EFFECT OF METAL PHASE COMPOSITION ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF Fe-GLASS COMPOSITES

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The effect of metal phase composition in the Fe-based + (2 % glass) powdered composites on the basic mechanical and tribological properties of the composites, made by means of sintering and hot forging, have been investigated. As a basis for the metallic phase of the composite the mixtures of iron powders with additives of graphite, B4C, BN and Cu at different ratio were used. It was shown that at sintering of metal-glass material the reaction of glass phase with oxides on the surface of iron powder particles takes place, resulting in a change of glass phase chemical composition. The results of materials mechanical properties investigations had shown that the highest strength properties and hardness have the composites with the content of the initial powder mixture of 5% Cu and 2% B4C, while the best tribological properties have the composites with 2% B4C, 5% Cu and 1% BN.

Keywords: Fe-GLASS COMPOSITE, SINTERING, HOT FORGING, FRICTION, POWDER, STRENGTH, HARDNESS, TRIBOLOGICAL PROPERTIES.

Introduction

One of the major advantages of powder metallurgy is a capability for manufacturing of pseudoalloys, whose synthesis by conventional casting techniques is almost impossible.

A prime example of such materials are the metal-glass composites, that consist of relatively plastic metal matrix in which the glass inclusions are uniformly distributed [1]. These composites showed high efficiency as the tribological materials when used for the manufacturing for the parts of friction units that operate in diverse and complex mediums (for instance - without lubrication, in vacuum, in abrasive-carrying medium, etc.). Having relatively high hardness and wear resistance, the glass when combined with ductile metal, is an effective component of tribological composites.

Manufacturing of this kind of materials is impossible by casting owing to the large difference in melting points of metal and glass, the coagulation and segregation of the latter by density during the melting process. At the same time, in case of powder metallurgy techniques, in the process of sintering of metal-glass material the glass phase interacts with iron oxides on the surface of the powder particles, that enhances the adhesive bond strength between the components of the mixture. Furthermore, a change in the chemical composition of the glass phase takes place with separation therein of solid chemical compounds that increase the tribological properties of the material due to formation of substantially heterogeneous composite structure.

In most publications devoted to investigations of structure and properties of metal-glass materials, as starting materials to obtain composites with glass the mixtures of unalloyed iron and carbon powders were used. Besides, as our previous studies had shown [1], the optimum content of the glass phase in the glass-metal composite that provides relatively high durability at a stable value of the friction coefficient and relatively high strength characteristics, is about 5÷7 % (wt.). At the same time, obviously, we can expect an increase in the basic physical and mechanical properties and performance of materials by modifying of metal matrix phase with appropriate additives that enhance both tribological characteristics when using the composite as the friction material.

Thereby, the aim of this article was to investigate the effect of some additives in the composition of the initial powder mixture and technological schemes of metal-glass composites manufacturing on features of structure, basic mechanical and tribological characteristics of the latter.

Materials and methods of the experiment

In the investigations of interaction of iron with glass phase during sintering powders used glass of two kinds were used - pane and "Pirex". Their chemical composition is presented in the table. 1. Glass particle size was 75÷80 microns.

As the metallic phase of the powder mixture iron powder with a particle size of 80-160 microns of industrial purity was used. The glass content in the mixture was 15 % (wt.).

The initial powder mixtures were pressed on the hydraulic press at different compression pressures in order to obtain different initial porosity of the preforms - from 10 to 30 %. Sintering of the preforms was realized in the medium of hydrogen at temperatures of 700, 800, 900, 1000 and 1100 ^{0}C.

