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Study on Improvement of Casting Conditions for Some Aluminum Bronze Alloys

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Abstract

Two types of aluminium bronze alloys have been studied to determine the proper methods of melting and casting in two different conditions; with treating materials as (Albral 2, Logas 50 and deoxidizing tube E3) and without and determine the effects of these conditions on mechanical properties of alloys. These alloys are :-

a) Aluminium bronze alloys (AB_1).

b) Nickel-aluminium bronze alloys (AB_2).

These alloys were produced using different melting processes and cast method. The first one was made by preparing the charge materials to be melted and then, to the cast process without using any types of additions and treatment materials. The second one was made with casting conditional control, using proper techniques of casting and using protective layers to minimize the oxidation and other casting defects. The molten metals from both processes were poured into two types of moulds; sand and metal moulds, both types were in dimensions (Ø100×250) mm.

The final products of each type of alloys in each type of conditions were used to perform many types of inspections; chemical analysis, visual test, structure examinations, hardness test and tensile test.

The results of all processes and inspections show that the properties of alloys which were treated and cast in metal moulds were better than that cast in sand moulds. These alloy castings are free from shrinkage cavities, inclusions and porosities due to using suitable sequence in alloy contents melting, no overheat, reducing the melting time, selecting non-turbulence casting method and suitable selection of pouring temperatures. The mechanical properties (hardness and ultimate tensile strength) for treated nickel-aluminium bronze alloys (T-AB_2) were better than that for other alloys.

دراســـة تحسين ظروف السباكة لبعض ســـبائك برونـــز الالمنيـــوم

الخلاصة

تتضمن الدراسة إنتاج نوعين من سبائك برونز الألمنيوم لتحديد الطـــرق المناســـبة للصـــهر والصـــب وبظـــرفين مختلفـــين؛ باســـتخدام مـــواد المعالجـــة مثـــل(Albral 2, Logas 50 وdeoxidizing tube E3) وبدونها وايجاد تأثير تلك الظروف في خواص تلك السبائك. وهذه السبائك هي:-

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أ. سبائك برونز الألمنيوم -(AB_1) .
ب. سبائك برونز النيكل-ألمنيوم -(AB_2).
تضمن الإنتاج لهذه السبائك استخدام عمليات صهر وطرق سباكة مختلفة.
أنتج النوع الأول ابتداءآ من تحضير المواد إلى عملية الصهر ومن ثم إلى عملية الصب بدون استخدام أي نوع من الإضافات ومواد المعالجة. وأنتج النوع الثاني بالسيطرة علـــى ظـــروف السباكة، استخدام الأساليب المناسبة للسباكة واستخدام وسائل حماية من الأكســدة وعيــوب السباكة الأخرى.
إن المواد المنصهرة من كلا العمليتين أعلاه صبت في نوعين من القوالب؛ رمليـــة ومعدنيـــة وبالأبعاد (Ø100×250) ملم.
المنتجات النهائية لكل نوع من السبائك ولكل نوع من الظروف استخدمت لتحضير نماذج عدة أنواع من الفحوصات؛ التحليل الكيمياوي، الفحص العياني، فحص التركيب الـــداخلي، اختبـــار الصلادة واختبار مقاومة الشد.
النتائج لكل الفحوصات والعمليات أظهرت أن خواص السبائك التي تم معالجتها وصـــبها فـــي القوالب المعدنية كانت أفضل من تلك التي في القوالب الرملية. المسبوكات الناتجة كانت خالية من فجوات التقلص، المسامات والمتضمنات نتيجة استخدام التسلســل المناســب فـــي صـــهر مكونات السبيكة، بدون إفراط في التسخين، تقليل زمن الصهر، اختيار طريقة السباكة الغيـــر مضطربة والاختيار المناسب لدرجات حرارة الصب. أما الخواص الميكانيكية (الصلادة ومتانة الشد القصوى) لسبيكة برونز النيكل-ألمنيوم المعالجة كانت أفضل مما للسبائك الأخرى.

Introduction

Modern industrial processes need final or semi-final products which are used in the manufacturing of several types of products without loss a long time and efforts by machining processes. Therefore, modern industry looks at improving casting processes.

Basically, a casting process consists of several steps which start from prepering the charge melting and pouring a liquid alloy into a previously prepared cavity or mould, and permitting it to solidify to obtain a desired shape. In nother words, the casting processes mean shaping metal by pouring a liquid metal into a mould cavity and allowing it to freeze or solidify and thus to take the form of the prepared mould [1].

Casting process is the most economical method for obtaining a part of any desired composition, or by any size from a few millimeters and weighing a fraction of a gram, such as the individual teeth in a zipper, to ten or more meters and weighing many tons, such as the huge propellers and stern frames of ocean liners [2]. Casting processes have become one of the important techniques which are used to produce several types of alloy especialy, in case of mass production and complicated parts.

Copper and copper alloys are usually produced by casting process. Copper alloys including several type of alloys, aluminium and nickel-aluminium bronze (AB_1 and AB_2) are the common alloys. Both alloys have the same specified range of aluminium (8.5 - 10.5) %, but (AB_2) contains higher levels of iron and nickel as shown in Figure (1) [3]. The strength of these alloys as cast is beyond that of mild steel and the mechanical properties of (AB_2) alloy can be modified by heat treatments [4, 5]. The castings properties can be improved by heat treatment (i.e. by heating the products for (2-3) hours and quenching in water or fan cooling) [6].

