STRUCTURE EVALUATION OF DUAL-PHASE COPPER-10.2 % ALUMINIUM BRONZE

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الملخص

يتعرض هذا البحث لدراسة تمهيدية للبنية ذات الطورين في البرونز الالومنيومي الذي يحتوي على 10.2 % الومنيوم.أظهرت قياسات الصلادة علاقة خطية بين صلادة السبيكة وبين النسبة المئوية لكل من المارتنزايت والطور α بالاتفاق مع قانون الخلائط. وقد أوضحت هذه الدراسة أنه في حدود المعالجات الحرارية التي تم دراستها فإن تأثير النسبة المئوية للطور α على الصلادة العامة ضئيل و يمكن إهماله مقارنة بتأثير نسبة المارتنزايت. وقد تمت مناقشة ما توصلت إليه الدراسة من استنتاجات في ضؤ النظريات القائمة.

ABSTRACT

An aluminum bronze alloy containing 10.2 %Al, thermally treated to dual-phase structure, was investigated. The obtained results showed that the overall hardness of the dual phase (α + martensite) structure is linearly proportional to the volume fraction of both martensite and α-phase in agreement with the law of mixture. However, in the investigated range of volume fractions, the participation of the α-phase to the overall hardness is negligible in comparison with the martensite phase. The obtained results were discussed in the light of the existing theories.

KEEWORDS: Dual-Phase; Al-Bronze; Volume Fraction; Martensitic Transformation

INTRODUCTION

The aluminum bronze alloys are characterized by their high mechanical properties and high corrosion resistance [1]. These alloys are similar to steel from the structural point of view and transformation behavior. Therefore, a wide range of mechanical properties can be obtained in these alloys by heat treatment [2]. Although the mechanical properties and phase transformation in both single- and double-phase Al-bronzes were extensively studied [2-7], the dual-phase (α + martensite) structure characteristics of such alloys are still not yet clear. Such structural similarity of aluminum bronze with steel allows us to think that the mechanical properties of these alloys could be improved by similar treatments, usually carried for steel [4, 5, 8]. In the present research it was aimed to investigate the characteristics of dual phase structures developed in Al-bronze by the appropriate treatment.

EXPERIMENTAL PROCEDURE

Alloy preparation and treatment

A binary alloy of nominal composition 88.2 wt% Cu and 11.8 wt% Al was prepared locally from red copper rods and technical purity aluminum. Such composition corresponds to the eutectoid composition in the binary Cu-Al phase diagram (Figure 1). After casting and homogenization at 900^{o}C for 12 hours followed by furnace cooling,

the microstructure (Figure 2) showed ~ 40 % eutectoid micro-constituent, indicating that the actual aluminum content of the alloy is ~ 10.2 wt.%,. The homogenized ingots were then cut into specimens of 10x10x4 mm. These specimens were then equilibrated at 650^{o}C, 720^{o}C and 750^{o}C (within two phase region α + β) for 20 minuets before quenching in 10 % brine solution to freeze-in the high temperature phases.

