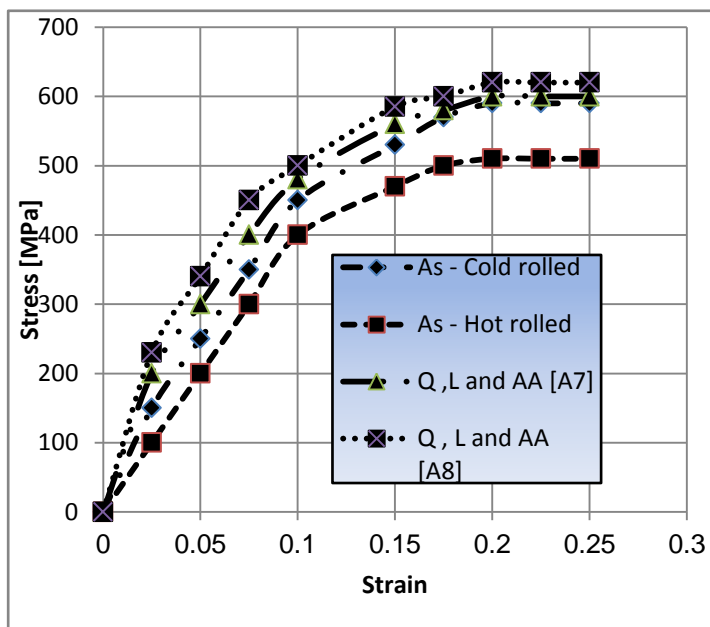
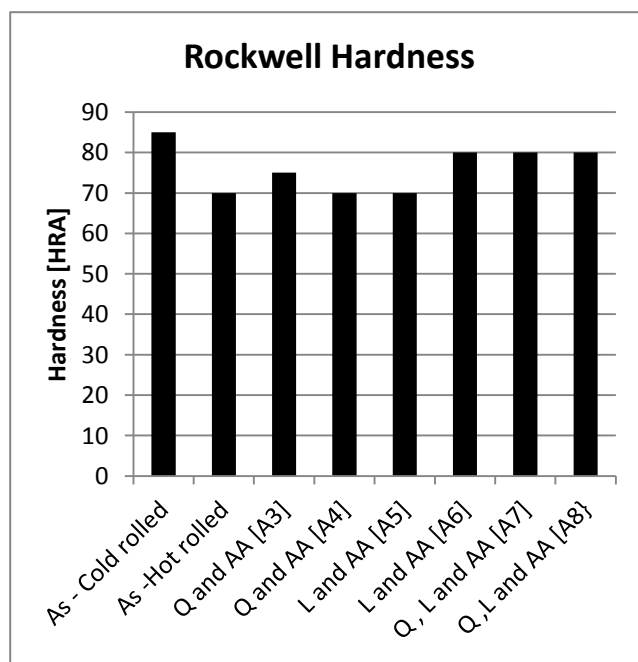


Figure (4): Stress - Strain curves for As-Rolled (Cold /Hot ) Quenching, Lamellae Formation and **artificial aging** heat treatment Specimens



Figure(5): Coparasion between hardness for As-Rolled (Cold /Hot ) and heat treatment A7072-T6 Specimens

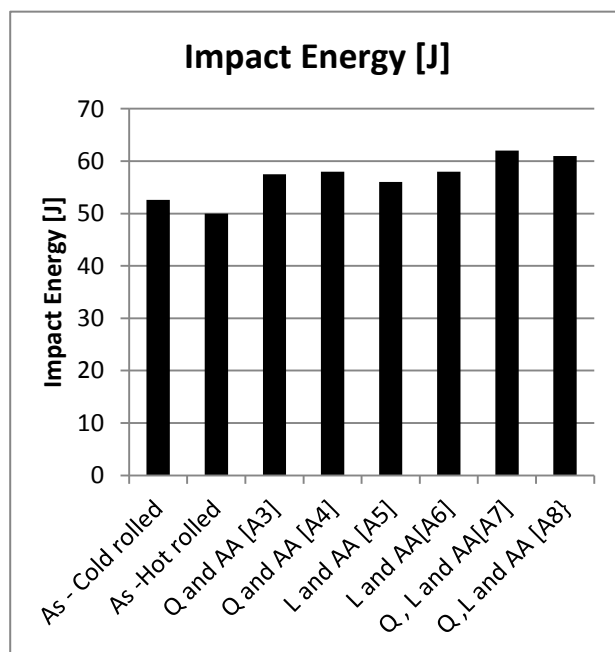


Figure (6):Coparasion between Impact energy for As-Rolled (Cold /Hot ) and heat treatment A7072-T6 Specimens

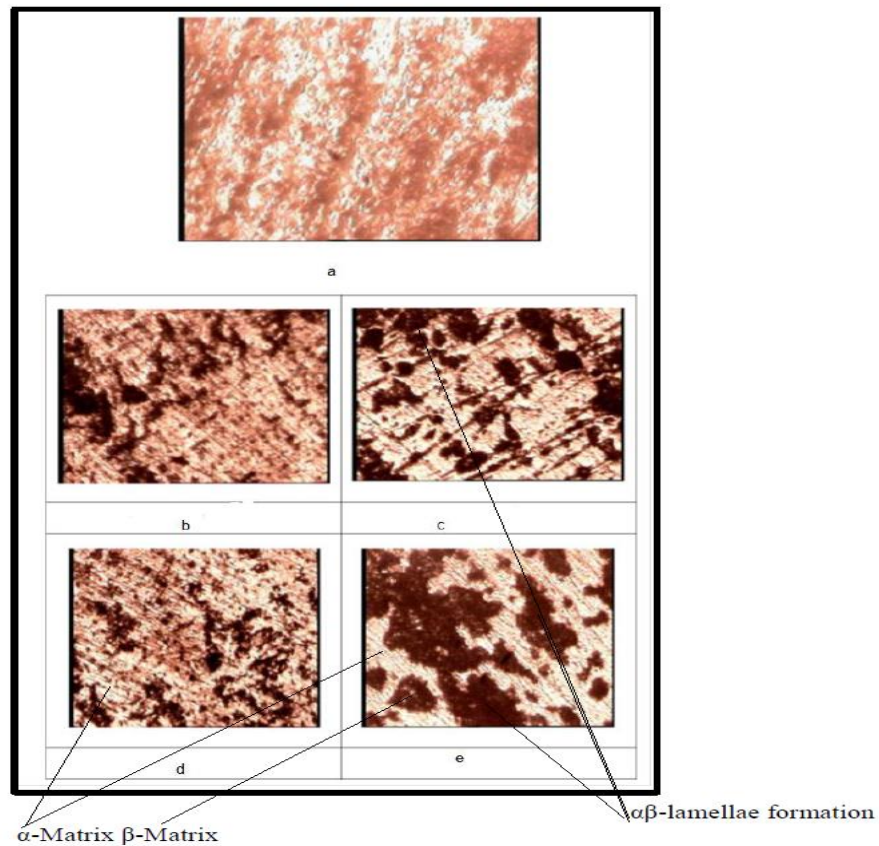


Figure (7): Revealed the microstructure of the phases that are present)  
 [ magnification of 200X]

- a) Microstructures of as-rolled A7072 (A<sub>1</sub> cold rolled).
- b) Microstructures of as-rolled A7072 (A<sub>2</sub> Hot rolled).
- c) Microstructures of heat treatment specimen A<sub>3</sub> (Q and AA)
- d) Microstructures of heat treatment specimen A<sub>5</sub> (L and AA)
- e) Microstructures of heat treatment specimen A<sub>7</sub> (Q, L and AA)

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