THE IMPACT OF ADDING COPPER TO ALUMINUM ON MICROSTRUCTURE AND HARDNESS

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ABSTRACT

Solidification and microstructure are important indexes to evaluate the mechanical properties and qualities of casting. Directional solidification describes solidification that occurs from the farthest end of the casting. This study is devoted to show the directional solidification effect of copper-aluminum alloy (95%Al,5%Cu) on hardness and microstructure.. This was achieved by varying the temperature of water flowing from the base in three different temperatures (0,10,20)^{o}C by using a chilling base. It was concluded that the difference in the solidification of the three samples was due to the different cooling rates applied and as a result of low temperature of sample, which the chilling base temperature was (0^{o}C) compared with the rest of the samples which led to soften the dendrites crystals, and highest hardness reading obtained due to low temperature of the cooling base of sample.

Key Words: directional solidification, hardness, microstructure, chilling base, Al-Cu alloy.

دراسة تأثير اضافة النحاس الى الالمنيوم على البنية المجهرية والصلادة

ملخص البحث

ان البنية المجهرية للسبائك وطريقة تجمدها يقيم الخواص الميكانيكية و نوعية السبيكة المستخدمة. ان التجمد الاتجاهي يوصف التجمد من ابعد نهايةفي القالب المعدني. و يخصص هذه الدراسة الى إظهار تأثير التجمد الاتجاهي لسبيكة المنيوم-نحاس (95٪ المنيوم، 5٪ نحاس) على الصلادة والبنية المجهرية .. وتم تحقيق ذلك من خلال تغيير درجة حرارة المياه المتدفق من خلال القاعدة المصنوعة من معدن النحاس النقي وذلك لضمان الحصول على موصلية حرارية عالية وبثلاثة درجات حرارة مختلفة (0، 10، 20) درجة مئوية حيث تم استخدام القاعدة كمصعقة للتبريد, وتبين ان الفرق الحاصل في درجة حرارة القاعدة ادى الى الحصول على معدلات تبريد مختلفة للعينات الثلاثة المستخدمة في الدراسة وكنتيجة لكون درجة حرارة العينة رقم (1) الاقل بالمقارنة مع بقية العينات وهذا ما ادى الى تنعيم البنية المجهرية و كذلك الحصول على اعلى قيمة للصلادة بالمقارنة مع بقية العينات المستخدمة في الدراسة.

كلمات الدلالة: التجمد الاتجاهي, الصلادة, البنية المجهرية,قاعدة تبريد, سبيكة المنيوم-نحاس.

INTRODUCTION

Aluminum is the third most plentiful element known in industrial, where oxygen and silicon exist in greater quantities. Aluminum, chemical symbol Al, has the atomic number 13.. Aluminum, like copper, silver and gold, crystallizes with the face-centered-cubic arrangement of atoms, common to most of the ductile metals. Lightness is the outstanding and best known characteristic of aluminum. The metal has an atomic weight of 26.98 and a specific gravity of 2.70, approximately one-third of the weight of other commonly used metals [1]. Aluminum has a density of only 2.7 g/cm^3, approximately one-third as much as steel (7.83 g/cm^3), copper (8.93 g/cm3), and brass (8.53 g/cm^3). It can display excellent corrosion resistance in most environments, including atmosphere, water (including salt water), petrochemicals, and many other chemical systems[2].

Aluminum-Copper Alloys are typical solid-solution alloys[3] and the eutectic phase consists of alternate lamella structure of α phase(ductile) and Ɵphases Al_2Cu (brittle) [4]. Copper (Cu) has the single greatest impact of all alloying elements on the strength and hardness of aluminum casting alloys, both heat-treated and non heat-treated and at both ambient and elevated service temperatures. Copper also improves the mach inability of alloys by increasing matrix hardness, making it easier to generate small cutting chips and fine machined finishes. On the downside, copper generally reduces the corrosion resistance of aluminum; and, in certain alloys and tempers, it increases stress corrosion susceptibility [5].Casting and solidification of metals are critically dependent upon temperature, rate of cooling and thermal mass. Thus, heat transfer between the solidifying metal, the mold , and surroundings is a key factor in the properties of the final solidified metal [6].