Experimental Part

a) Tools and Equipments

There are several types of tools and equipments used to melt and cast aluminium and nickel-aluminium bronze alloys experimentally, such as:-

1. Crucible gas furnace: - This furnace is used to melt the raw material of alloy and has (100) kg capacity as shown in figure (2).
2. Thermocouple Type (k): - This device is used for measuring the molten metal temperature.
3. Moulds: - In this work, we used four moulds (two sand moulds and two metal moulds); all moulds have same dimensions (Ø100×250) mm.
4. Skimming Tools: - These tools are used to skim the metal dross and treat the molten metal.
5. Charge Materials: - The raw materials consist of copper cathodes, nickel, aluminium and iron to produce the required alloy (nickel-aluminium bronze).
6. Sand Moulding Equipment:- -This equipment involves;
   - Moulding Requirements:- These requirements include drag and cope which contains the sand and the components of mould, wood patterns, plastic sprue and gate system.
   - Moulding Sand:- The sand used was high silica sand with avarge grain size about (3) mm.
   - Risen:- This material was made in Germany and used as binder of the sand.
7. Auxiliary Materials: - Some additive materials are used such as;
   - Albral 2:- A calcium and sodium fluoride powder is used as a protective cover for the molten metal during melting process.
   - Deoxidizing tubes (E3):- These tubes are made of copper and contain a powder of phosphorus and other elements and are by weight about (25) g used as a deoxidizing material.
   - Logas 50:- A small block which is made from a crushing dolomite blocks ($CaMg(CO_3)_2$) and, used as a liquid of sodium silicate as a binder, each block weighs about (50) g.
8. Atomic Absorption Spectrophotometer (IL 457 type):- This device is used for perform the chemical composition of alloys in the libratories of Al-Shaheed State Company.
9. Digital Camera:- This device is connected to a computer to make a photographs for a final products.
10. Optical Microscope (OLYMPUS BX- 60M) type:- This device is used for checking the structure of alloys.
11. Hardness Inspector Device:- This is a programming device type GNEHM hardness tester. “SWISS MAX 300".
12. Tensile Test Device:- The device used is a "Resistenze Macchine Unificate" (RMU) type, which was made by L. GIAZZI (ITALY).

b) Melting and Casting Methods

The preparation of charges was done for two types of copper-aluminium alloys, the first was aluminium bronze

(AB_1) of (50) kg weight, which was divided into two charges (i.e. 25 kg for each charge). These charges contain many elements such as (Cu, Al, Ni, Zn, Mn and Fe) according to the international specifications (IS) [7], as shown in Table (1). The second type of alloy was nickel-aluminium bronze alloy (AB_2), which contained the same elements in different percentages in (50) kg weight and divided into two charges (i.e. 25 kg for each charge).

After the elements of each type of alloys (AB_1 and AB_2) were prepared, melting process was started for both types of alloys in two types of condition and named as in Table (2), by putting the elements of alloys on each charges as follows : -

1) Aluminium bronze alloy (AB_1).

Casting process of this alloy started with the melt of pieces of copper cathode and other elements such as iron, nickel, manganese, zinc and aluminium. During the melting process of alloy elements, the temperature of molten metal increased to about (1300) °C, but without using any type of treatment. In addition, the molten metal suffered from severe atmospheric conditions, due to the absence of protective fluxes. Before pouring the molten metal, a specimen was taken from the molten metal to check the alloy composition by spectrometer. Then, the molten alloy was poured into two moulds; sand and metal moulds as shown in Figure (3 a and b).

The melting process was repeated for the second charge from the same alloy with sufficient care during melting operation by using suitable protective layer (Albral 2) to keep the molten metal away from atmospheric conditions. In addition, steady melting operation was used (no stirring or turbulence). Layer of charcoal was used on the surface of melt to prevent the oxidation. When the melting process was finished, a specimen from the molten metal was taken to check the composition of alloy by spectro-analysis. Preheat the mould to about (100–150) °C before pouring the metal. The molten metal was poured into a ladle carefully, then, one piece of (Logas 50) was added to remove the gases out from the molten metal. Two pieces of deoxidizing tubes (E_3) were added for reduction of the oxide [7].

Finally, a "non-turbulence casting method" was used to pour the molten metal into prepared moulds [8].

2) Nickel - aluminium bronze alloy (AB_2). This is the major alloy for this work. The alloy melting is applied as follows: -

After the crucible furnace was discharged from first alloy, it was continued on fire and the crucible walls show a red colour. The melting process started by charging the pieces of cathodic copper. Then, pieces of iron were added and followed by nickel, manganese, zinc and aluminium. After the melting operation was finished, molten metal was stirred into the furnace without any protective layer. The temperature of molten metal increased for about (150) °C above its pouring temperature (i.e. to about 1350 °C) by increase the furnace flame. The furnace charge was poured into a prepared sand and metal moulds. In order to explain the importance of the right procedure of melting for the elements of nickel-aluminium bronze alloy, the process was performed as follow : -