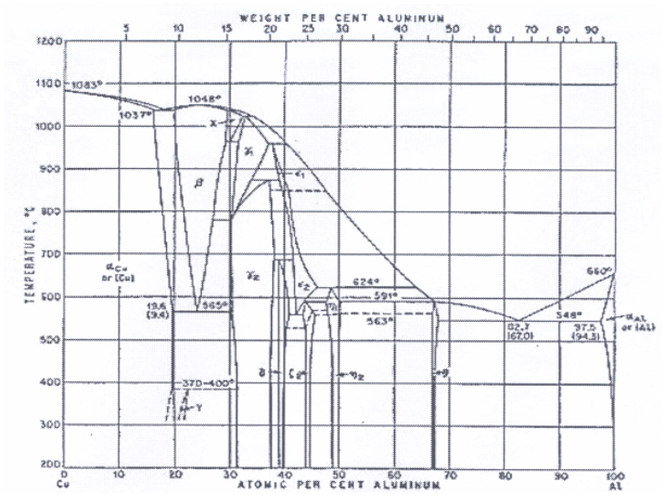

Figure 1: The binary Cu-Al phase diagram

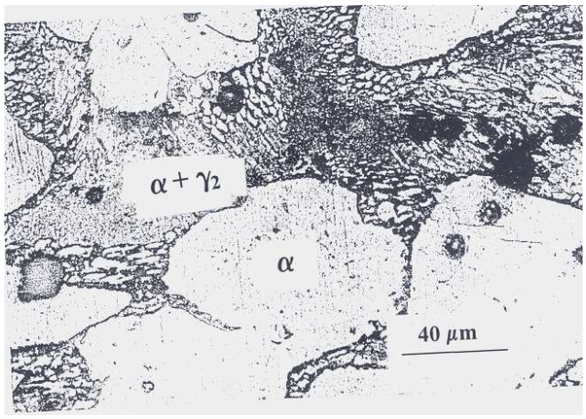

Figure 2: Microstructure of as-annealed Cu-10.2 wt. % Al

Specimens' preparation for investigation

After grinding, polishing and etching, different areas on the microstructure were randomly selected in each specimen to perform quantitative metallographic calculations. Three different areas from each specimen were subjected to study using both the point counting method P_p and the linear fraction method L_1 [9, 10]. In the former case a point net of 10 mm interspacing was used to count the relative number of points occasionally falling in the α–phase to the total number of points in the net. In the latter case the point net was replaced by a linear net of the same interspacing and the total line lengths occasionally found in the α–phase was related to the total length of lines of the net.

Table 1: Volume fraction of α–phase of the dual-phase structure equilibrated at different temperatures

Temp. °C	Linear fraction				Point counting			
	1st area	2nd area	3ed area	Average	1st area	2nd area	3ed area	Average
650	55.29	53.26	47.39	51.98	54.26	50.01	52.20	52.16
720	42.98	44.17	45.24	44.13	43.63	44.10	44.37	44.03
750	37.21	35.91	37.60	36.91	37.33	36.20	35.97	36.50

RESULTS AND DISCUSION

Study of the dual-phase structure

A typical microstructure of the dual-phase structure is introduced in Figure (3). Summary of the volume fractions of the α–phase determined by both methods, for specimens equilibrated at the selected temperatures, are given in Table 1. Although the volume fraction from each single determination could vary considerably from one area to another, the average values determined by each method are almost identical. The average value of the volume fractions of the α–phase in specimens equilibrated at 650°C, 720°C and 750°C were considered as 0.52, 0.44 and 0.37 respectively.

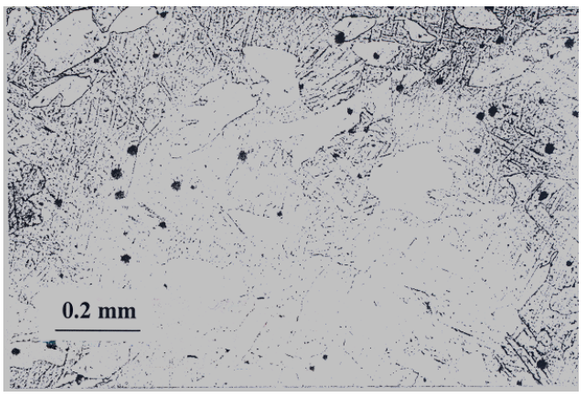

Figure 3: A representative microstructure of the dual-phase structure obtained in Al-bronze after equilibration at 750°C followed by brine quenching

The Vickers micro-hardness values of Martensite and α–phase determined using a load of 50 gr. for all specimens are introduced in Table (2). Each value is the average of 10 readings. In the same table the average overall hardness values of the investigated specimens measured using a load of 10 kg is also given. Figure 4 represents the overall hardness values of the investigated specimens as a function of the equilibrating temperature. The straight line obtained, together with the straightness of the lines separating the α + β region of the Cu-Al phase diagram from either the α-phase region or the β-phase region, makes it reasonable to check the validity of a linear relation connecting the micro-structural characteristics of the investigated specimens with their overall hardness values.

