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Abrasive wear of BA1055 bronze with additives of Si, Cr, Mo and/or W

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Abstract

Aluminium bronzes belong to the high-grade constructional materials applied on the put under strongly load pieces of machines, about good sliding, resistant properties on corrosion both in the cast state how and after the thermal processing. It moves to them Cr and Si in the aim of the improvement of their usable proprieties. The additions Mo and/or W were not applied so far. It was worked out therefore the new kind of bronzes casting including these elements. Make additions to the Cu-Al-Fe-Ni bronze of Si, Cr, Mo and/or W in the rise of these properties makes possible. The investigations of the surface distribution of the concentration of elements in the microstructure of the studied bronze on X-ray microanalyzer were conducted. It results from conducted investigations, that in the aluminium bronze BA1055 after makes additions Si, Cr, Mo and/or W the phases of the type κ_{Fe}, κ_{Ni} crystallize, probably as complex silicides. Elements such as: Fe and Si dissolve first of all in phases κ, in smaller stage in the matrix of the bronze; Mn, Ni and W they dissolve in matrix and phases κ. It dissolves Cr and Mo in the larger stage in phases κ than in the matrix. The sizes of the abrasive wear were compared in the state cast multicomponent new casting Cu-Al-Fe-Ni bronzes with the additives Cr, Mo or W with the wear of the bronze CuAl10Fe5Ni5Si. The investigations of the wear were conducted on the standard device. It results from conducted investigations, that make additions to bronze BA1055 of the additives of Si, Cr, Mo, and/or W it influences the rise of the hardness (HB) of the bronze in the cast state, in the result of the enlarged quantity separates of hard phases κ, and in the consequence the decrease of the abrasive wear. The addition of molybdenum made possible obtainment of the microhardness of the phase α and γ_2 on the comparable level. From the microstructure of the bronze CuAl10Fe5Ni5MoSi is characterizes the smallest abrasive wear among studied bronzes. More far works over new multicomponent aluminium bronzes will be guided in the direction of the identification of the changes of mechanical properties of studied bronzes under the influence of the thermal processing.

Keywords: Resistant alloys on the wear; Abrasive wear; Multicomponent aluminium bronze; Cast state; Microstructure; Mechanical properties

1. Introduction

Aluminium bronzes make up the group of high-grade constructional materials applied on casts of the strongly load pieces of machines, resistant on abrasion and corrosion especially in sea water. [1]. The rise of their resistance on the wear will make possible decrease of the dimensions of the piece of machines and aspect ratio the time of their exploitation. The newest investigations of bronzes in the range of the resistance on the wear relate to mechanical and trybological properties of new type - matters including 14% Al (and different elements) applied on drawing dies [2], if also the adhesive wear of aluminium bronzes applied as tool material in sheet metal forming of stainless steel [3]. They are guided the investigation over new high-grade Cu-Al-Fe-Ni bronzes with additions in the Department of Material Engineering and Systems Production of Technical University of Lodz singly or the simultaneous of Si, Cr, Mo and/or W [4,5].

2. Methodic of research

Sample to the measurement of the abrasive wear about the diameter 20 mm was introduced on Figure 1. Samples executed from bronzes: CuAl10Fe5Ni5Si (P1), CuAl10Fe5Ni5CrSi (P2), CuAl10Fe5Ni5MoSi (P3), CuAl10Fe5Ni5SiW (P4) were subjected the investigations of the abrasive wear. Bronzes P2, P3 and P4 were got on the base camp of the bronze P1. The investigation resistance on the abrasive wear of multicomponent aluminium bronzes in the cast state was conducted on measuring device introduced on Figure 2. The parameters of the test were following: the elementary pressure F = 318309,9 N/m^2, time 480 minutes (road s = 5690m), the abrasive paper about the granularity P40. It was subjected every of samples abrasion by 8 hours, each time after 60 minutes clean ethanol and weigh with exactitude to 0,01 g. The used abrasive paper - P40, it was exchanged every 60 minutes. The device was connected to the device the sucking in formed products of the abrasion.

Investigations on the metallographic and electron microscope were conducted on samples before the abrasion. Microsection it was etched the reagent Mi17Cu. The surface and punctual microanalysis of the distribution of elements was executed on the microanalizer of the firm Thermo Electro Corporation.

The investigations of microhardness HV were conducted at the duty 50g on microhardness tester Zwick 3212, and measure the Brinell hardness at following parameters 2,5/187,5/15.