- The crucible gas furnace was continued on fire.
- Charging the cathodic copper pieces into the crucible.
- After melting the copper pieces, a flux of (Albral 2) was used as a protective layer over the surface of molten metal by 1 % of metal weight. Therefore, the required quantity from the fluxes during melting operation was about ¾ of all quantity and the reminder was added before the pouring stage, this quantity is used according to the world specifications [7].
- A amount of charcoal was added over the surface of molten metal to prevent the chance of oxidation.
- Make an interest to Control on the temperature of the liquid during the melting operation to prevent the increase in temperature above the required limits.
- The pieces of iron were charged under a protective cover carefully.
- The pieces of nickel and then the pieces of manganese were added under a protective cover too, followed by zinc pieces and aluminum.
- The reminder quantity of (Albral 2) flux was added over the surface of liquid. .
- The alloy temperature was raised to 1180 °C.
- A specimen from the molten metal was taken to check the composition of alloy by using a spectro- analysis.
- Two pieces of (Logas 50) were added and submerged into the furnace crucible to remove gases from the molten metal.
- The molten metal was tilted from the furnace into a ladle to transport it to the moulds.
- Two pieces of deoxidizing tubes (E_3) were placed in the ladle before tilt the molten metal to reduce the oxides and to increase fluidity to the molten metal.

c) Inspection Processes

1) Chemical Composition Test

This operation was performed many times after the melting process was finished to correct the alloy composition.

This operation consists of : -

- Samples were taken from molten metals by graphite spoon and poured into a cylindrical sample mould, when the melting processes of all alloys elements were finished and the metal was poured.
- Small amount of chips from these samples were taken by drilling machine to check the percentage of every element in the alloys.
- Using atomic absorption spectrophotometer (IL 457 type) to check the chemical composition of each alloys.

2) Visual Inspection

This process consists of the following : -

- Required samples or castings were selected from the alloys produced.
- Using camera "Intel" type, model: CS630, was connected to computer to make photographs of suitable regions of castings surface and sections to see or check the presence of porosities, shrinkage cavities and the shape of casting surfaces, etc.

3) Structure Examination

The cast Cu-Al alloys specimens were selected from the top and the bottom half of the produced casting and cut be examined by using an optical microscope (OLYMPUS BX-60M) type, which was provided with digital camera as shown in Figure (4). The specimens were examined after grinding with abrade paper of grades (320, 600, 800 and 1000). Then, followed by using a polishing machine with 5 µm alumina paste for polishing. Finally, the specimens were etched before optical microscopic examination by etching solution as in table (3).

4) Mechanical Tests

These processes include the following tests:-

a) Hardness Test

This process is performed as follows: -

- The specimens from 8 types of aluminum bronze alloys produced in metal and sand moulds, were cut on a rectangular sections in dimensions of about (5×10×20) mm.

- A programming hardness was used to test the hardness of alloys by using a "Brinell hardness" at (2.5) mm diameter of ball and (62.5) N minimum load by using the following equation [10] : -

$$\mathbf{BHN = P/ \{(\pi D/2)\ [D-(D^2-d^2)]^{1/2}\}} \quad \text{----------} \quad (1)$$

where, **BHN:** is Brinell hardness number, **P:** is applied load (N), **D:** ball diameter (mm), **d:** notch diameter (mm).

b) Tensile Test

In this test, 4 standard of (12.7) mm diameter and 4 standard of (8) mm diameter tensile specimens were machined from bars in according to DIN 50125 specification as shown in figure (5). At room temperature, tensile testing was performed at a strain rate of approximately 2 mm/sec. The tensile strength was calculated from the maximum load and original cross-section area.

Results and Discussions

1. Chemical analysis

The results in Table (4) illustrates the percentages of all elements for aluminium bronze (AB_1) in both cases ($NT-AB_1$ and $T-AB_1$) which are within the standard limits. But, the percentages of all elements such as (Al, Fe, Mn and Zn) increased in case of treated alloy ($T-AB_1$). This is due to using auxiliary materials or fluxes. These fluxes; such as "Albral 2" minimize the oxidation, zinc vapor production and material loss.

Therefore, the protective layers of Albral 2 and charcoal prevent the progressive oxidation which occurs by forming a thin film over the molten metal surface.

From Table (4), the percentages of all alloy's elements for ($NT-AB_2$) are at low levels. Iron percentage is less than the required level, aluminium and nickel percentages are near the lower limits (8.8 and 4) %. This reduction in percentages of these elements occurs due to absence of the protective layers (i.e. no fluxes or charcoal).

Therefore, the oxidation of alloy's elements and losses increases, but in ($T-AB_2$), the case is different. The percentages of elements increase and the metal losses decrease due to the use of fluxes and charcoal. In addition, the melting temperature of this alloy doesn't increase above its proper limit (i.e. 1180 – 1200 °C).

The proper melting procedure for alloy's elements (i.e. no stirring and turbulence) minimizes the oxidations and metal losses.

2. Visual Inspection Results

The casting photographs which are shown in Figure (6 a, b, c and d,) illustrate the importance of typical conditions used in aluminium bronze castings (AB_1 and AB_2).

Shrinkage cavities, porosities and bad casting surface shown in these photographs are due to the abnormal conditions used. The abnormal conditions include super heating and stirring for the molten metal with absence the protective layers.

