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The Effect of Toughening Combined with Microjet Cooling During Quenching (Solution Heat Treatment) of Calcium Carbide-modified CuAl10Fe4Ni4 Alloy on its Mechanical Properties

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Abstract

The work presents the results of the experimental research concerning the impact of a heat treatment (toughening) of aluminum bronze CuAl10Fe4Ni4 on its mechanical properties. The conditions of the experiments and selected results are described. A detailed description of the effects of individual heat treatment conditions namely low and high temperature aging is also presented in the work.

Keywords: Cast aluminum bronzes, Heat treatment

1. Introduction

Within the framework of long-lasting research of cast aluminum bronzes, recently the effect of heat treatment of CuAl10Fe4Ni4 alloy modified with calcium carbide and cooled in microjet during quenching was investigated.

Concurrent modification with C + Ca additives and calcium carbide (CaC_2) was introduced. The aim was to produce an effect of the investigated factors on the mechanical properties (R_m, $R_{p0,2}$, A, Z, HBW).

2. Test conditions

Melting and casting of specimens for mechanical testing was investigated (Fig. 1).

Melting was carried out in a Radyne AMF145 induction crucible furnace of high frequency (2.3 kHz). The 40 kg charge consisted solely of BA 1044 alloy ingots. The process of molten metal preparation included the following steps: introducing the charge and refiner (Longgaz), melting, overheating, deslagging, deoxidising with CuP, refining with compressed nitrogen (8 minutes at a pressure of 0.1-0.2 bar), deslagging, deoxidation with magnesium, possibly modification. Mould for casting the specimens was poured at 1250°C. For the calculated charge, 46g CuP, 40g Mg and modifiers: 0.06% Ca+

0.15% C or 0.18% CaC_2 were applied. The disintegrated modifiers were wrapped in aluminium foil.

Table 1 gives the chemical analysis of individual melts: L (1) without modification, M (2) modification with Ca + C, and N (3) modification with CaC_2. A GDS 850A emission spectrometer (Leco) was used in the studies.

Table 1.
Chemical composition of the examined specimens, wt.%

BA1044	**Al**	**Fe**	**Mn**	**Ni**	**Si**	**Zn**	**Cu**
Melt L (1)	9.5	4.45	0.17	4.2	0.22	0.3	rest
Melt M (2)	9.7	4.45	0.17	4.30	0.20	0.15	rest
Melt N (3)	10.3	4.45	0.18	4.5	0.18	0.15	rest
Ingot	10	4.5	0.15	4.1	0.23	0.3	rest
EN 1982 (PN-91/H87026)	9-11	3.5 -5.5		3.5 -5.5			rest

Figure 1 shows the cast sample with gating and feeding system (uper drawing) and sample after preliminary machining used for testing of the heat treatment effect (down drawing).

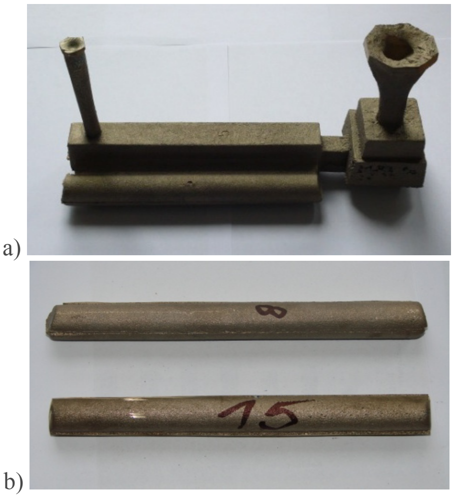


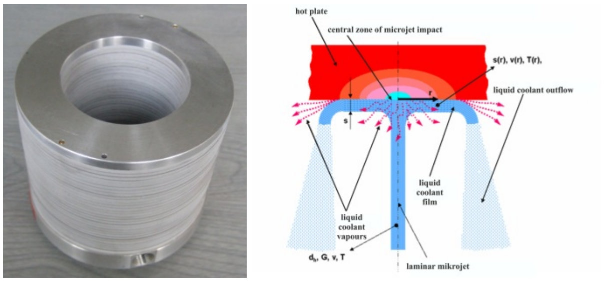
Fig. 1. Specimens for mechanical testing and structure examinations: a) casting, b) specimens machined for studies of heat treatment

Studies of the heat treatment carried out with a microjet device during solutioning (quenching) are shown in Figure 2. The work stand consists of a microjet device, special furnace for high-temperature heat treatment, a digital recorder of temperature changes with a control computer and additional terminal feeding microjet module with the cooling medium.

Figure 4a shows the specimen after heat treatment, while Figure 4b shows the machined specimen for testing of mechanical properties. An example of microjet solution heat treatment is shown in Figure 5, while Figure 6 shows the course of an ageing treatment; ageing (tempering) was applied in two temperature variants, i.e. low-temperature (a) and high-temperature (b).

