# INVESTIGATION OF THE INFLUENCE OF MODIFICATION WITH B, Zr AND Ti ON THE STRUCTURE AND HARDNESS OF CUAL9FE3 ALLOY BRONZE IN THE CAST STATE

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**ABSTRACT**

*In view of the changes occurring in the global production plan and the imposition by the business on the market for metal products and parts, there is a tendency to replace basic parts and castings made of cast iron and steel with those made of non-ferrous metals and alloys. Some of the most used metals are copper and aluminium, and their alloys. These alloys are alloyed or modified to produce alloys with better casting, performance and corrosion properties. Aluminium bronzes are of scientific interest because they are of industrial importance at a content of 6 - 12 % Al with or without the addition of other elements, crystallizing in a narrow temperature range, which determines a good thinness and a high tendency to form concentrated suctions, and alloys with a content of 9 - 15 % Al, where the mechanical strength and hardness increase with increasing aluminium content, but their ductility and impact toughness decrease. The development aims to increase the hardness, preserve or finesse the structure and change the grain shape of aluminium bronzes by adding a small amount of B, Zr and Ti as modifiers so that the resulting castings and parts of CuAl9Fe3B, CuAl9Fe3Zr and CuAl9Fe3Ti alloys in the cast state possess high technological, corrosion and service properties.*

Keywords: *aluminium bronze, difficult-to-melt modifier B, Zr and Ti, microstructure, Brinell hardness.*

## INTRODUCTION

Cast aluminium bronzes are usually additionally alloyed with iron, nickel or manganese, which have a positive influence on the mechanical and technological properties, as well as on the refinement of the structure and the increase in hardness, especially after heat treatment. In the literature, there are many works proving the positive effect of alloying bronze type CuAl9 after heat treatment [1 - 4].

The addition of difficult-to-melt elements Ti, V, Zr, B, W, Mo, etc., is intended to obtain the refinement of primary grains in copper alloys containing Al, but it should be borne in mind that the modifying action of these difficult-to-melt elements is largely determined by the presence of Fe in the alloy, and in non-iron-containing alloys, the modifying action of Ti, W, and B does not occur. Moreover, the addition of hard-to-melt modifiers also induces a change in the microstructure of the alloys (change in the shape of the alloy grains) especially after heat treatment [4].

The experiments envisaged in the paper are designed to investigate whether the positive effect of adding the modifiers Ti, W, and B in minute amounts to iron alloyed bronze of CuAl9Fe3 type will be manifested, namely to maintain the high hardness, the refinement of the primary grains, and the grain shape change in cast alloys, resulting in high quality castings and parts. If a positive effect of the modification is achieved, a shortening of the technological process will be realised (heat treatment will be excluded) to obtain high quality castings and workpieces made of copper-aluminium alloys, which in a global production perspective will lead to the replacement of basic workpieces and castings made of cast irons and steels with those made of non-ferrous metals and alloys in the cast state or after heat treatment depending on the environment in which they will work.

The difficult-to-melt modifier B, Zr and Ti is introduced into the alloy by using Al-V (50 %), Mn - B (3 - 4 %), Al - Ti, Mn - Ti ligatures or ferroalloys FeB, FeZr, FeTi. at alloy temperature 1200 - 1250°C without overheating the alloy to be modified to avoid complete combustion of the modifying element and obtaining a coarse-grained structure. The amount of modifier added is within an optimum concentration of between 0.05 - 0.5 % [5, 6].

## EXPERIMENTAL

The methodology of the work and the conduct of the experiments were chosen based on a literature review. To accomplish the objectives of the study, a 25 mm diameter and 6.25 cooling modulus sample preparation flask was designed and fabricated. The mould was made from a standard sand-bentonite moulding mix (4 % bentonite, 96 % quartz moulding sand 0PC25 and 4 % water). The melting of the alloys was carried out in a laboratory electric furnace with a graphite crucible and a screen with LED display to set and monitor the required temperature so that the alloy did not overheat. The finished castings are in the cast state and are machined by cutting on a lathe, grinding on a Metasinex apparatus, polishing on a Montasupal apparatus, and a hydrochloric acid solution of ferric chloride was used to develop the structure. The microstructure of the alloys was examined with an Epitip-2 metallographic microscope at ×63 magnification and photographs were taken with a Sony digital camera. The hardness of the sample bodies was investigated by the Brinell method (BS 1SO 6506) with a sphere (ball) of 2.5 mm diameter and a load of 187.5 kgf (1875 N).