Table 2: Summary of dual-phase structure characterization

Temp. °C	α-phase			Martensitic-phase		H_{v10} overall
	Volume fraction	$H_{v0.05}$	Lattice parameter Á	Volume fraction	$H_{v0.05}$	
650	0.52	109.8±3.5	3.6584	0.48	229.6±4.3	140.5±5.2
720	0.44	109.3±2.8	3.6580	0.56	±7.2253	179.5±9.6
750	0.37	109.2±3.4	3.6578	0.63	261±6.6	207.1±7.3

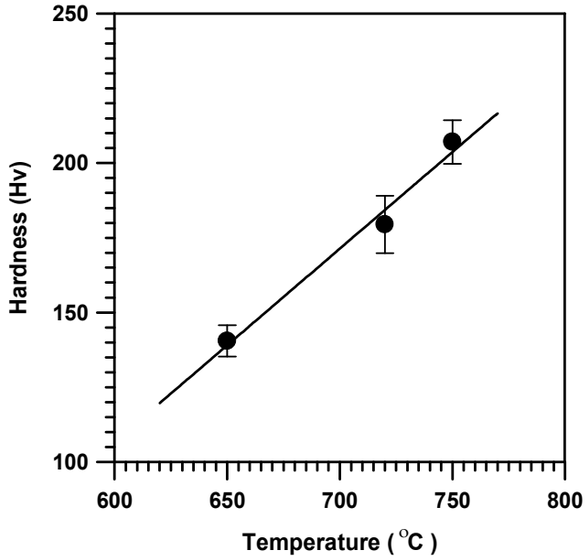

Figure 4: Effect of equilibrating temperature on the overall hardness of dual-phase aluminum bronze

Law of mixtures equation

A linear variant of the law of mixtures applied to composites is suggested to relate the overall hardness of the dual-phase Al-bronze to the micro-structural characteristics. The equation is of the form; [11].

$H_{v10} = A\ V_{v\alpha}\ H_{v0.05\alpha} + B\ V_{vm}\ H_{v0.05m}$

Where: A and B are constant parameters;

$V_{v\alpha}$ and V_{vm} are volume fractions of α–phase and martensite phase, respectively;

$H_{v0.05\alpha}$ and $H_{v0.05m}$ are micro-hardness of –phase and martensite phase, respectively.

Substituting the corresponding values from measurements at 650°C and 720°C respectively we get:

$140.5 = A \times 0.52 \times 109.8 + B \times 0.48 \times 229.6$ (1)

$179.5 = A \times 0.44 \times 109.3 + B \times 0.56 \times 253$ (2)

Solving these two equations for A and B we get

A = 0.05 B = 1.25

Now the final equation should be checked for measurements at 750°C

L.H.S. = 207±7.3

R.H.S. =0.05 x 0.37 x 109.2 + 1.25 x 0.63 x 261 = 207.52

Thus hardness and micro-hardness measurements at the three investigated temperatures fulfill the equation:

$Hv10 = 0.05\ V_{v\alpha}\ H_{v0.05\alpha} + 1.25\ V_{vm}\ H_{v0.05m}$

The X-ray charts of the dual phase structures showed the characteristic peaks of both the martensite and α-phase. Based on the peaks of the α–phase corresponding to reflections from {331} and {420} (high angle peaks) the lattice parameter of the Al-saturated α–phase was determined for each case. They are also introduced in Table (2).

The data given in Table (2) and the hardness equation obtained allow the following points to be highlighted;

- The micro-hardness of the α–phase was not affected by the change in the volume fraction of the martensite phase in spite of the differences in the amount of strain

exerted during the martensitic transformation, taking place on quenching from different temperatures. This is consistent with the fact that Cu-base alloys do not work harden markedly on the initial stage of plastic deformation, probably because the Al solute atoms shift the activation of the secondary slip systems in the α–phase to higher stress levels and thus lengthen the easy glide stage at the onset of plastic deformation.