The cooling rate reflects the heat extraction rate and is measured in K/s. Cooling rate is closely connected to the solidification rate which can define either the velocity of solidification front or as liquid -solid phase transformation rate, measured in units of m/s or s^{-1} respectively[7].

The following paragraphs provide a summary of studies on the effect of directional solidification of aluminum alloys on hardness and microstructure:

M. Gu¨ndu¨z a,*, E. C¸ adırl (2002) Directional solidification experiments have been carried out on different Al–Cu alloys as a function of solidification parameters, temperature gradient *G*, growth rate *V*, and composition[8].

L.A. Dobrzañski a,*, R. Maniara a, J.H. Sokolowski (2007) The solidification process was studied using the cooling curve and crystallization curve at solidification rate ranging from 0,16 ºCs-1 up to 1,04℃[9].

Hui Chen, Yu Shi Chen, X. Wu, S.N. Tewari(2003) studied the history dependence of primary den-drite spacing during directional solidification of binary metallic alloys and interdendritic convection[10].

H. Kaya[a],E Cadirli[b],U Boyok[a],N. Marasli (2008) studied the variation of micro indentation hardness with solidification and microstructure parameters in the Al based alloys [11].

EXPERIMENTAL PROCEDURE

Equipments used in the present study :

- Sensitive balance device three digits.
- Electric furnace.
- Grinding machine (AP04-wet grinder -Buehler Metaserv machine).
- Polishing machine 100 V, 50Hz.
- Digital camera with resolution 12 megapixle.

- thermocouple K-type (up to 1200°C)
- Microscope (Euromax trinocular metallurgical micriscope. 400x).
- Portable hardness tester (TH120).
- Water pump (600ltr/hr , 220V, 10 W).
- Electric heater (220V, 1400W)
- Thermometer (-50-70°C).

PREPARATION OF CASTING

The chilling base was made from pure copper because of its high thermal conductivity and isolated by glass wool and covered by plate as shown in figure (2), and using a submerge electric pump to circulate the water in the system, then the tests was done by the following procedure:

1-Operating the cooling system by using ice in the water tank to reach (0°C) temperature in the chilling base for sample number (1) before the casting procedure about (5 minutes) to stabilize temperature on (0°C) and using two thermometers to record the inlet and outlet water temperatures, then the casting was done by the following steps:

a) Using two thermocouples in two different places (K-type thermocouple) with a digital camera to record the casting temperatures specially during the first temperature drop as shown in figure (3) and a digital camera used to record temperatures.

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

c) Pouring the molten metal into a carbon steel mold (the dimension of the carbon steel mold shown in figure(4). followed by leaving the casting to cool down to room temperature.

2- The second step was done by repeating step (1) and using electric heater to heat the water to reach temperature of the circulating water to (10°C) for sample (2).

3- The third step was done by repeating step (1) and using electric heater to heat the water to reach temperature of the circulating water to (20°C) for sample (3).

PREPARATION OF SPECIMENS

The preparation procedure included cutting specimens into three parts by a hand saw (each with length 30 mm) and each sample was lettered an numbered, then the following steps were preformed to prepare specimens for microstructure and hardness tests:

- Wet grinding was performed by using emery paper in grades (320, 400,600,800,1200)
- Polishing procedure by using alumina particles oxide (Al_2O_3) with size 0.3µm then specimens were cleaned by water and degreased with ethanol and dried for (microstructure and hardness tests.
- Etching :

The etchants used to reveal the microstructure of the specimens consisted of :

- 99.5% distilled water.
- 0.5% Hydrofluoric acid (HF) [12].