Deep cavity due to shrinkage of molten metal, layers of oxidation skins and inclusions are shown in Figure (6 a). So, this shrinkage cavity is continued through a distance about (50) mm from the top end of alloy casting, as shown in Figure (6 b and c). In addition, the cavities and porosities due to gas absorption are illustrated clearly in figure (6 d).

Most of these casting defects were prevented or minimized by using proper conditions and good mould design. For example, shrinkage cavities were prevented or minimized as a result of controlling the melting and pouring temperatures and modifying a mould design, as shown in Figure (7 a and b). While, the oxidation and gas absorption were prevented by using auxiliary fluxes such as Logas 50 and deoxidizing tubes "E3".

3. Structure Examination Results

Optical microscope was used to explain the microstructure of Cu-Al alloys. Microstructure of aluminium bronze castings (AB_1) for both cases (NT-AB_1 and T-AB_1) are shown in Figure (8). When shows structural photographs by microscope. Figure (8 a) illustrates the structure of (NT-AB_1) in metal mould. It shows large size of alpha phases (α) with white colour and small amount of (γ_2) within (β) phase. These structures occur due to the decrease in aluminium and iron contents, absence of a nickel content and increase in the cooling rate due to used a metal mould.

In addition, the structure involves some inclusions and oxidation due to absence of the treating of molten metal. Whilst the structure of (NT-AB_1) in sand mould shown in Figure (8 b) illustrates the increase in alpha phase size, small shrinkage cavities and inclusions exist between alpha dendrites due to lower cooling rate.

Treated aluminium bronze castings (T-AB_1) produced in metal and sand moulds are shown in Figure (9a and b). Figure (9a) illustrates that the absence of inclusions and oxidations with the homogeneity of the phases was obtained. Figure (9 b) shows a similar structure with the presence of fine particles of aluminium oxide (Al_2O_3). The structure of non-treated nickel-aluminium bronze castings (NT-AB_2) are shown in Figure (10 a and b). This structure illustrates the effect of iron and nickel percentages on alpha phase size. Therefore, the structure contains medium size of particles of alpha (α) phase and lamellar form of kappa (K) phase, but, no gamma 2

(γ_2) phase due to nickel and iron effects. In addition, the structure illustrates the oxidation film on the grain boundaries and some inclusions due to using bad conditions (no protective cover, over heating and stirring the charge materials) during melting and degassing processes. Grain size of crystals for sample of (NT-AB_2) taken from the casting produced in sand mould as shown in figure (10 b), is larger than the crystals of casting produced in metal mould as shown in figure (10 a). The reasons are due to the lower cooling rate for sand casting during solidification process.

The structure of (T-AB_2) casting produced in metal mould as shown in Figure (11 a) illustrates small grains of alpha (α) phase and few amount of kappa (K) phase grains which are black lamellar in form. On the other hand, the grains in the casting produced in sand mould include; alpha (α) phase in medium size and fine kappa (K) within alpha grains, as shown in Figure (11 b). The reasons are due to high cooling rate in metal mould and the kappa (K) phase was limited.

4. Mechanical Test Results

a) Hardness Test Results

The results in Table (5) show that, the hardness values of (AB_1) alloys are less than of (AB_2) alloys, due to increasing the iron and nickel contents in the second alloy. These elements refine the grain sizes of these alloys.

Hardness values of treated alloys were better than that for non-treated due to minimizing the losses of alloying elements, such as (Al, Fe and Ni) and due to minimizing the castings defects such as porosities, inclusions and cavities.

b) Tensile and Elongation Tests Results

The results in Table (5) show that, the ultimate tensile strength values of non-treated alloys such as for samples (1, 3, and 7) of alloys, were less than that of treated alloys. In the same time the elongation values of non-treated alloys were less than that for treated alloys. The reasons were due to the effects of cavities, porosities, inclusions and losses in alloying elements may be involves in alloy's samples.

The comparison of results of ultimate tensile strength and elongation with the mechanical properties in Table (6) shows that, most of these results are near the required limits except the elongation value of sample (8) which is less than that in Table (6) due to the rise in hardness and ultimate tensile strength of this alloy.

Conclusions

From this study, the following conclusions are drawn : -

1. The sequence of charge elements melting which depend on the melting temperature of alloy elements and the fluxes used with non-turbulence casting method improve the quality of the products.
2. The preheat of both types of casting moulds for about (100–150) °C before pouring minimizes the casting defects such as shrinkage cavities and refines the grain size obtained.
3. The casting defects such as porosities, inclusions and shrinkage cavities in (AB_2) are less than that in

(AB_1) alloys due to the effects of (Ni and Fe) contents on the refining of the grain size.

4. Metal losses and of alloying elements oxidation were decreased due to use of proper pouring temperature of alloys with using the protective fluxes.

5. The best mechanical properties such as ultimate tensile strength and hardness are found in treated nickel-aluminium bronze alloys (T-AB_2), due to the effects of fluxes material such as (Logas 50 and deoxidizing tubes E_3) to minimize the casting defects. In addation, the effects of rise of (Ni and Fe) contents on the improving on the mechanical properties.