Fig. 1. The shape of the measuring sample

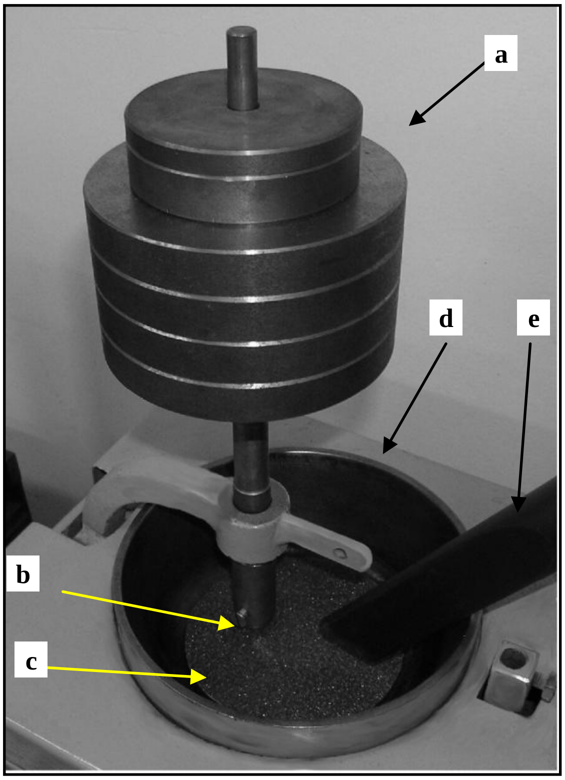

Fig. 2. The laboratory measuring device
a) load, b) the chuck of the sample, c) abrasive paper, d) revolving pan, e) exhaust fan

3. The results of investigations

3.1. Microstructure of studied multicomponent aluminium bronzes

On the Figure 3 and 4 was introduced suitably the microstructure of the bronze CuAl10Fe5Ni5CrSiMoW (P5) and the map of the surface distribution of elements: Al, Si, Mn, Fe, Ni, Cu, In, Cr and Mo. Distribution of elements in the phases of microstructure it is characteristic and representative for individual type-matters bronzes including only single additions Cr, Mo and W. On the Figure 5 was introduced the results of the X-ray punctual analysis of the concentration of chosen elements in the phases of the microstructure of the bronze. It results from introduced investigations, that in the aluminium bronze BA1055 after makes addition Si, Cr, Mo and/or W the phases of the type κ_{Fe} crystallize and/or κ_{Ni} in dependence from their proportional part. Complex silicides (Fig. 4) probably are this. Phase κ_{Fe} in the comparison from κ_{Ni} contains more Fe, Mo, Si, Cr and W, and less Cu, Al, Ni and Mn (Fig. 5).

The phase α in the comparison with the phase γ_2 contain Cu more, and less Al and Ni (Fig. 5). Both in phase α as and in phase γ_2 the concentration Mn, Fe, Ni and W it is comparable. In phase α and γ_2 almost do not occurrence Si, Cr and Mo. These elements dissolve in primary phase β. However because of the presence in the studied bronze of iron and nickel, they crystallize in phase κ. It the crystallization of phases κ exhausts entirely Si, Cr and in the considerable piece Mo yet before the partial break-up of the phase β ($\beta \rightarrow \alpha$), and now yet before the eutectoidal transformation during which the phase crystallizes γ_2 ($\beta \rightarrow \alpha+\gamma_2$).

The results of the X-ray punctual analysis of the concentration of chosen elements in phases of studied bronzes were introduced on Figures 6 ÷ 14.

On Figures 15÷18 was introduced the photo of microstructure studied bronzes:

- Fig. 15 – CuAl10Fe5Ni5Si (P1),
- Fig. 16 – CuAl10Fe5Ni5CrSi (P2),
- Fig. 17 – CuAl10Fe5Ni5MoSi (P3),
- Fig. 18 – CuAl10Fe5Ni5SiW (P4).

Studied bronzes have comparable folded microstructure from the phases differing the concentration of dissolved in them elements. Microstructure of the aluminium bronze CuAl10Fe5Ni5Si consist from following phases (Fig. 15):

- α – the solid solution of aluminium in the copper,
- γ_2 – the solid solution on the matrix of the intermetallic compound Cu_9Al_{14} entering in type-matter eutectoid ($\alpha+\gamma_2$),
- κ – intermetallic compound:
  - κ_{Fe} –rich in iron (Fig. 8 and 9),
  - κ_{Ni} – rich in iron with the raised concentration of the nickel (Fig. 8 and 9).

Analysing the influence of made additions elements to the bronze BA1055 it results, that in the phase α the concentration of copper and iron underwent in the range to small hesitations 81,52÷85,21% Cu and 2,50÷3,42% Fe, independently from the kind made addition element (Fig. 6 and 8). The concentration of copper and iron in the phase undergoes similarly small changes γ_2 (76,16÷79,50% Cu; 2,10÷2,95% Fe). Characteristic for phase α and γ_2 are the lack in them dissolved Si (Fig. 11; existing in analyses indications are even concentrations what to the value the error of estimating). The concentration of aluminium in the phase α change in the range 6,87÷8,89% Al (Fig. 7). In the phase γ_2 are the higher concentration of aluminium than the phase α and change in the range 11,48÷12,73% Al. The concentration of the nickel changes in the phase suitably α in the range 4,46÷5,99% Ni and in the phase γ_2 5,31÷7,76 %Ni (Fig. 9). The concentration of manganese in the phase α and γ_2 keep in the range 0,41÷0,69% Mn (Fig. 10).

Microstructure did not undergo the change after make additions to studied aluminium bronze Cr, Mo or W fundamentally.