The calculation of the charge was carried out based on bronze grade CuAl9Fe3 according to a standard methodology; the standard tolerances in the chemical composition of the alloys were taken into account by providing for a 10 % set-aside of aluminium. For the preparation of the alloys, the following batch materials were used based on 568 g of alloy - electrolytic copper - 500 g (88 %); aluminium - 51 g (9 %); armco iron - 17 g (3 %). To modify the obtained CuAl9Fe3 alloy, 1.7 g (0.3 %) of modifier was used, or more precisely FeB - 8.5 g (20 % B), FeZr - 2.4 g (70 % Zr), FeTi - 5.7 g (30 % Ti), so that the amount of modifier meets the condition of being in the range of 0.05-0.5 % [7 - 9].

The sequence of the smelting process is as follows: first the copper is charged and smelted; the modifier and iron are added, after their dissolution the aluminium is introduced. The alloy is cast at the set temperature in a pre-prepared casting mould. After cooling, the sample bodies are knocked out of the mould and machined by turning. From the sample bodies prepared in this way, grinding and polishing are used to produce the grinds for metallographic analysis. The structure is developed by means of a reagent consisting of 5 g of water. FeCl3, 20 mL concentrated hydrochloric acid and distilled water to 100 mL. The reagent stains the α-phase dark and the second phase (β or eutectoid) remains light [7, 8].

## RESULTS AND DISCUSSION

The microstructure of the CuAl9 base alloy in the cast state is shown in Fig. 1 [4].

Fig. 1 and Fig. 2 show that aluminium bronzes, and CuAl9 in particular, tend to form a coarse, ladder-like primary structure, and the addition of iron as an alloying element to an aluminium bronze result in a refinement of the structure. The mode (rate) of cooling (6.25) determines the progress of primary crystallization and of eutectoid β-phase decomposition and hence influences the final hardness of the alloy [4].

It can be seen in Fig. 3 that modification with B yields a eutectoid structure about five times smaller than the base CuAl9 alloy, but with a slightly more elongated eutectoid crystal shape, a more uneven distribution of the beta phase relative to the alpha phase, and a more coarse-grained structure than the CuAl9Fe alloy structure. The measured Brinell hardness is 166 HBS.

It is evident from Fig. 4 that modification with Zr results in a structure about five times smaller than the baseline (CuAl9), but the eutectoid is more evenly distributed. Compared to the iron-doped alloy (CuAl9Fe3), the CuAl9Fe3 Zr-type bronze differs in the needle-like structure. The measured hardness is 197 HBS.

It can be seen from Fig. 5 that when modified with Ti, the structure of the studied alloy is about three times smaller than the base CuAl9. Compared with the iron-doped alloy (CuAl9Fe), the eutectoid has a larger structure, and the alpha phase is more. The measured hardness is 176 HBS.

The results of the measured Brinell hardnesses of CuAl9 alloy in the cast state alloyed with Fe and modified with the difficult-to-melt modifiers B, Zr and Ti are shown in Fig. 6.

In Fig. 7 is presented the measured hardness of alloys CuAl9, CuAl9Fe3, CuAl9Fe3Mo, CuAl9Fe3W, CuAl9Fe3V, CuAl9Fe3B, CuAl9Fe3Zr and CuAl9Fe3Ti, to illustrate the positive effect in hardness enhancement in Ti-modified aluminium bronzes and especially the Brinell hardness enhancement upon Zr modification of CuAl9Fe3 grade alloy bronze in the cast condition.