Table 1

Chemical composition of the used glasses

Kind of the glass	Склад скляної фази, %							$t_{subsidence}$, ^{0}C
	SiO_2	Na_2O	CaO	MgO	Al_2O_3	B_2O_3	K_2O	
Pane	71,5	15	8,5	3,5	1,5	--	--	530
“Pirex”	80	4	--	--	2	12	1	620

For investigations of mechanical and tribological characteristics of metal-glass composites initial mixture for synthesis of metal-glass composites were prepared from a mixture of iron powder and 5 % (wt.) pane powder with a particle size of 40 microns, obtained by grinding the sheet glass in a rotary mill. As anti-score additives powders of graphite and boron nitride were used. To increase the hardness and the friction parameters of materials boron carbide was added in a powder mixture, and for improving the strength and thermal conductivity of the base material copper powder was used.

Options of the studied compositions of raw powder mixtures, which are used in the experiment, are presented in the table 2.

The powder mixture obtained by mixing of the powders, the performs were compacted at a pressure of 700 MPa which were processed by two different technological modes:

- presintering in hydrogen at 800 ^{0}C for 1 hour, then second compaction at a pressure of 700-800 MPa and subsequent sintering at 1100 ^{0}C;
- sintering at 1100 ^{0}C, then hot forging on screw press from a temperature of 1100 ^{0}C (in argon).

Table 2

Mixture compositions for manufacturing of metal-glass composites (%, wt.)

Elements	Mixture, No.							
	30	31	32	33	34	35	36	37
Glass	5	5	5	5	5	5	5	5
C	2	--	2	--	--	2	2*	--
Cu	--	--	--	--	5	5	--	5
B_4C	--	2	--	2	2	--	--	2
BN	--	--	1	1	1	--	--	--
Fe	93	93	92	92	87	88	93	88

* Carbon was used in granules with size of 1-1,5 mm.

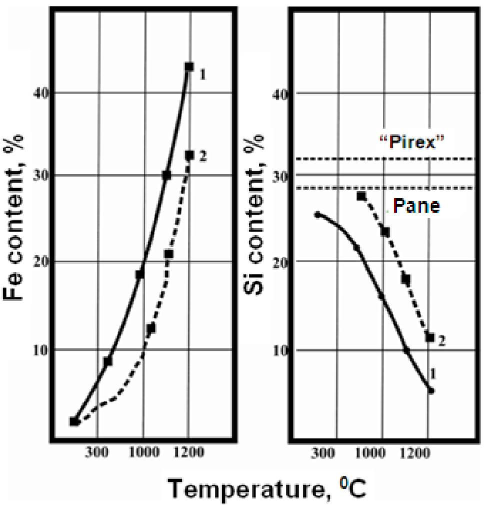
Tribological properties of the materials were determined in terms of the butt end friction without lubrication at sliding speeds of 4, 8 and 12 m/s and a load of 1.5 and 2.1 MPa. As a counter body 0,65 % C – 1 % Mn steel, hardened to 52 ÷ 55 HRC was used. During the test, the coefficient of friction and wear rate were estimated.

Experimental results and their discussion

Results of the study of glass particles saturation with base metal during sintering had shown that glass particles changes the color, that denotes on their active saturation with metal ions.

The results for investigation of iron and silicon content in glass particles depending on the sintering temperature is shown on fig. 1.

As can be seen from the figure, with increasing of sintering temperature saturation of glass with metal increases. Significant effect on the saturation of glass with Fe makes the kind of the glass and its melting temperature. Thus, in hte glass-metal samples with "Pireks" glass its satiation with metal and reduction of silicon content in the glass is less intensive than in the pane glass. This is because the "Pireks" glass has a higher viscosity at the same temperatures than pane glass, hereupon the contact between glass and metal deteriorates and mobility of melt glass reduces.



a b

Fig. 1. Effect of sintering temperature on the average content of iron (a) and silicon (b) in glass phase of sintered composite:
1 – pane; 2 – «Pirex" glasses