The addition of chrome is fix in the phase κ_{Fe} exclusively and κ_{Ni} (Fig. 12). The chrome caused small enlargement of the areas of the occurrence of the phase α and the separates of phases κ_{Fe} and κ_{Ni} (Fig. 16).

Molybdenum melted first of all in the phase κ_{Fe} and in the comparatively small stage in the phase γ_2 (Fig. 13). The addition of molybdenum caused considerable enlargement of the areas of the occurrence of the phase α and the quantity small separates of phases κ_{Fe} and κ_{Ni} (Fig. 17).

In bronze with the addition of the wolfram do not identificate separates of the phase κ_{Ni}. Similarly as molybdenum, he melted first of all in the phase κ_{Fe}, and in the phase α reached the concentration 0,25% W (Fig. 14). The addition of the wolfram caused enlargement of quantity large separates of intermetallic phase κ_{Fe} and the areas of the occurrence of the phase α (Fig. 18).

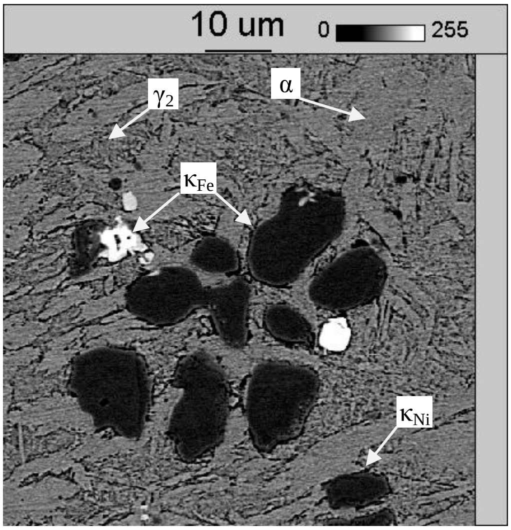

Fig. 3. The microstructure of the bronze CuAl10Fe5Ni5CrSiMoW

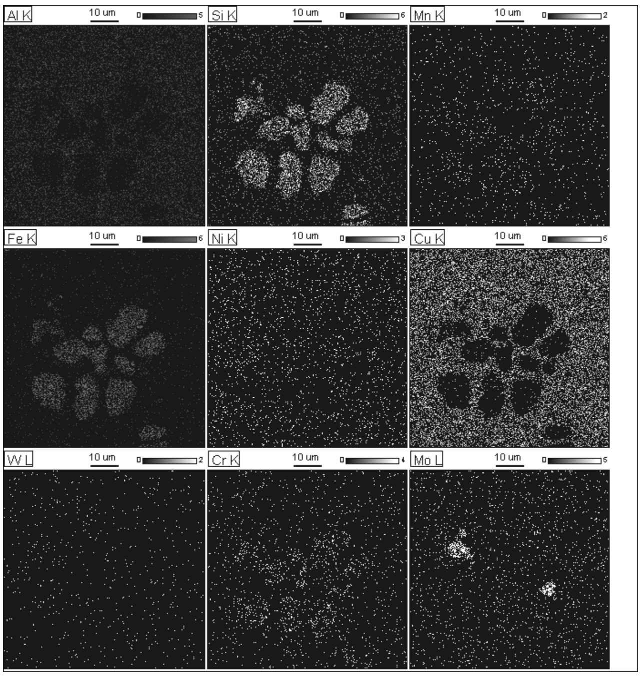

Fig. 4. The map of the surface distribution of elements in the microstructure of the bronze CuAl10Fe5Ni5CrSiMoW

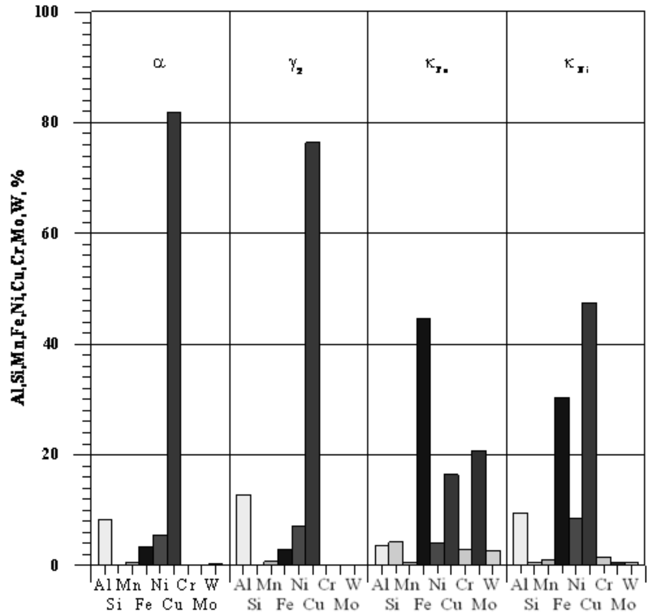

Fig. 5. The concentration of elements in the phases of the bronze CuAl10Fe5Ni5CrSiMoW (P5): α, γ_2, κ_{Fe}, κ_{Ni}