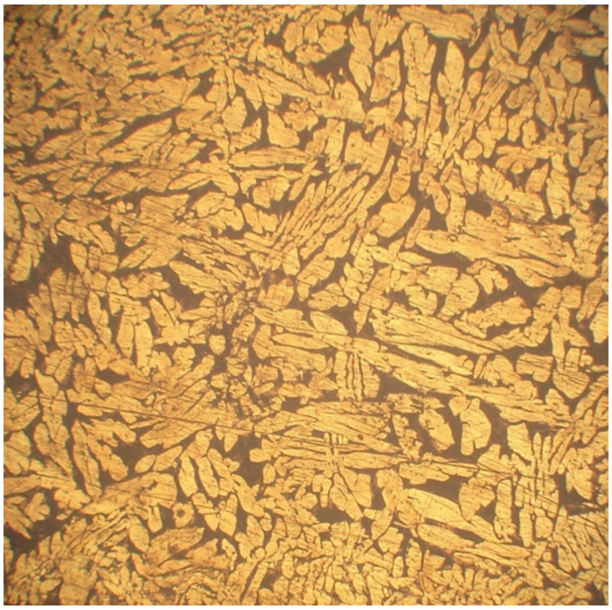

Fig. 1. Base alloy microstructure CuAl9 (× 63) [4].

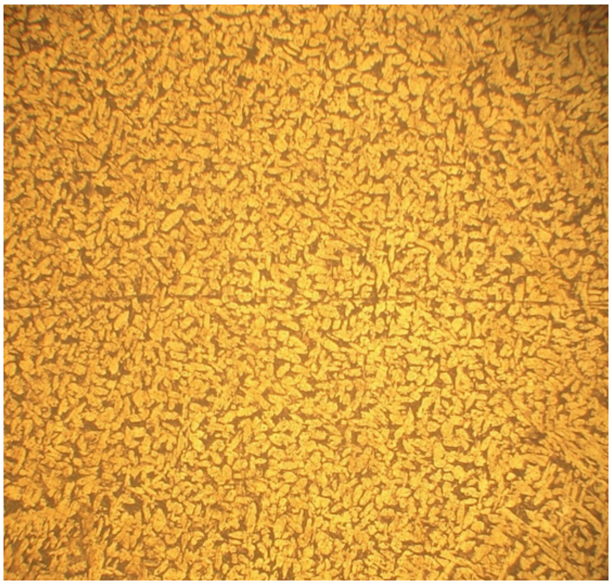

Fig. 2. Base alloy microstructure CuAl9Fe3 (× 63) [4].

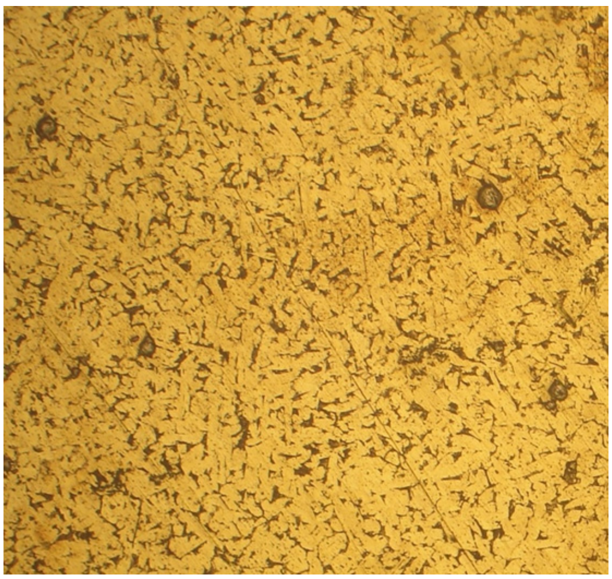

Fig. 3. Alloy microstructure CuAl9Fe3B (× 63).