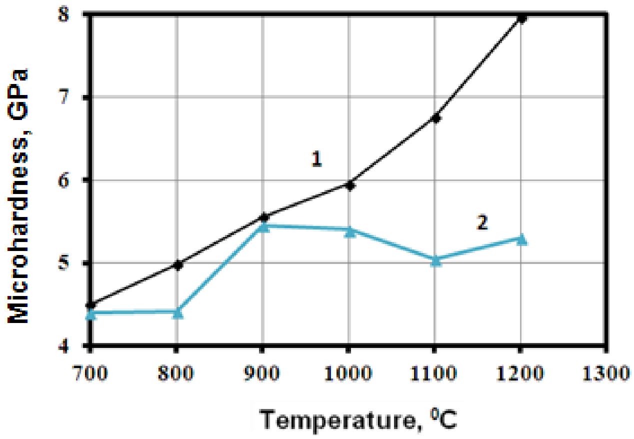


Fig. 2. Effect of sintering temperature on microhardness of glass phase for Fe-glass composites with pane (1) and "Pirex" (2) glasses

Increase of sintering temperature assists the growth of the intensity of base metal ions dissolution in the glass. As a consequence of changes in glass chemical composition of sintered Fe-glass materials the increase in the average microhardness of glass particles takes place. With increasing of sintering temperature the microhardness values of glass particles increases too (fig. 2).

Examination of sintered samples microstructure has shown the effect of formation of crystalline phase in glass particles (fig. 3), that usually starts from the surface of a particle. The columnar crystals, formed in the surface layer, with increasing of sintering temperature and exposure time grow deep into the glass.

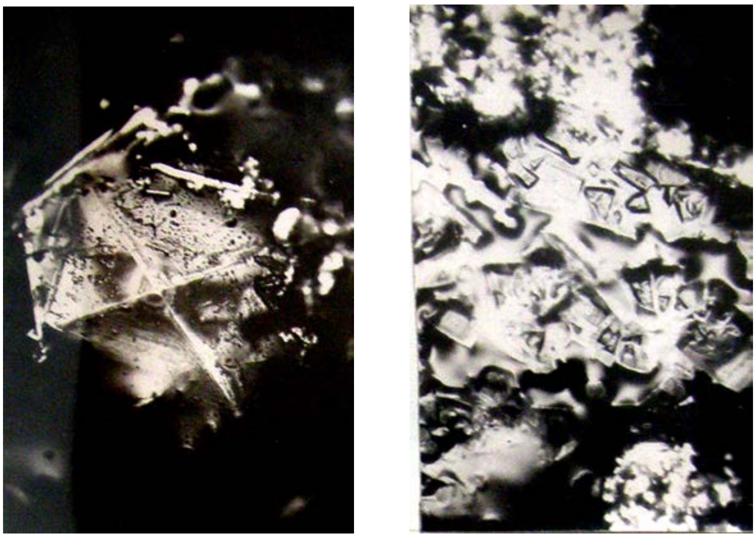
Analysis of results for evaluation of strength and hardness of sintered and hot forged metal-glass materials (fig. 4) had showed that almost for all of the investigated composites values of these characteristics increase when used boron carbide in material composition (samples No. 31, 33, 34 and 37) as a result of boron carbide dissociation when heated to temperatures that exceed 1050 ÷ 1100 ^{0}C [2]. The use of copper in the initial powder mixture (samples 34, 35 and 37) increases the hardness and strength of the materials too due to formation of solid solution after sintering. Infusion in the mixture of boron nitride (samples 32, 33 and 34) leads to the desired effect of reduction of the composites strength and hardness because the latter is virtually insoluble in the iron-carbon alloy during sintering, but presenting itself the antiwelding solid lubricant leads to a significant decrease of level of adhesion force between the friction material and the material of the counter body that supports the smooth friction and reducing wear of the friction surfaces.

The using of hot forging had leaded to expected significant increase in both strength and hardness of the samples compared to the same materials composition produced by sintering without forging.

The results of investigations of the sintered composites tribological characteristics had showed that the best wear properties had the materials which included boron carbide in the initial powder mixture (No. 31, 33, 34 and 37) due to synthesis of solid boride phases in the sintering process [2]. Among them the best wear properties had the composites alloyed with copper (No. 33, 34 and 37) (fig. 5,a). The single-valued influence of boron nitride according to wear characteristics was not revealed.