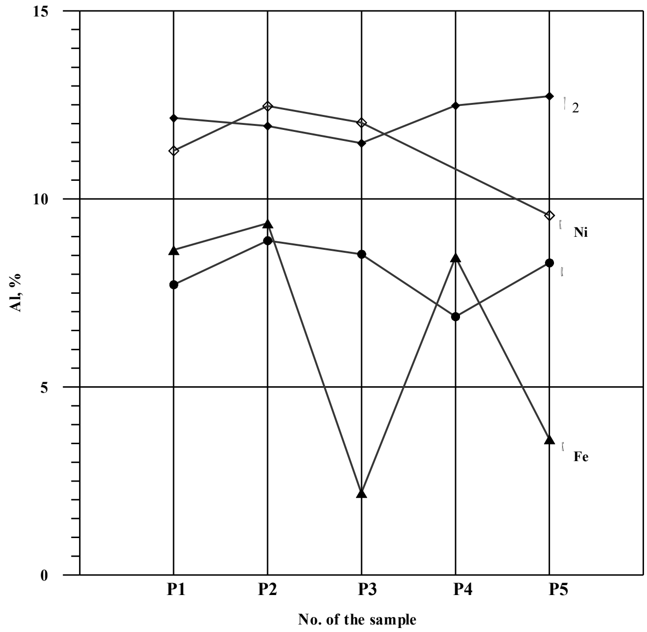

Fig. 7. The concentration Al in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

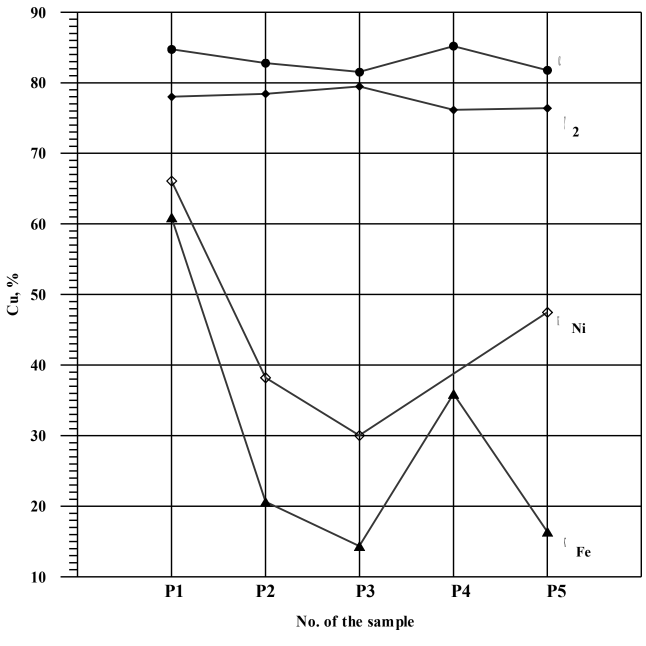

Fig. 6. The concentration Cu in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

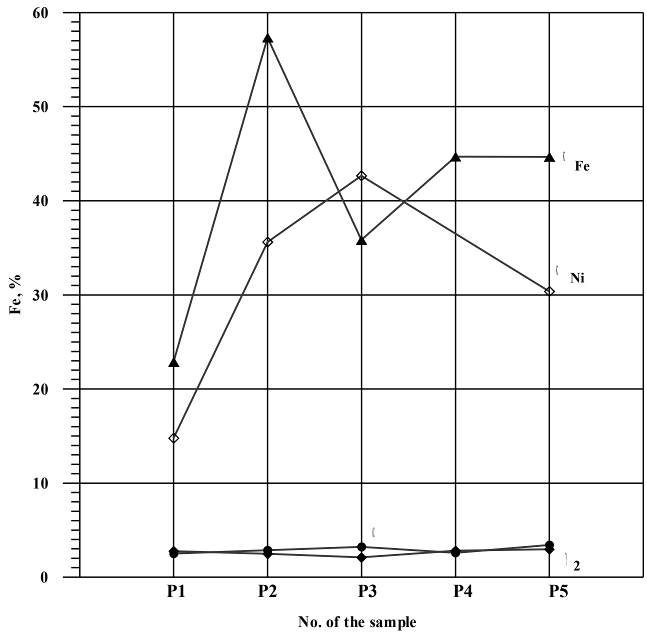

Fig. 8. The concentration Fe in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

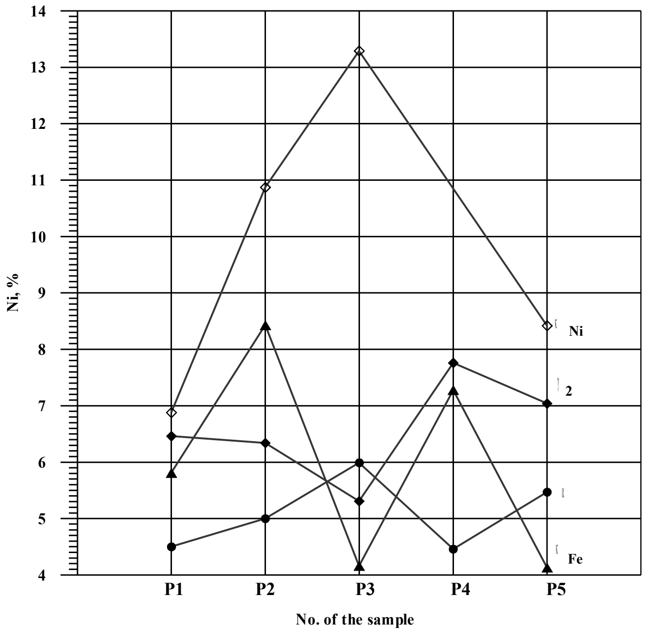

Fig. 9. The concentration Ni in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