RESULTS AND CONCLUSIONS

1-Cooling Rates for chilling Die Castings

From the results obtained in the experiments have been able to observe the time temperature curves illustrated in the figures (5,6 and 7) , it was noticed that the most of the heat loss was through the chilling base (80%); in addition to secondary cooling of the alloy will be by the environment encapsulating the die (20%) [13]. The geometrical shape of the mold cavity has direct effect on progressive and directional solidification, type geometries divergent heat flow occurs, which causes that area of the casting to cool faster than surrounding areas; this is called an end effect[14]. The aluminum-copper time- temperature diagram is a simple eutectic systems

The basic process of solidification and morphology formation is as follows. When the temperature goes below the liquidus line, the solid-solution phase (α) solidifies first, while most of the copper remains in liquid form. As the temperature approaches the solidus, the α solid phase becomes more enriched with copper. When the temperature falls below the solidus temperature in alloys containing less than the maximum solubility (5wt% Cu), solidification is complete to the solid-solution phase condition (α), two terminal solid-solution phases (α and θ) separate out simultaneously from the molten liquid. On cooling below the eutectic temperature, a network of eutectic forms in the residual liquid surrounding the dendrites or grains of primary α.

It was observed that the high temperature drop took effect in the three specimens till approximately (100ºC) as then the temperature started gradually cooling down till it reached room temperature. It was also observed that the temperature difference in cooling time of specimen number (1) ,(0ºC) was used as a chilling temperature which recorded the less cooling effect compared to specimen (2) were (10ºC) was used as a chilling base (23.33 min.) was recorded as solidification time, whereas the difference between specimen (1) and specimen (2) was (8.67 min.) with regard to specimen number (3), it was observed that cooling rate was decreased due to temperature rise of the chilling base to (20ºC), it was recorded the cooling time (25.5 min.) as a cooling time, this leads to concluding that for lower temperatures the cooling rate increases and this what was proved by the researcher[15].

2-MICROSTRUCTURE RESULTS

The micro scale (microstructure) is of the order of 10^{-6} to 10^{-5} m. The micro scale describes the complex morphology of the solidification grain. The importance of microstructure to the properties of alloys has long been recognized in the microstructure test, grain size, the distribution of second-phase particles (Al_2Cu) are important in determining the behavior of the most structural metals. Direction of heat flow out of a mold also impacts where the last metal freezes and where solidification shrinkage takes place cooling rates also determine the subsequent grain size of the solidified metal[6] . Inspecting the curves of time-temperature, it was observed that the two main factors influence the microstructure is cooling rates which reflects the temperature loss and cooling rates is linked to solidification rate which defined as solid solution phase and measured by (m/sec), figure-8 (1a,2a and 3a) where the temperature of chilling base was fixed to (0^{O}C) compared to the microstructure of the specimen facing the chilling base this was due to the grain refining of the microstructure for specimen number (1) whereas in figures (2a,2b and 2c) and (3a,3b and 3c) it was observed that the grain size is a little bigger compared to specimen (1) and this what was proved by the researcher [16].

3-HARDNESS RESULTS

To evaluate the influence of solidification on the properties of the castings hardness measurements as applied to specific classes of materials convey different fundamental aspects of the material. Thus, for metals hardness is directly proportional to the uniaxial yield stress at the strain imposed by the indentation. Figures (9) inclusive shows the relationship between the properties and characteristics of the various alloy groupings and especially the alloy used in the study 2xx(1) which was the same results as in the present study. The relation between Brinell hardness test and the different chilling base temperatures figure (10), where the sample had been cut into three pieces as shown in figure (11) and the series (1a,1b and1c) are the position of the sample in the mold which had been cut into, its observed that the series number (1) for the three specimens with a temperatures(10 and 20) ^{o}C has recorded the maximum values of hardness due to its direct contact with the chilling base which led to a grain refining and this factor is enhanced with the results if microstructure tests, while the specimens (2a,2b,2c, 3b and 3c) recorded a decrease in the hardness values due to its far distance with the chilling base which led to rough grain structure**.**

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Figure (1a): shows photographic of The testing system