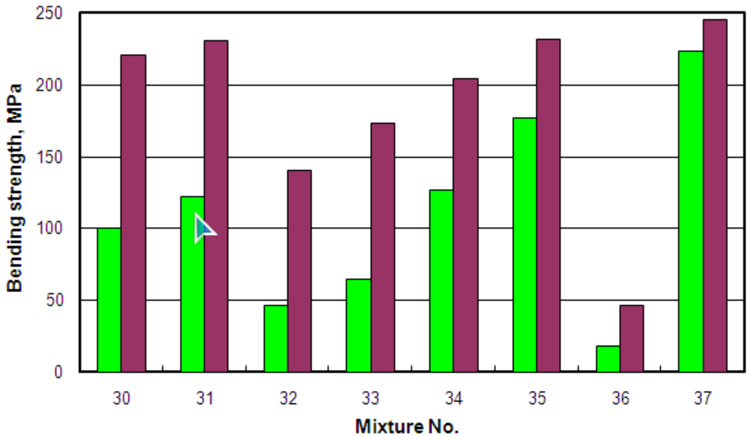
For all the compositions of alloys wear rate increase with increasing of sliding speed from 4 to 12 m/s was established. Increasing of contact friction pressure from 1.5 to 2.1 MPa also leads to a certain increase in the degree of wear level (fig. 5,b).

Analysis of the evaluation of friction coefficients (fig. 5,c) showed a significantly lower dependence of this parameter on the composition of the initial powder mixture, but much more sensitive compared to the characteristic of wear proof properties dependent on sliding speed. As can be seen from the presented on fig. 5,c data, if the sliding speeds of 4-8 m/s friction coefficient is in the range of 0,35-0,44 (higher values correspond to lower the sliding velocity), then with increasing of slip velocity to 12 m/s values of the friction coefficient is reduced to 0.28-0.36. Increasing contact pressure to 2.1 MPa very little effect on the behavior of the friction coefficient (fig. 5,d).

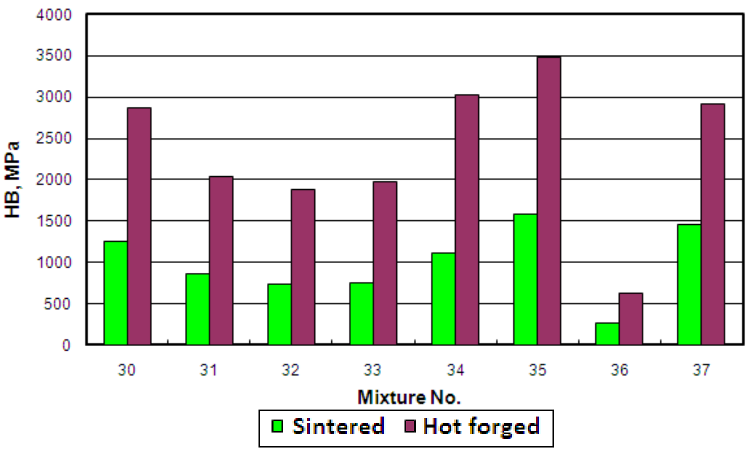


a b

Fig 3. Types of glass crystals, synthesized at sintering of metall-glass composites with pine (a) and "Pirex" (b) glasses