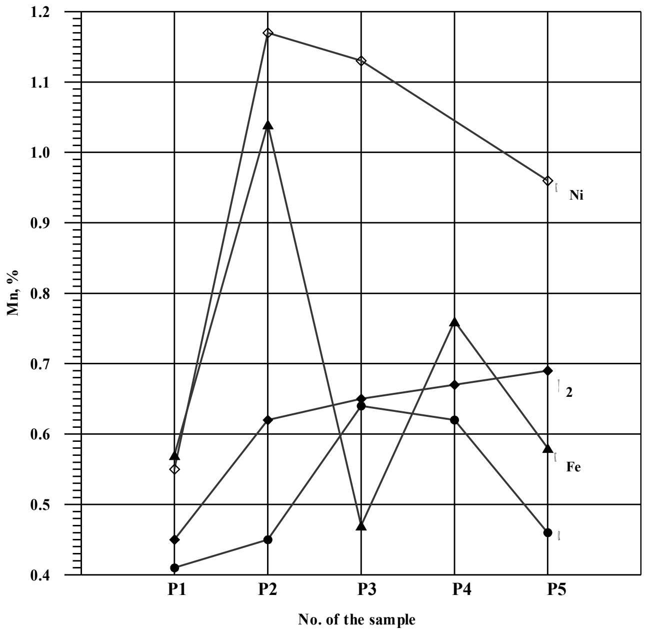

Fig. 10. The concentration Mn in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

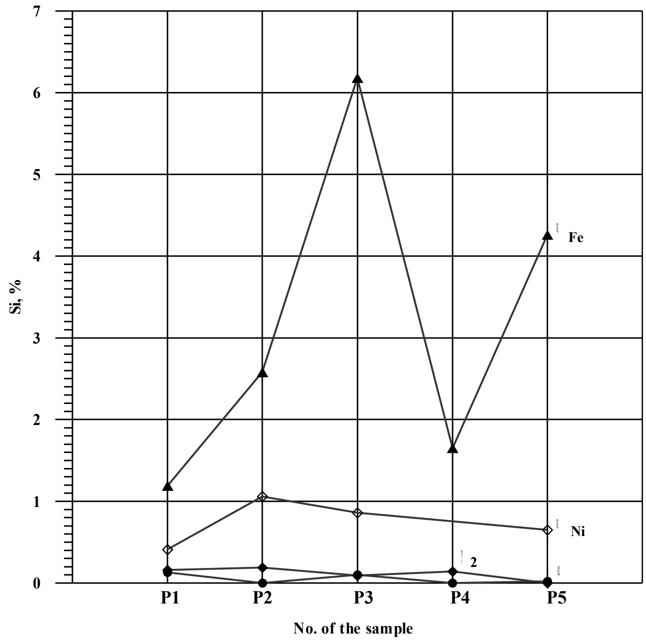

Fig. 11. The concentration Si in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

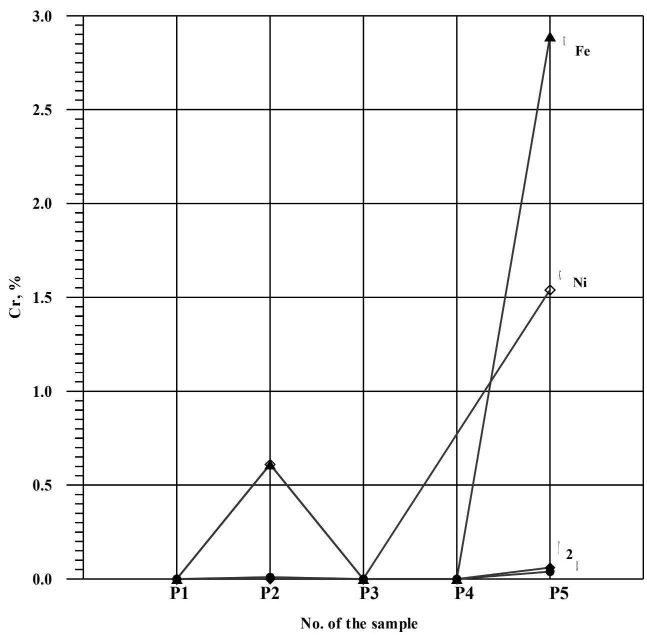

Fig. 12. The concentration Cr in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