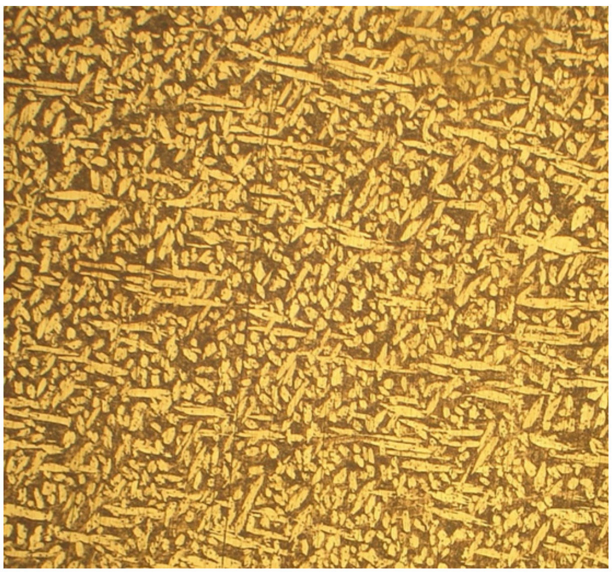

Fig. 4. Alloy microstructure CuAl9Fe3Zr (× 63).

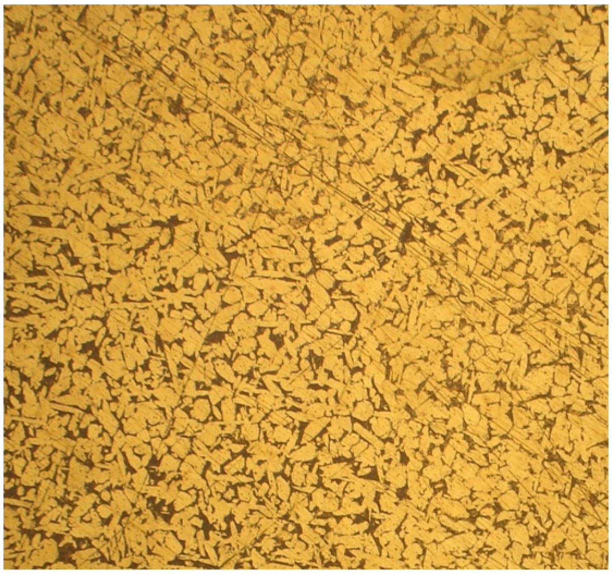

Fig. 5. Alloy microstructure CuAl9Fe3 Ti (×63).

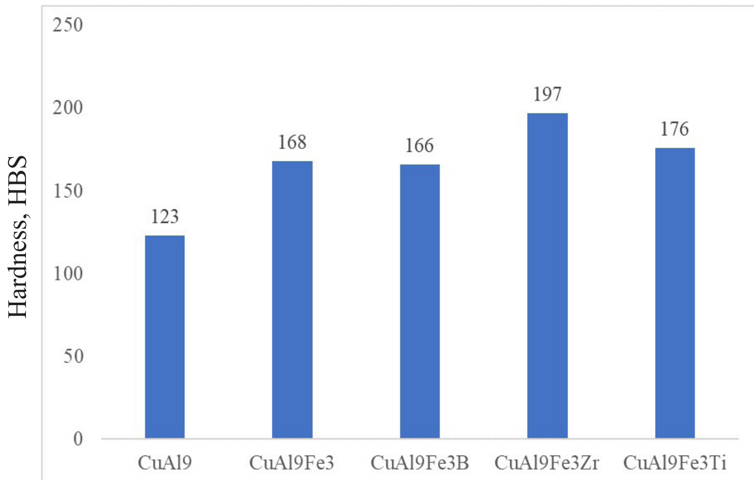


Fig. 6. Hardness change upon modification with B, Zr and Ti of Fe-doped CuAl9 alloy.