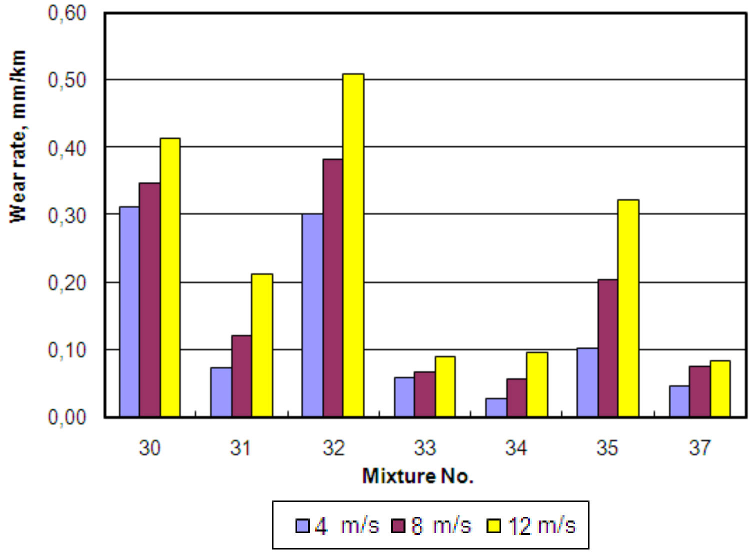


a)



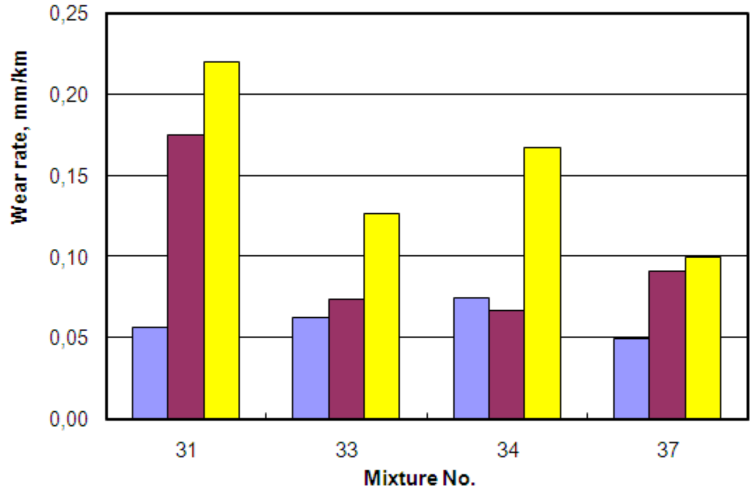
b)

Fig. 4. Bending strength (a) and Brinelle hardness (b) of sintered and hot forged materials, manufactured from powder mixtures of different compositions (see table 1)



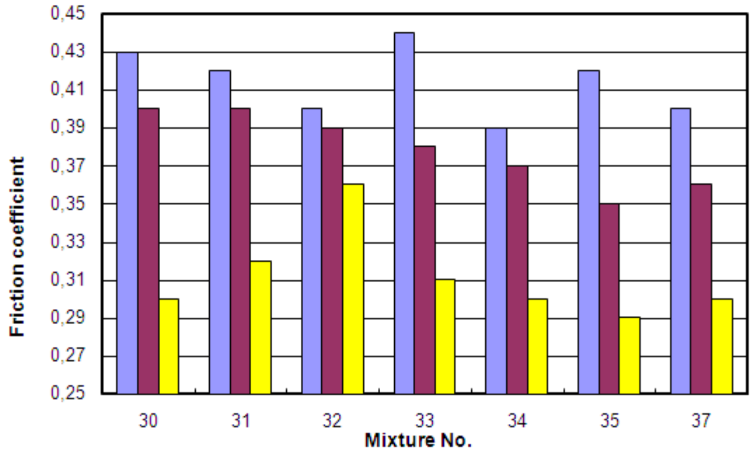
Wear rate, mm/km
0,60
0,50
0,40
0,30
0,20
0,10
0,00
30
31
32
33
34
35
37
Mixture No.
4 m/s
8 m/s
12 m/s

a)