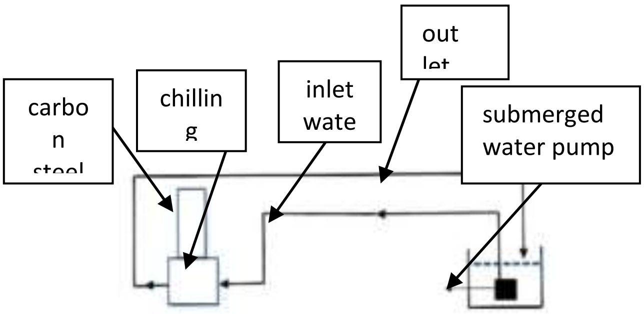


Figure (1b): shows sketch diagram of the testing system

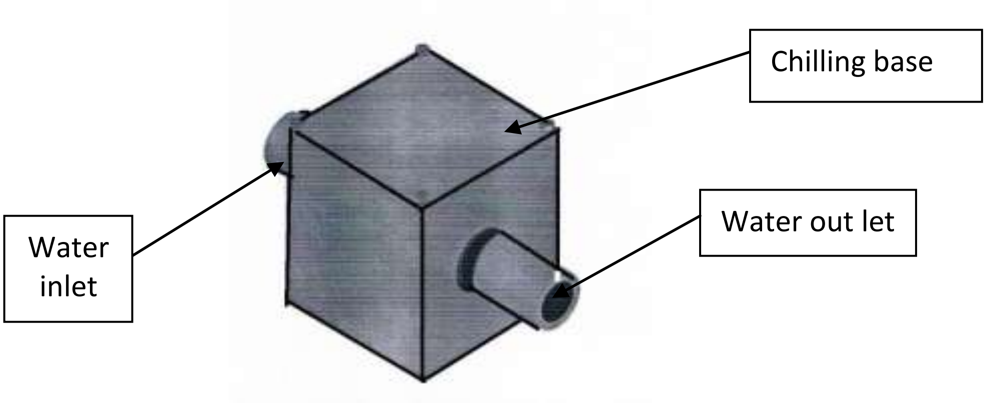


Figure (2): demonstrates the model of chilling base

Figure (3): demonstrates the digital camera and thermometer reader

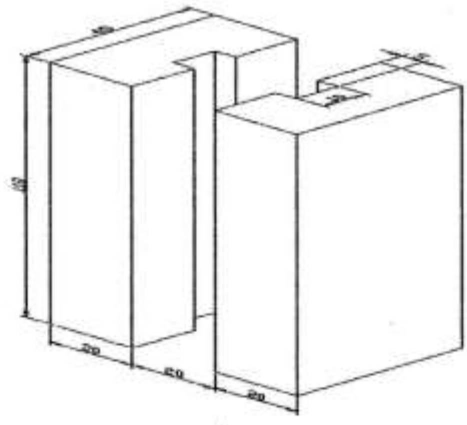
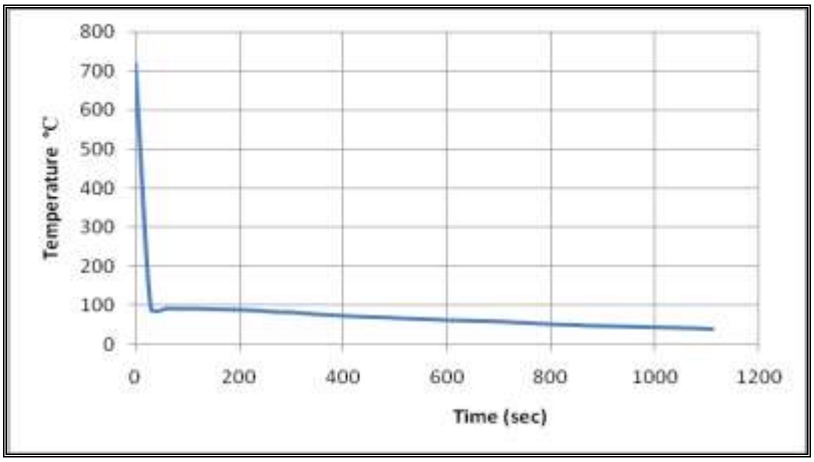
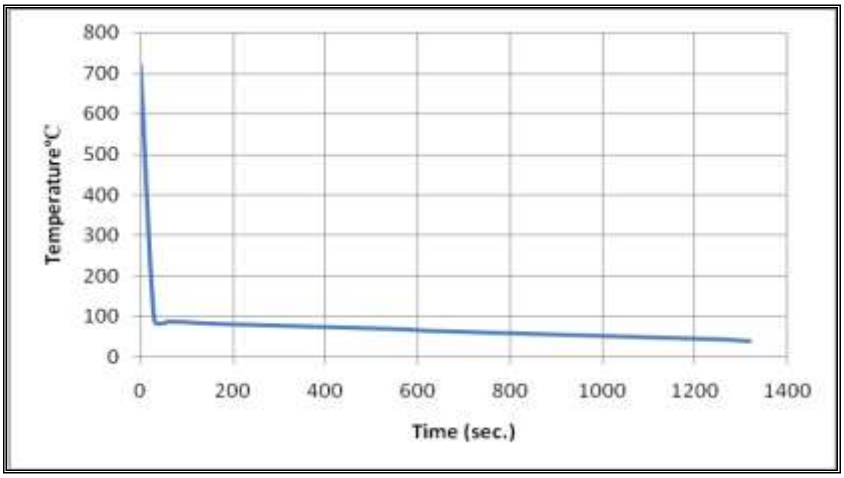