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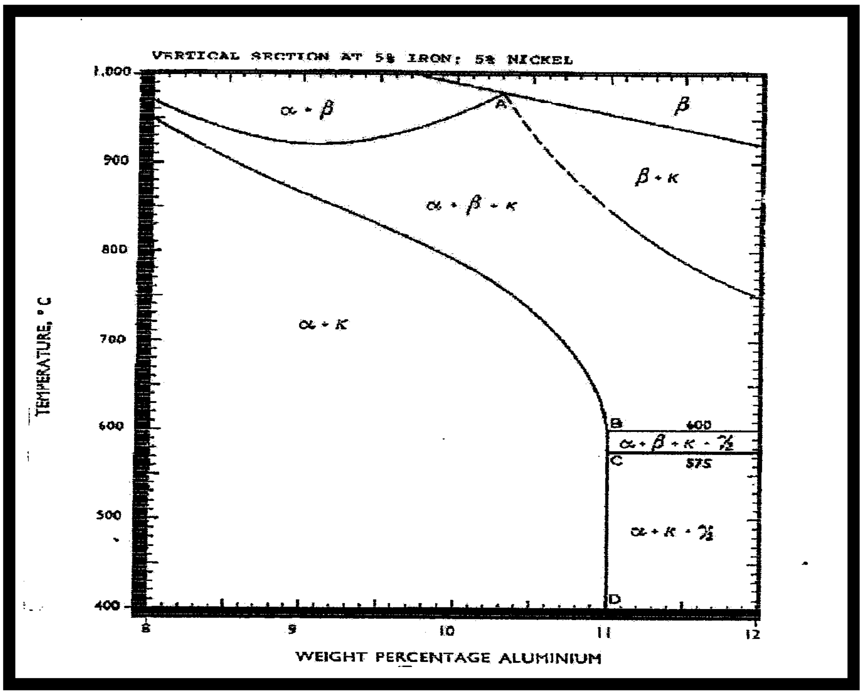


Figure (1) A vertical section in nickel-aluminium bronze phase diagram [3].

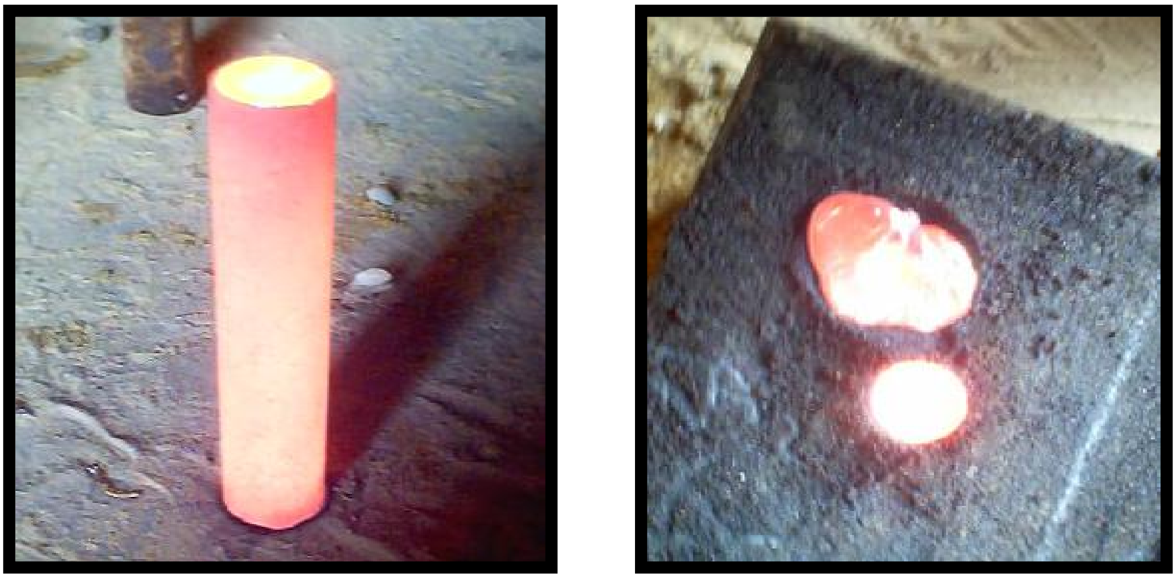
Figure (2) A crucible gas furnace which used in this work

Table (1) A composition of alloys and the weight of each element

Type of alloy	Type of element	Cu	Al	Zn	Mn	Fe	Pb	Ni	Si	Sn
AB_1	Percentage %	Remin.	8.5 10.5	Max. 0.5	Max. 1	1.5 3.5	Max. 0.5	Max. 1	Max. 0.25	Max. 0.1
	Weight (kg)	42.75	5	0.25	0.375	1.25	–	0.375	–	–
AB_2	Percentage %	Remin.	8.8 10	Max. 0.5	Max. 0.5	4 5.5	Max. 0.05	4 5.5	Max. 0.1	Max. 0.1
	Weight (kg)	40.5	4.75	0.25	–	2.25	–	2.25	–	–

Table (2) The number of samples and their description

Sample	Description
1	NT-AB_1 which produced in metal mould
2	T-AB_1 which produced in metal mould
3	NT-AB_2 which produced in metal mould
4	T-AB_2 which produced in metal mould
5	NT-AB_1 which produced in sand mould
6	T-AB_1 which produced in sand mould
7	NT-AB_2 which produced in sand mould
8	T-AB_2 which produced in sand mould