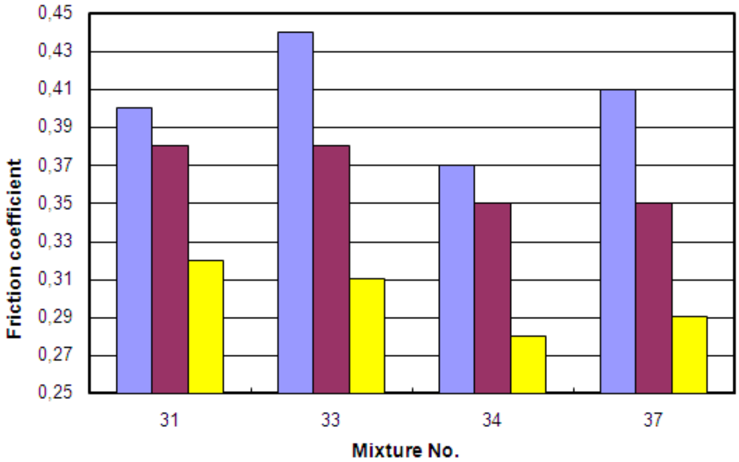
Wear rate, mm/km
0,25
0,20
0,15
0,10
0,05
0,00
31
33
34
37
Mixture No.

b)



Friction coefficient
0,45
0,43
0,41
0,39
0,37
0,35
0,33
0,31
0,29
0,27
0,25
30
31
32
33
34
35
37
Mixture No.

c)

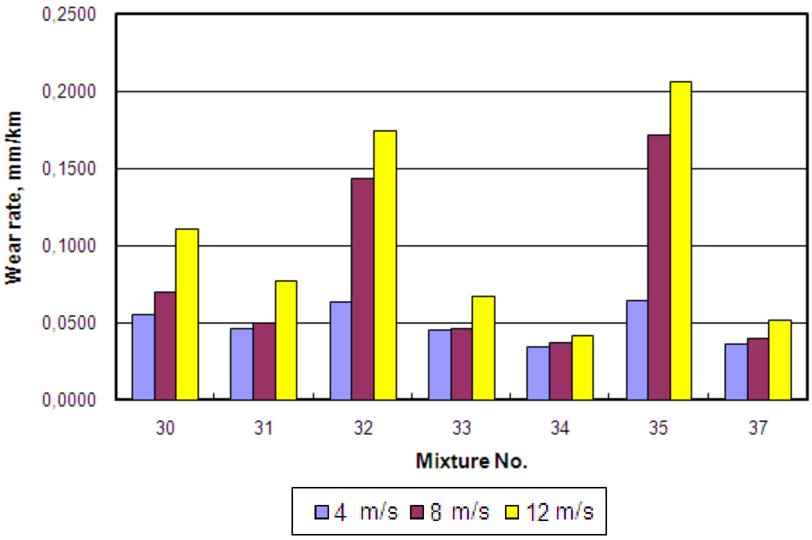


d)

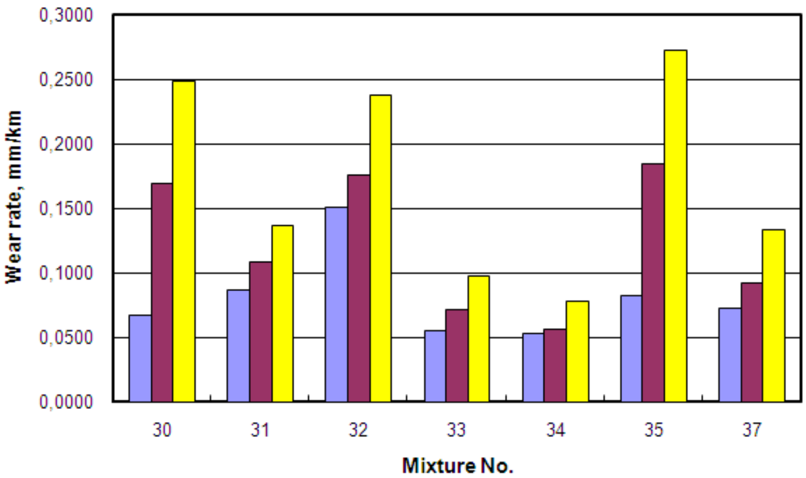
Fig. 5.Tribological properties of sintered and repressed materials manufactured from powder mixtures of different compositions; contact pressure: a, c - 1,5 MPa; b, d - 2,1 MPa