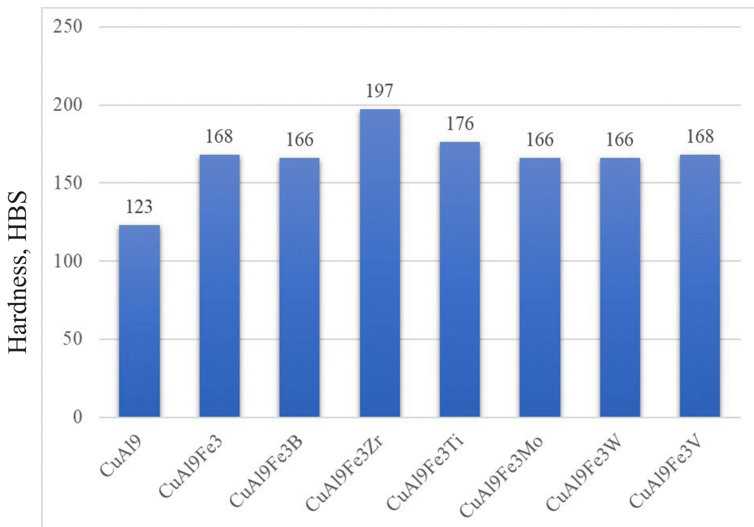


Fig. 7. Hardness change upon modification with B, Zr, Ti, Mo, W and V of Fe-doped CuAl9 alloy.

## CONCLUSIONS

Dual foundry alloys of the copper-aluminium system do not find practical application due to the coarse structure and unsatisfactory performance characteristics, and to overcome this, alloys alloyed with iron, manganese and nickel separately and in combination, and by adding difficult-to-melt elements W, V, B, Zr, Ti and Mo are used.

From the experiments carried out for the modification with B, Zr and Ti of CuAl9 alloy pre-alloyed with Fe, the following conclusions can be drawn:

- When modifying CuAl9Fe3 alloy with B, a finer eutectoid structure than the base alloy is obtained, more coarse-grained than the iron-doped alloy, and it possesses a hardness of 166 HBS, which is 43 units more than the base alloy and two units less than CuAl9Fe3 alloy.
- Modification with Zr results in a structure about five times smaller than the base CuAl9, but the eutectoid is more evenly distributed. Compared to the iron-doped alloy, however, it differs in its needle-like structure and the amount of the second phase. The measured hardness is 197 HBS, which significantly exceeds the hardness of the CuAl9 (by 74 units) and CuAl9Fe3 (by 29 units) steels.
- The addition of Ti as a modifier results in a three times smaller structure than the base alloy CuAl9. The resulting CuAl9Fe3Ti alloy has a larger eutectoid structure, the alpha phase is more relative to that in CuAl9Fe3 alloy. The hardness measured by Brinell is 176, which means that modification with Ti results in an increase in hardness relative to the iron-doped base alloy by about 8 HBS units and an increase in hardness by about 53 units relative to the base alloy.
- Regarding the effect of modifying the alloys with the difficult-to-tolerate modifier B, Zr and Ti, the following fact can be noted: modification with Zr and Ti leads to a significant increase in the hardness of the alloy, while modification with B keeps almost unchanged the structure and hardness of the alloy compared with the Mo-modified alloy and the same hardness with it and the iron-doped alloy.

In conclusion, it can be said that alloying CuAl9 type bronze with Fe in the cast state has a beneficial effect on the alloy structure by refining it and increasing its hardness, while additional modification with the hard-to-melt modifiers Zr and Ti will lead to a fining of the structure and an increase in Brinell hardness compared to CuAl9, CuAl9Fe3, CuAl9Fe3Mo, CuAl9Fe3W, CuAl9Fe3V and CuAl9Fe3B alloys in the cast state. The castings and parts obtained from copper-aluminium alloys alloyed with iron and additionally modified with hard-to-melt modifiers W, V, B, Zr, Ti and Mo in the cast state will be able to work in production conditions and replace a part of cast iron and steel parts and castings. It is of course necessary to extend the scope of research by doing experiments with different amount of modifier; to do XRD, EDS, EBSD, etc. analyses; to study the corrosion resistance of alloys, etc.

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