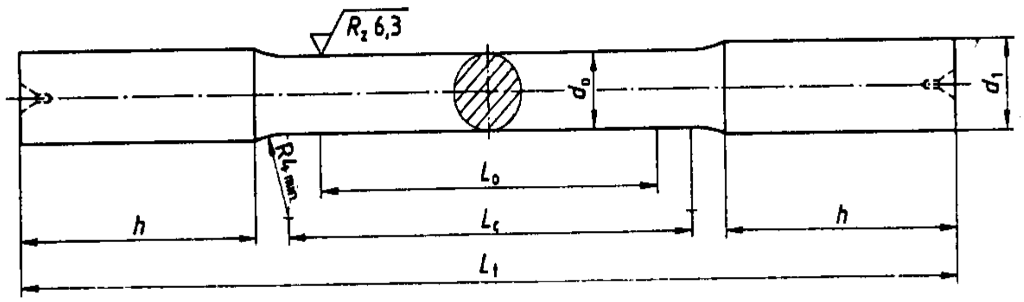
(a) **(b)**

Figure (3) Types of moulds; (a) metal moul (b) sand mould.

Figure (4) Optical microscope for metallographic examination
"OLYMPUS BX 60M" type.

Table (3) Etching solution constituents of aluminium bronze alloys [9].

Material type	Potassium dichromate ($K_2Cr_2O_7$)	Sulfuric acid (H_2SO_4)	Water (H_2O)	HCl
Quantity	0.5 g	2 ml	10 ml	2 drops add before use



d_0 test piece diameter
d_1 diameter of gripped ends (approx. 1,2 d_0)
h length of gripped ends
L_0 original gauge length ($= 5\,d_0$)
L_c parallel length ($\geq L_0 + d_0$)
L_t total length

Figure (5) Tensile Test specimen

Table (4) Results of chemical analysis

Type of Alloys / *Alloying elements*	*NT-AB$_1$*	*T-AB$_1$*	*NT-AB$_2$*	*T-AB$_2$*
Cu	*Remin.*	*Remin.*	*Remin.*	*Remin.*
Al	*9.2*	*10*	*8.9*	*9.5*
Ni	*0.45*	*0.8*	*4.1*	*4.8*
Fe	*2.2*	*3*	*3.98*	*4.3*
Zn	*0.09*	*0.2*	*0.15*	*0.3*
Mn	*0.5*	*0.8*	*-*	*-*

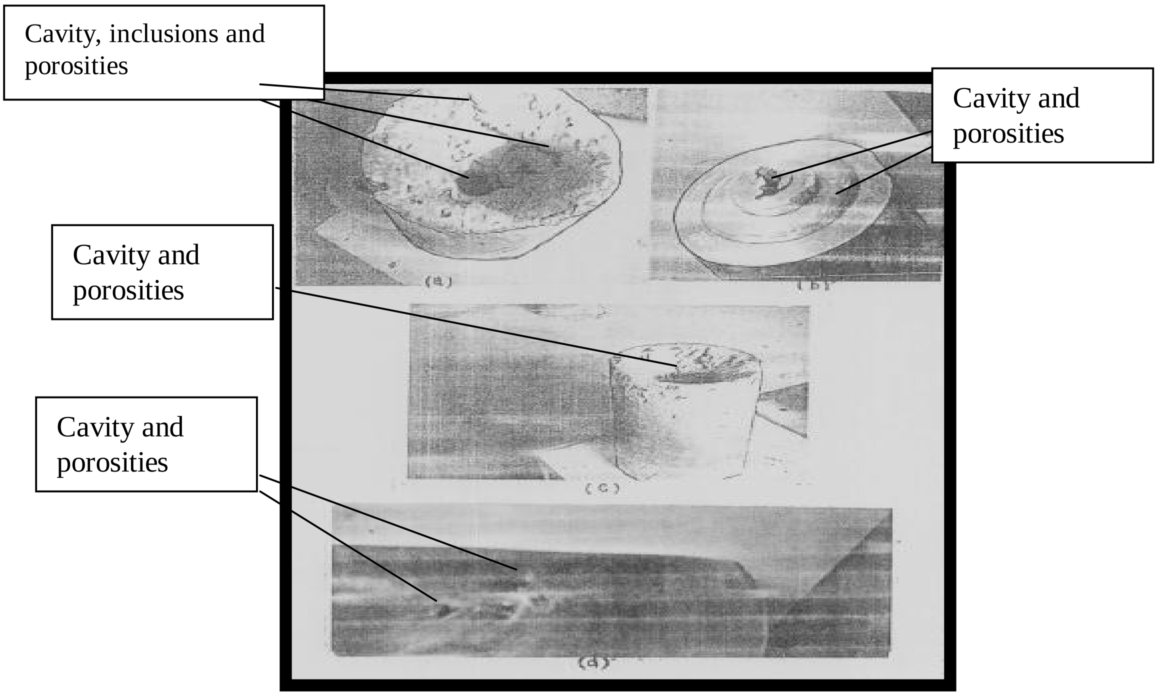


Figure (6) Four casting photographs; (a) shrinkage cavity with layer of oxidation skins and some inclusions, (b and c) shrinkage hole height within an ingot, (d) cavities and porosities sue to gas absorption.