Fig. 2. General view of the stand for microjet treatment

Figure 3 shows a general view of microjet module (a) and model of microjet striking against the surface of the plate (b).



a) b)

Fig. 3. Microjet device: a) general view of module, b) model of the zone of microjet impact against the plate surface

Fig. 4. Specimens for mechanical testing: a) heat-treated specimens, b) specimen machined for tensile test

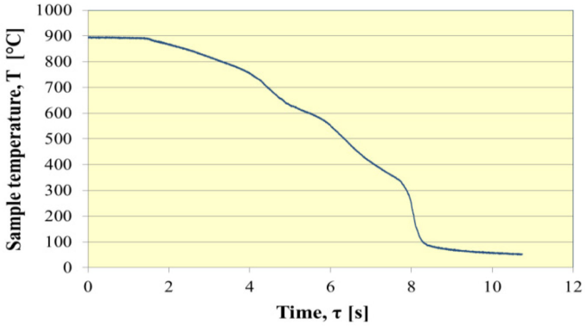


Fig. 5. Solution heat treatment curve in microjet cooling

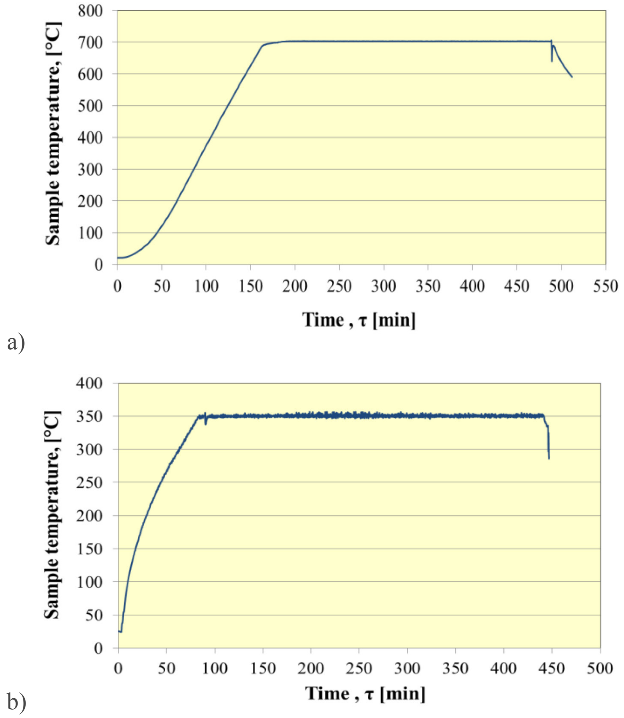


Fig. 6. Ageing curves for: a) low-temperature process, b) high-temperature process

3. Mechanical properties

The following designations of the sample condition were introduced: L- as-cast, P – solution heat treated, S1 – low-temperature aged (350°C) and S2 – high-temperature aged (700°C).

Table 2 presents mean values of the results obtained during variant studies of the CuAl10Fe4Ni4 alloy. Table 3 gives the corresponding maximum values of the properties, demonstrating the potential these alloys can offer in different states.

Table 2.
Average mechanical properties of CuAl10Fe4Ni4 alloy in as-cast state, after solution heat treatment and toughening combined with low- and high-temperature ageing of unmodified melts (L) and melts modified with Ca+C or CaC_2 (M and N)

State	Modification	R_m MPa	$R_{p0,2}$ MPa	A_5%	Z%	HBW 2.5/187.5
as-cast	unmodified	676	282	4.9	5.2	195
	Ca+C	640	314	9.1	8.3	201
	CaC_2	618	317	9.6	7.6	196
solution heat treated	unmodified	816	289	4.1	3.9	275
	Ca+C	801	499	3.2	4.4	246
	CaC_2	718	577	2.5	2.0	290
aged at 350°C	unmodified	849	420	1.5	2.0	283
	Ca+C	890	668	2.5	1.9	313
	CaC_2	815	774	2.0	1.0	314
aged at 700°C	unmodified	719	367	11.7	12.8	218
	Ca+C	756	394	16.7	15.6	215
	CaC_2	683	389	10	9.1	212

Table 3.
Maximum mechanical properties of CuAlFe4Ni4 alloy in as-cast state, after solution heat treatment and toughening combined with low- and high-temperature annealing of unmodified melts (L) and melts modified with Ca+C or CaC_2 (M and N)