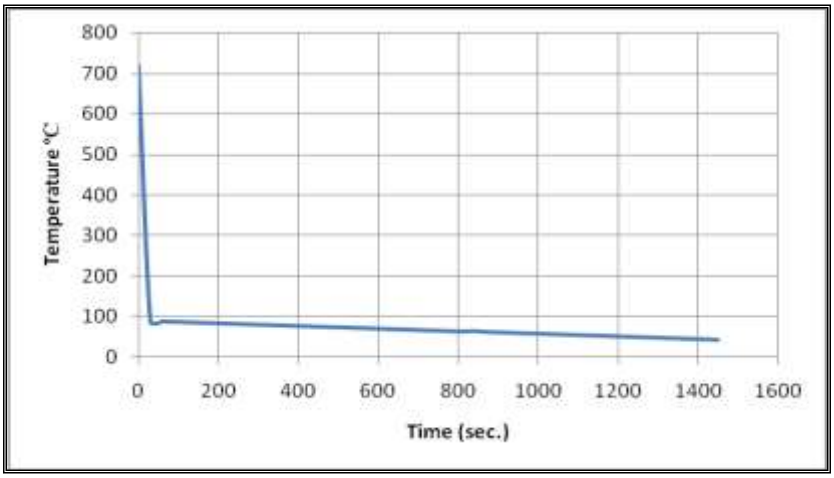
Figure (4): demonstrates the carbon steel die dimensions



Figure(5): shows time- temperature curve for specimen number(1) using a chilling temperature (0°C)



Figure(6): shows time- temperature curve for specimen number(1) using a chilling temperature (10ºC)



Figure(7): shows time- temperature curve for specimen number(1) using a chilling temperature (20ºC)