In case of using of hot forging for production of the metal-glass composites a similar regularities with respect to the effect of the initial powder mixture composition on the wear resistance of the material (fig. 6,a) was observed. At the same time, comparison of the absolute values of wear rate indicates that hot forging allows to reduce substantially (for some compositions by more than half) the wear rate of materials in comparison with analogous compositions obtained by sintering and cold repressing.

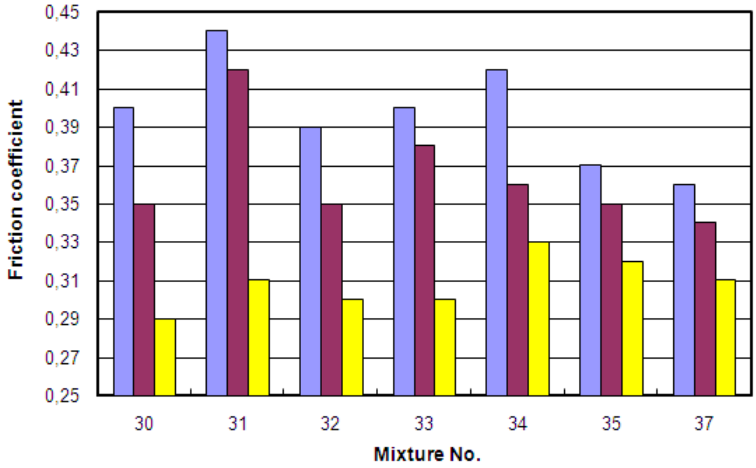
Unlike the wear resistance, the values of friction coefficient of hot forged composites small differ from these properties of sintered and repressed material of similar composition.



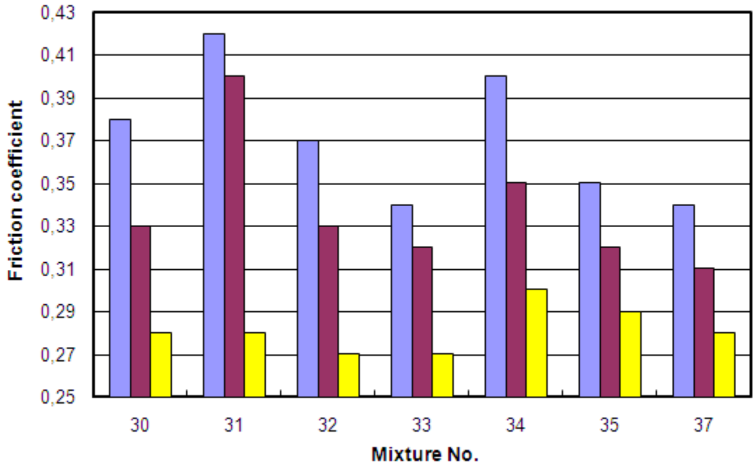
a)



b)



c)



d)

Fig. 6. Tribological properties of hot forged materials manufactured from powder mixtures of different compositions; contact pressure: a, c - 1,5 MPa; b, d - 2,1 MPa

Conclusions

1) The highest values for the mechanical properties of the sintered and hot forged composites have the materials made of powder mixtures containing 5% glass, 5% copper and 2% of carbide former components of mixture (graphite, boron carbide).

2) The results of investigations of the tribological properties of metal-glass composites leads to the conclusion about the perspectives of their use as a friction material for use in a wide range of sliding speeds.

3) Modification of the metal matrix phase with boron carbide provides significant improvement of wear resistance of the material and stable coefficient of friction in the range of 0,27-0,42.

4) The use of hot forging promotes significant increase in wear resistance of the material compared with sintered and repressed but little effect on variation of friction coefficient.

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