State	Modification	R_m MPa	$R_{p0.2}$ MPa	A_5, %	Z, %	HBW 2.5/187.5
as-cast	unmodified	678	287	5.6	5.2	207
	Ca+C	658	321	9.9	9.4	208
	CaC_2	637	332	10	8.2	203
solution heat treated	unmodified	825	345	4.8	4.3	293
	Ca+C	826	556	3.4	5.1	290
	CaC_2	783	602	3.4	4.0	321
aged at 350°C	unmodified	915	489	2.1	2.0	300
	Ca+C	930	700	3.0	2.4	340
	CaC_2	828	805	2.3	1.2	338
aged at 700°C	unmodified	735	414	12.6	12.8	232
	Ca+C	765	420	16.9	15.8	223
	CaC_2	690	404	11.0	9.7	215

4. Summary

The effect of heat treatment when applied to the alloy in both unmodified and modified state is particularly well visible during toughening (solution heat treatment and annealing). The highest values of R_m are obtained in low-temperature annealing (350°C) but at the cost of plastic properties (A, Z) and at a relatively high hardness. On the other hand, the application of high-temperature annealing (700°C) during toughening leads to the, so-called, bethatision, i.e. obtaining at room temperature a partially transformed β phase at the expense of a brittle $\gamma 2$ phase, which enables obtaining much higher plastic properties at lower values of R_m and HBW. Quite notable is the increase of $R_{p0,2}$ after this heat treatment as compared to as-cast state.

Differences in the properties of alloys unmodified and after variant modification are relatively small with respect to R_m in as-cast state, but with clear improvement in the value of $R_{p0,2}$ for alloy modified with the additions of Ca + C and CaC_2.

In a similar way is behaving the alloy in a solution heat treated state and after toughening combined with low-temperature annealing.

The use of CaC2 modifier yields the mechanical properties inferior in all states to those obtained with an addition of Ca + C. As regards Rp0,2, better results after solution heat treatment and toughening combined with low-temperature annealing are obtained when modification is done with an addition of CaC2.

As regards plastic properties (A, Z), only in as-cast state the addition of CaC2 gives better results compared to alloy unmodified. In multi-variant heat treatment, the preferred addition is Ca + C.

Modifying of CuAl10Fe4Ni4 alloy with additions of Ca + C and CaC2 has a beneficial effect on plastic properties, while the effect on Rm still remains ambiguous, making this property worse in as-cast state and after solution heat treatment, and improving it after toughening. The effect of the examined modifying additives is not significant, except for the values of $R_{p0,2}$ in the state after toughening combined with low-temperature annealing.

More clear is the effect of heat treatment. In terms of mechanical properties (R_m), special attention deserves toughening combined with low-temperature annealing, allowing in particular cases obtaining even the R_m = 930 MPa. On the other hand, toughening combined with high-temperature annealing leads to a significant improvement of plastic properties (A, Z) with mechanical properties kept at a satisfactory level.

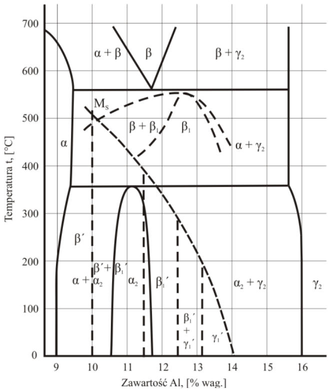


Fig. 7. Martensitic transformations in Cu-Al alloys [4]

A variant of the concept of high-temperature annealing during toughening is based on partial preservation of the β phase to room temperature at the expense of the γ2 phase. Figure 7 shows the martensitic transformations occurring in Cu-Al alloys. In the eutectoid reaction there is a partial transformation of β phase (with A2 lattice) into a β1 phase (with DO3 lattice), followed by a peritectoid reaction of β1 phase transforming into a β'1 phase (with DO22 lattice). In alloys containing up to 10 wt.% Al, the solution heat treatment often makes β phase transform directly into a disordered fcc β' martensite; this martensite is designated as an α' phase (with 3R lattice).

A characteristic feature of Cu-Al alloys is the reversibility of phase transformations:

$$\beta \rightleftarrows \beta' \rightleftarrows \beta_1 \rightleftarrows \beta_1' \text{ and } \beta_1 \rightleftarrows \sigma'_1$$

In these alloys, in the region of the β phase, also a bainitic transformation with participation of the β_1 phase can occur when high-speed cooling is applied during the solution heat treatment. In hypoeutectoid alloys (in the state of equilibrium at <11.8 wt.% Al), coarse bainite is forming (a mixture of coarse lamellar α ' + β'_1 phases). The eutectoid and hypereutectoid alloys can have a fine-grain bainite.

Partial transformation of the β phase into martensite or bainite stimulates changes in mechanical properties of the heat treated CuAl10Fe4Ni4 alloy.

The additions of Fe and Ni are partially included in the solid solution (Fe has a low solubility in the solid state) and form phases rich in Fe and Ni.

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