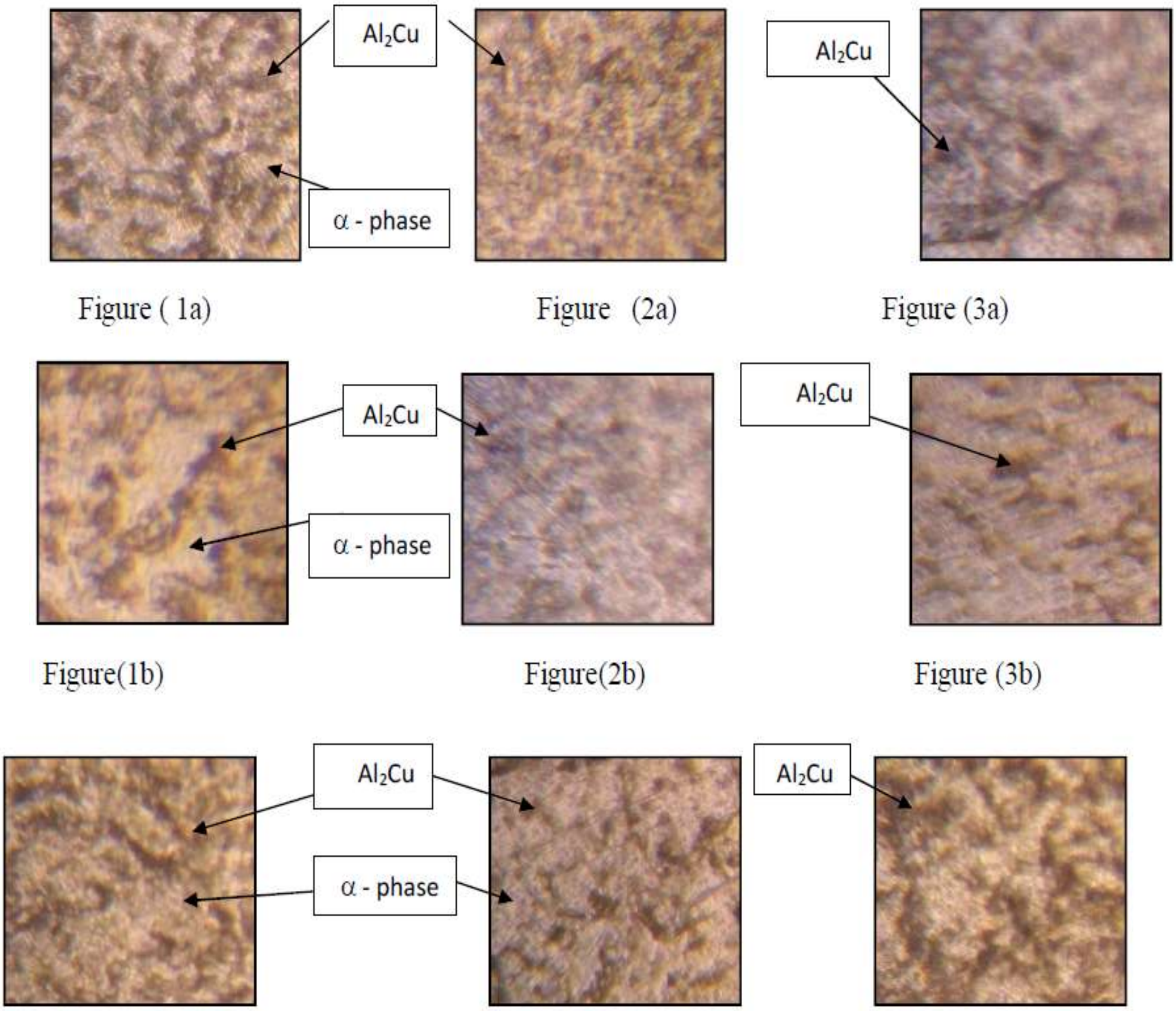
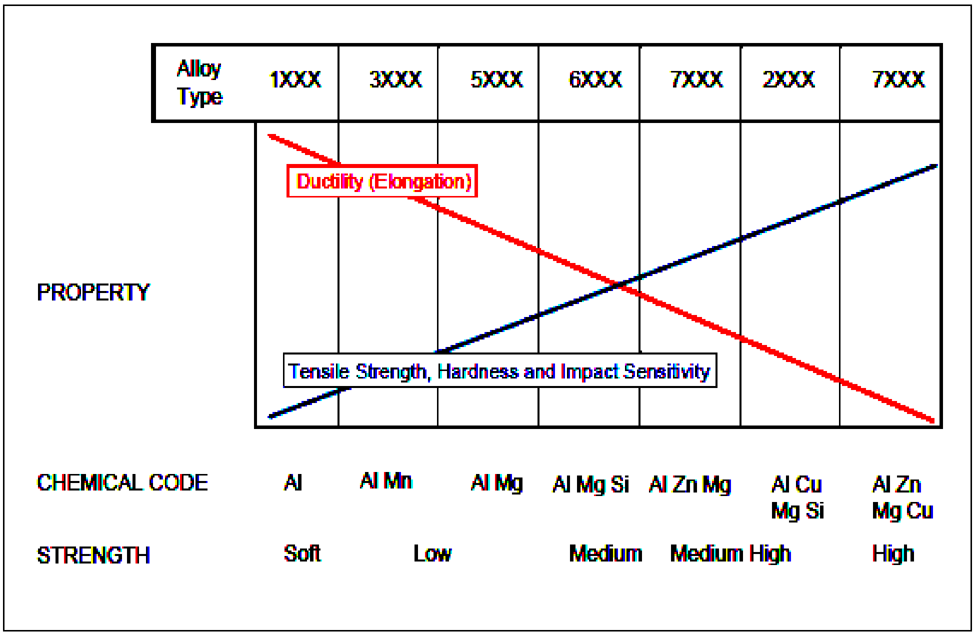