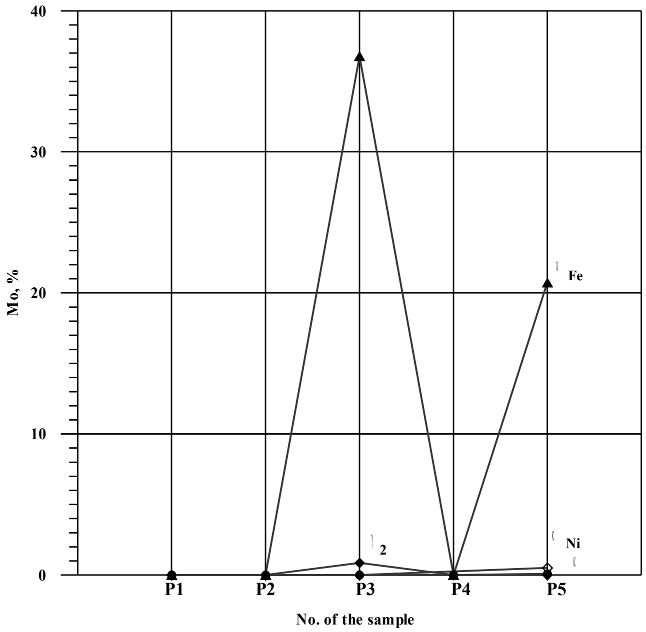

Fig. 13. The concentration Mo in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

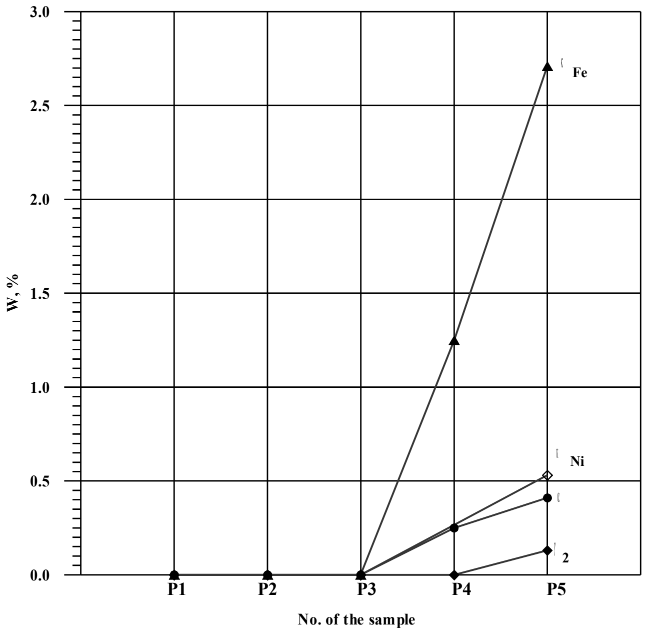

Fig. 14. The concentration W in the phases of the bronze P1÷P5: α, γ_2, κ_{Fe}, κ_{Ni}