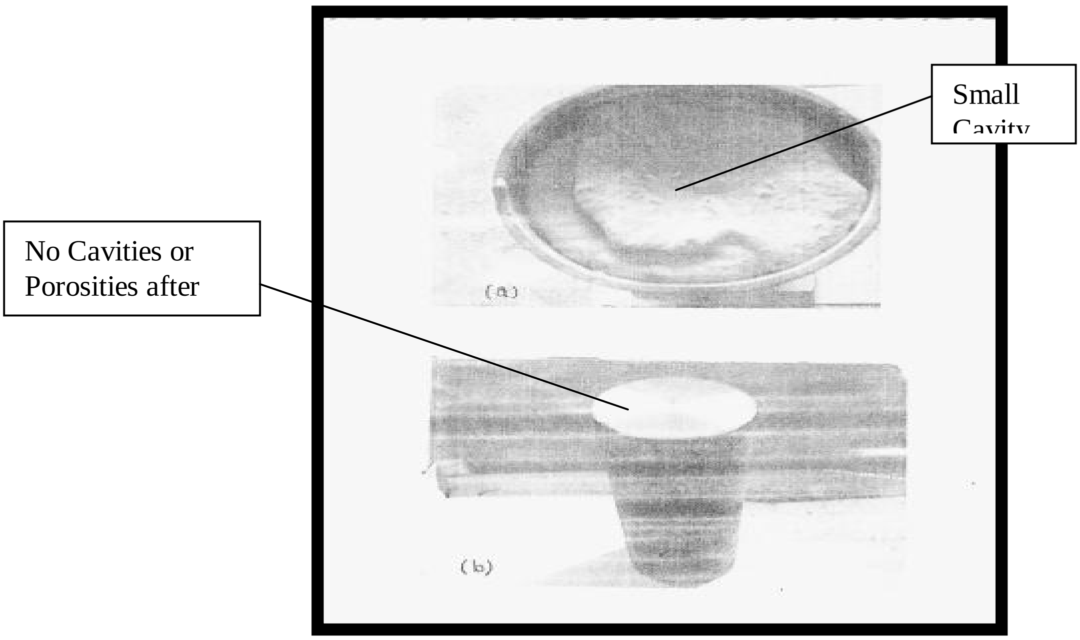


Figure (7) Two casting photographs; (a) small shrinkage cavity, little amounts of oxidations and inclusions. (b) No shrinkage cavity and better surface finish after cutting the top end of casting on height of (15) mm.

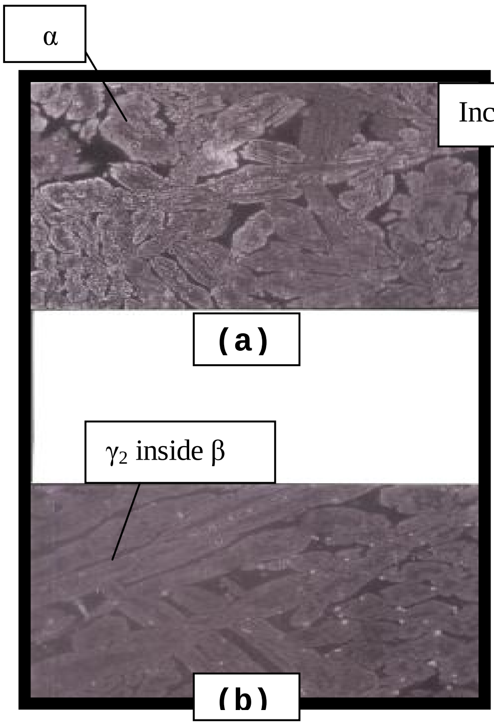


Figure (8) The structure of (NT-AB$_1$) which produced in ; (a) Metal mould (b) Sand mould

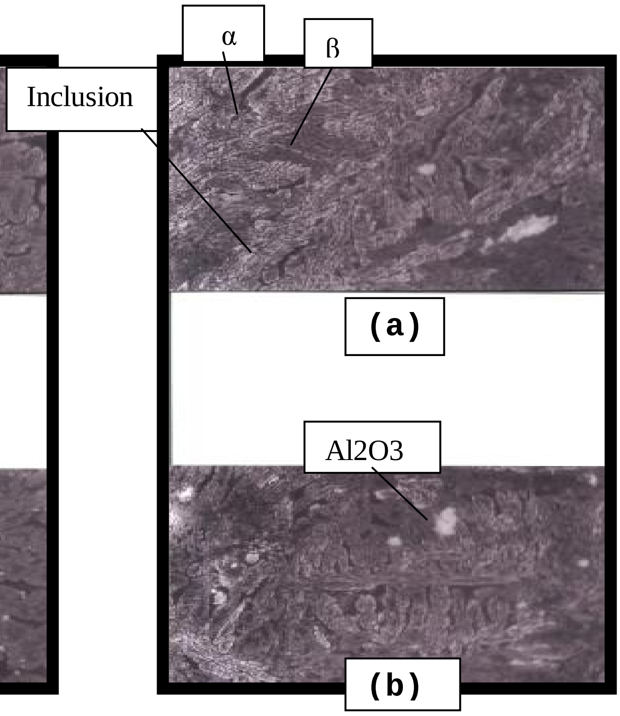


Figure (9) The structure of (T-AB$_1$) which, produced in; (a) Metal mould, (b) Sand mould