- The micro-hardness of the martensite phase decreases with increasing the volume fraction of the α–phase from 261 kg/mm^2 at α volume fraction of 0.37 reaching ~230 kg/mm^2 when the volume fraction of the α–phase is ~ 0.52. This observation may be explained in terms of the transformation relaxation of martensite into the α–phase during the martensitic transformation. Such relaxation is expected to decrease the strain energy of the martensite phase leading to its softening.
- The constant A which characterizes the participation of the α–phase to the overall hardness of the alloy is very low (A=0.05) compared with the constant B which characterizes the participation of martensite phase (B=1.25). This observation seems to be logic since the martensite phase is the continuous one in the explored range of volume fractions. This result is in agreement with the results reported by Mader [11] for dual-phase structures in steel.
- With increasing the equilibration temperatures the lattice parameter of the α–phase decreases. The phase diagram of Cu-Al shows that with increasing the equilibration temperature the Al-content of the saturated α–phase decreases. Based on the measured lattice parameters of table 2 and the saturated Al-contents of the α–phase determined from the Cu-Al phase diagram at the studied equilibrating temperatures, a calibration curve between the Al-content and the lattice parameter of the saturated α–phase is constructed (Figure 5). The increase in the lattice parameter is probably due to the larger atomic radius of Al (0.143 nm) as compared to that of Cu (0.128 nm).

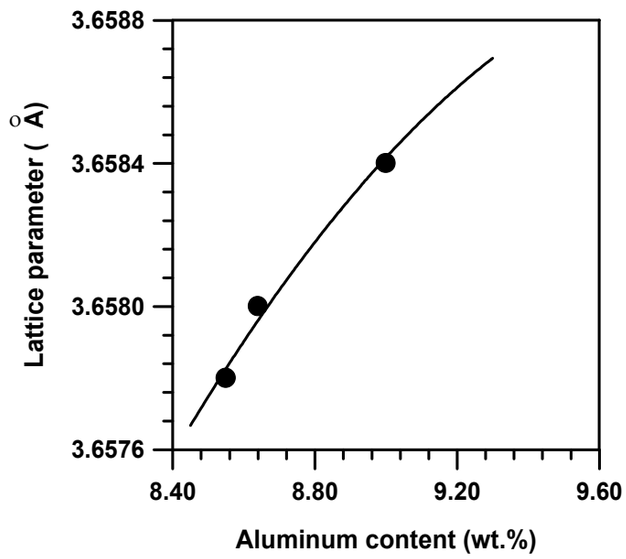

Figure 5: Effect of aluminum content on the lattice parameter of the α-phase

CONCLUSIONS AND RECOMMENDATIONS

- The overall hardness of the dual-phase aluminum bronze linearly increases with the equilibration temperature.
- In the explored range of martensite volume fraction (0.48-0.63) the overall hardness of dual-phase structure Al-bronze was found to follow a linear relation with the micro-hardness of the constituent phases and their volume fractions.
- The volume fraction of martensite in dual-phase Al-bronze does not noticeably affect the hardness of the α–phase.
- Increasing the volume fraction of α–phase decreases the hardness of the martensite phase in dual-phase structure.
- Aluminum increases the lattice parameter of the α–phase. A calibration curve relating the lattice parameter of the α–phase to the saturated Al-content was constructed.

REFERENCES

[1] V. Callcut; "Metallurgy of copper and copper alloys – Aluminum bronzes, Parts 1and 2"; CDA publication, London, 2002

[2] P. J. Macken and A. A. Smith, "The aluminum bronzes", CDA publication London, 1966.

[3] A. T. Adorno and R. A. G. Silva,"Thermal behavior of the Cu-10 wt.% Al and Cu-10 wt.% Al-4 wt.% Ag alloys", J. Thermal Anal. Cal., 75, 2004

[4] J. Kwarciak, "Phase transformationin in Cu-Al and Cu-Zn-Al alloys", J. Thermal Anal. Cal., 31, 1986

[5] R. G. Cope, "The tempering of martensite in Cu-Al alloys", J. Inst. Metals, 87, 1959.

[6] J. L. Murray, "The aluminum copper system", Int. Met. Rev., 30, 1985

[7] G. J. Arruda, A. T. Adorno, R. Magnani and C. R. S. Beatrice, "Kinetics of eutectoid decomposition in Cu-Al and Cu-Al-Ag alloys", Mater. Lett., 32, 1997.

[8] I. I. Novikov, "Theory of heat treatment of metals", Mir Publishers, Moscow, 1978.

[9] ASM, "Metals Handbook", V8, 8th ed, 1973.

[10] W. Rostoker and J. Dvorak, "Interpretation of metallographic structures", 2nd, Academic press, 1977

[11] A. R. Marder, "Metallurgical transaction A", V13, 1982.