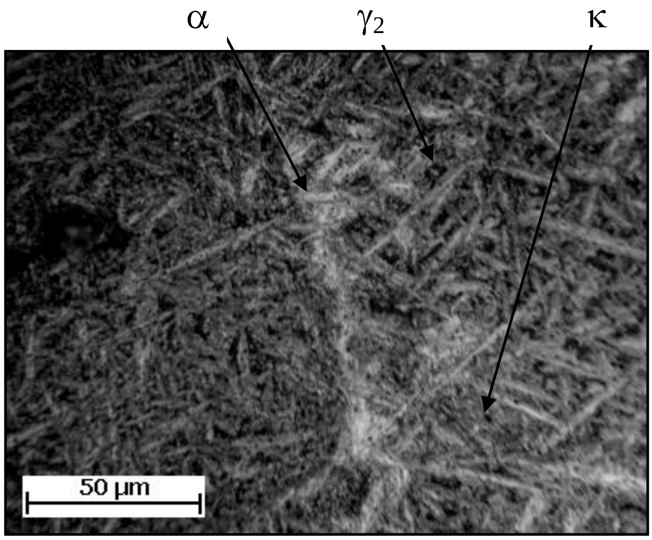

Fig. 15. The microstructure of the bronze CuAl10Fe5Ni5Si

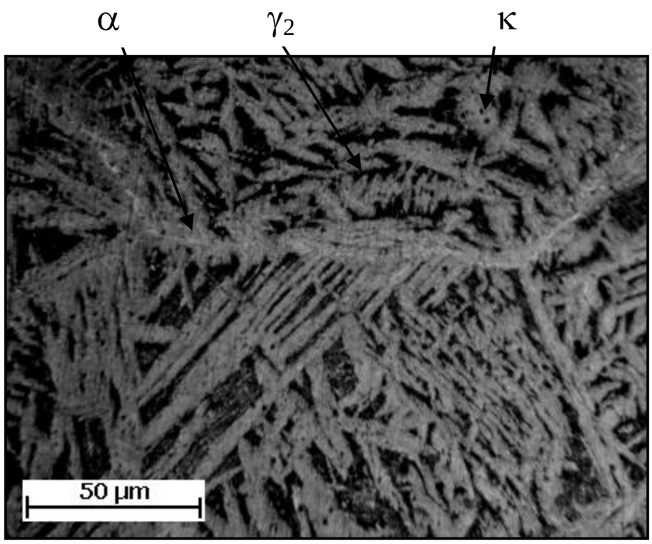

Fig. 16. The microstructure of the bronze CuAl10Fe5Ni5CrSi

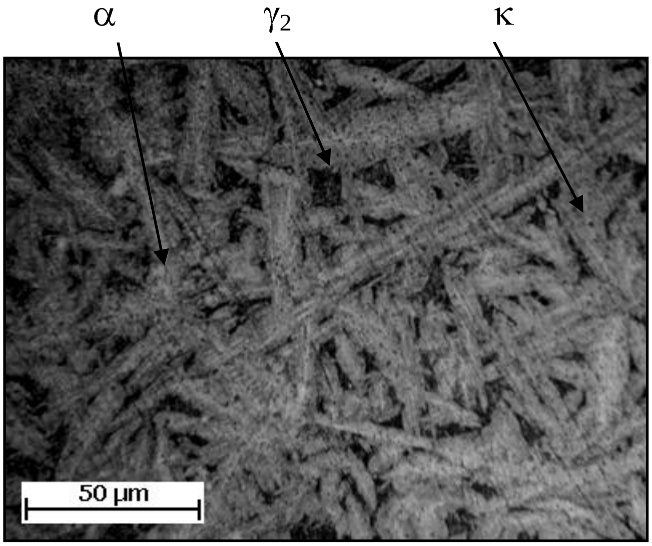

Fig. 17. The microstructure of the bronze CuAl10Fe5Ni5MoSi

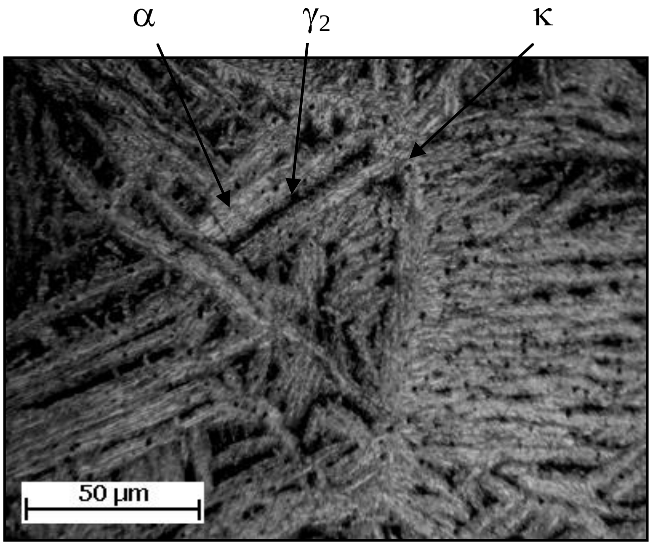

Fig. 18. The microstructure of the bronze CuAl10Fe5Ni5SiW

3.2. The mechanical properties of the studied bronze – HB , µHV

On the Figure 19 and in the table 1 was introduced the average values of the measurements of Brinell hardness of studied bronzes and microhardness µHV of phases α and γ_2.
The growth hardness HB the bronze BA1055 after makes additions to him Cr, Mo or W it is caused first of all the strengthening of his microstructure in the consequence of the growth quantities of the hard phase κ_{Fe} and κ_{Ni}.

The addition of chrome (P2) in the relation to the initial bronze (P1) caused growth of hardness HB of bronze from 177 to 200. The chrome did not influence significantly on the µHV of the phase α and γ_2.
The addition of molybdenum (P3) enlarged the hardness HB of the bronze to 209. He did not influence the growth of the microhardness of the phase γ_2. However the growth of the microhardness of the phase α it was caused first of all, in the comparison with the initial bronze P1, higher about 0,23 % concentration of manganese (Fig. 10).
The hardness of the bronze grew up to 218 HB after making additions the wolfram. The growth the µHV of the phase α it, in the comparison with the initial bronze, was caused both the larger concentration of manganese as and wolfram of dissolved in this phase (Fig. 10 and 14). The growth of the microhardness of the phase γ_2 were caused the higher concentration of nickel and manganese, in the comparison with initial bronze (Fig. 9 and 10).