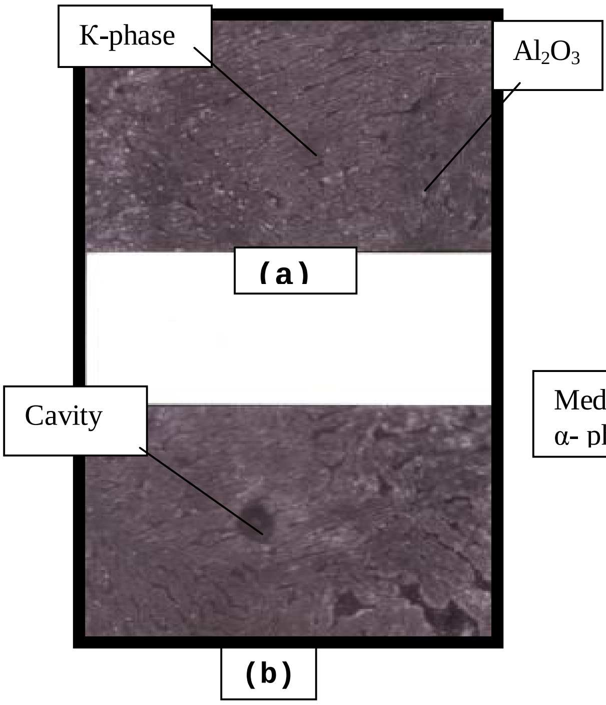


Figure (10) The structure of (NT-AB$_1$) which was produced in; (a) Metal mould, (b) Sand mould

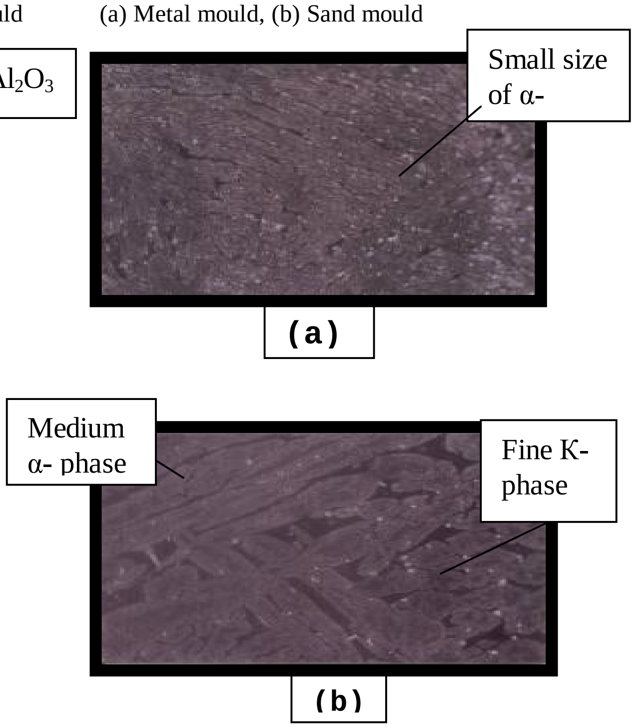


Figure (11) The structure of (T-AB$_1$) which was produced in; (a) Metal mould, (b) Sand mould

Table (5) The results of tensile strength, Brinell hardness and elongation tests for aluminium-bronze specimens.

Sample No.	d_o (mm)	d_{af} (mm)	A_o (mm^2)	Loud (KN)	U.T.S (N/mm^2)	L_o (mm)	L_1 (mm)	E %	BH
1	12.7	12	126.6	59.5	470	60	69.5	15.8	138
2	12.7	11.9	126.6	70	553	60	71	18.3	161
3	12.7	12.3	126.6	77	608	60	67	11.6	189
4	8	7.7	50.24	35	697	40	47.5	12.2	194
5	12.7	12.3	126.6	58	458	60	67.6	12.7	139
6	8	7.5	50.24	27.5	547	40	49	15	165
7	8	7.7	50.24	30.5	607	40	46	10	195
8	8	7.4	50.24	33.5	667	40	49.6	16	209

where, $\mathbf{d_o}$: the original diameter of sample.
$\mathbf{d_{af}}$: diameter of sample at the fracture.
$\mathbf{A_o}$: the original cross section area of samples.
$\mathbf{L_o}$: the original length of sample.
$\mathbf{L_1}$: length of sample after test.
E %: elongation percentage,
where **E** % = $\{(L_1 - L_o) / L_o\} \times 100$
U.T.S : ultimate tensile strength

Table (6) Comparative Mechanical Properties of Some Cast Copper alloys.

Alloy	0.1% proof stress (N/mm^2)	Tensile strength (N/mm^2)	Elongation (percent)	Hardness (BH)
Aluminium Bronze (AB_1 Die Cast)	215.82	588.6	30	164.7
Aluminium Bronze (AB_2 Sand Cast)	274.68	667.08	17	211.8
Aluminium Bronze (AB_2 Sand Cast and heat treated)	431.64	755.37	13	247.1
Copper-Manganese-Aluminium (CMA_1 Sand Cast)	294.3	696.51	25	235.3
Copper-Manganese-Aluminium (CMA_2 Sand Cast)	412.02	735.75	14	282.4
Phosphor Bronze (PB_1 Chill Cast)	127.53	235.44	5	105.9
High Tensile Brass (HTB_2 Sand Cast)	294.3	618.03	20	200