Figure (1a) Figure (2a) Figure (3a)

Figure(1b) Figure(2b) Figure (3b)

Figure(1c) Figure (2c) Figure(3c)

Figure(8): shows microstructure tests



1xx.xAl 99% or greater
Al alloys grouped by major alloying elements
2xx.xCu
3xx.x Si with added Cu or Mg
4xx.x Si
5xx.x Mg
7xx.xZn
8xx.xSn
9xx.x Other elements
6xx.x Unused series

Figure(9): shows the relation of adding alloying elements on tensile strength, hardness, and impact sensitivity [1]

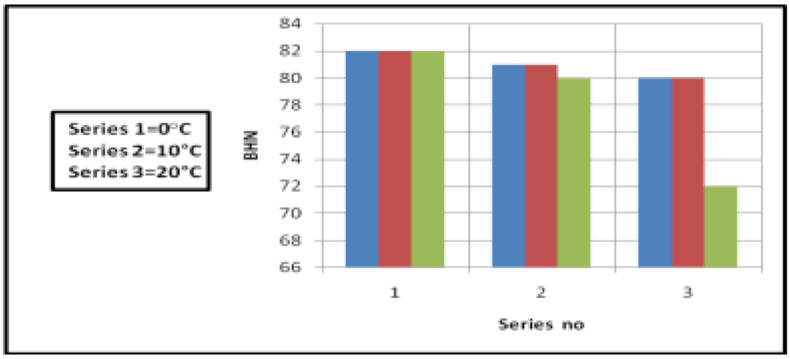
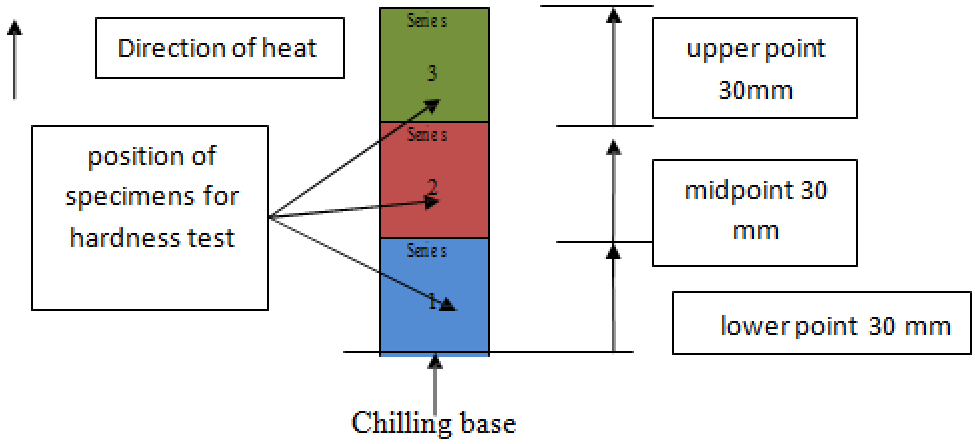


Figure (10): shows the relation between Brinell hardness test and the chilling temperature



Figure(11): shows the position of the specimens which had been cut into for brinell hardness test