Table 1.
Microhardness HV and Brinell hardness

Sample	µHV γ_2	µHV α	HB
P1	257,13	218,38	177,50
P2	266,25	210,33	200,25
P3	261,88	263,56	208,83
P4	294,25	272,25	218,00

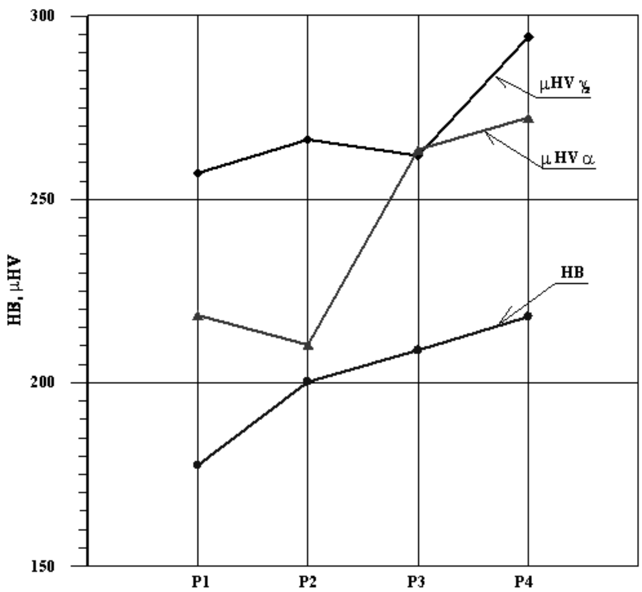

Fig. 19. The hardness HB of the bronze and the µHV of the phase α and γ_2

3.3. Abrasive wear

In the table 2 was introduced mathematical models (and their statistical parameters) the decrease of the mass Δm in the function of the time of the abrasion τ for the studied bronze CuAl10Fe5Ni5Si with the additions Cr, Mo and W. Essential mathematical models were got in the result of statistical calculations (the test F for model > $F_{critical}$) on the level $\alpha = 0,05$.

Table 2.
Mathematical models abrasive wear the bronze CuAl10Fe5Ni5Si (P1) with additions Cr (P2), Mo (P3) and W (P4)

P1	$\Delta m=0,228057\cdot\tau^{0,5}$			
	F	$F_{critical}$	R^2	SEE
	1300,01	5,59	99,38	0,29
P2	$\Delta m=0,240403\cdot\tau^{0,5}$			
	F	$F_{critical}$	R^2	SEE
	664,19	5,59	98,80	0,43
P3	$\Delta m=0,121465\cdot\tau^{0,5}$			
	F	$F_{critical}$	R^2	SEE
	377,85	5,59	97,92	0,29
P4	$\Delta m=0,50288\cdot\tau^{0,3}$			
	F	$F_{critical}$	R^2	SEE
	814,68	5,59	99,02	0,26

Chrome made addition to the studied bronze raised his hardness HB (P2; Fig. 19), but the considerable differentiation of microhardness among the phase α and γ_2, larger than in initial bronze (P1; Fig. 19), it is the reason of the largest abrasive wear among studied bronzes (P2; Fig. 20).

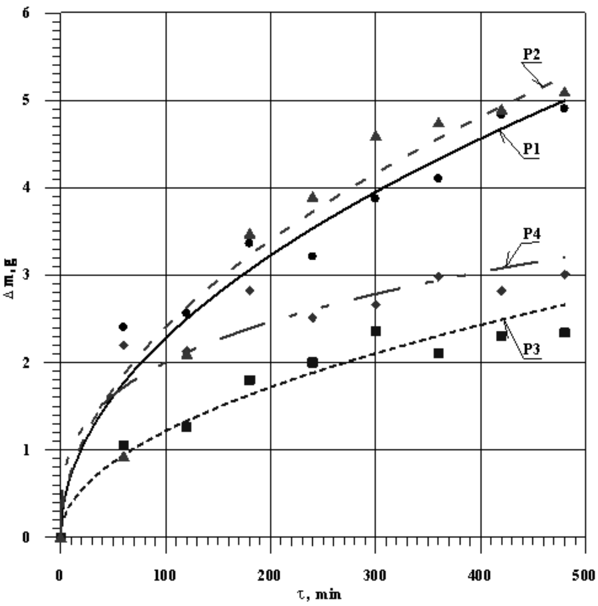

Fig. 20. The abrasive wear of the bronze CuAl10Fe5Ni5Si (P1) with additions Cr (P2), Mo (P3) and W (P4)

The smallest abrasive wear of bronze with addition Mo (P3; Fig. 20) is connected first of all with obtainment of the homogeneous microhardness of phases α and γ_2 (P3; Fig. 14), making up the metal matrix for hard phases κ_{Fe} and κ_{Ni}.
The Wolfram, raising the hardness HB of the bronze the most strongly, his abrasive wear also reduces, however in the somewhat smaller range than molybdenum (Fig. 20), this is connected with, that the larger differentiations of microhardness occur among the phase α and γ_2 (P4; Fig. 19).

4. Conclusions

Following conclusions result from conducted investigations over new high-grade aluminium bronzes:

- make addition Cr, Mo or W to the bronze CuAl10Fe5Ni5Si the quantity of crystallizing hard phases κ enlarges and the hardness of the bronze raises,
- the addition Mo to the bronze CuAl10Fe5Ni5Si influences the change of the concentration Mn and Ni in the phase α and γ_2 making possible obtainment of the even microhardness of these phases, what influences the decrease of the abrasive wear studied bronze in the consequence in the considerable range,
- through make addition W to the bronze CuAl10Fe5Ni5Si his hardness grows up the most strongly, but W does not make possible obtainment of the equal microhardness of phases α and γ_2, what including Mo influences a bit larger abrasive wear in the comparison with the bronze in the final effect.

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