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THE TRIBOLOGICAL PROPERTIES OF HIGH SPEED STEEL BASED COMPOSITES

WŁASNOŚCI TRIBOLOGICZNE KOMPOZYTÓW NA OSNOWIE STALI SZYBKOTNĄCEJ

Attempts have been made to describe the influence of the production process parameters and additions of powders, such as: copper, graphite, iron and tungsten carbide, on tribological properties of copper infiltrated HSS based composites. The powder compositions used to produce skeletons for further infiltration were M3/2, M3/2+20%Fe, M3/2+50%Fe M3/2+7.5%Cu and M3/2+0,3%C. The powders were cold pressed at 800 MPa. The infiltration process was carried out in vacuum. Both green compacts and preforms sintered for 60 minutes at 1150°C in vacuum were contact infiltrated with copper to yield final densities exceeding 97% of the theoretical value.

The as-infiltrated composites were tested for Brinell hardness and bending strength, and subjected to wear tests performed by block-on-ring wear tester. From the analysis of the obtained results it has been found that the mechanical properties are mainly affected by the manufacturing route and composition of porous skeletons used for infiltration. Considerable differences in hardness between materials obtained from the two infiltration routes have been observed, with lower wear rates achieved after direct infiltration of green compacts.

Keywords: high speed steel, composites, infiltration, wear rate, friction coefficient

Kompozyty na osnowie stali szybkotnących to materiały odznaczające się dużą odpornością na zużycie cierne, wynikającą przede wszystkim z odporności na zużycie cierne stali szybkotnącej tworzącej osnowę kompozytów. Poszukiwanie sposobu obniżenia kosztów wytwarzania stali szybkotnących oraz kompozytów na osnowie stali szybkotnącej polega na zastosowaniu procesu infiltracji do wytwarzania kompozytów na osnowie stali szybkotnącej z dodatkiem miedzi, gdzie jako porowate kształtki do infiltracji stosowane są wypraski lub spieki ze stali szybkotnącej lub stali szybkotnącej z dodatkami. Przedstawiono wyniki badań w zakresie badania odporności na zużycie cierne i współczynnika tarcia infiltrowanych kompozytów na osnowie stali szybkotnącej. Materiał badawczy stanowiły kształtki ze stali szybkotnącej gatunku M3/2 i M3/2+20%Fe, M3/2+50%Fe, M3/2+7,5%Cu, M3/2+0,3%C. Porowate kształtki przeznaczone do infiltracji prasowano pod ciśnieniem 800 MPa, część z nich poddano spiekaniu w piecu próżniowym w temperaturze 1150°C przez 60 minut. Następnie porowate kształtki infiltrowano miedzią, metodą nakładkową w piecu próżniowym w temperaturze 1150°C przez 15 minut. Badania odporności na zużycie cierne oraz współczynnika tarcia przeprowadzono testerem T-05. Testy prowadzono przy ruchu postępowym w styku ślizgowym suchym, bez udziału środków smarujących.

Techniką infiltracji miedzi do porowatych wyprasek i spieków ze stali szybkotnącej M3/2 oraz stali szybkotnącej M3 z dodatkami stopowymi można uzyskać kompozyty o gęstości zbliżonej do gęstości teoretycznej, sięgającej 97,0%. Własności otrzymanych kompozytów zależą od zastosowanych dodatków stopowych oraz od technologii ich wytwarzania. Odporność na zużycie cierne jest charakteryzowana przez ubytek masy poszczególnych kompozytów. Analizując wyniki testu można stwierdzić, że poza kompozytami M3/2+7,5%Cu i M3/2+0,3%C większą odpornością na zużycie cierne charakteryzują się infiltrowane wypraski. Dodatek 20% lub 50% żelaza nie powoduje obniżenia odporności na zużycie cierne infiltrowanych wyprasek w określonych warunkach procesu tarcia.

1. Introduction

High hardness, mechanical strength, heat resistance and wear resistance of M3/2 high speed steel (HSS) make it an attractive material for manufacture of valve train components such as valve seat inserts and valve guides [1÷3]. In this application, the material must exhibit resistance to oxidation, high hot strength and hardness, and superior wear resistance. Metal matrix composites were produced by the infiltration technique. Since technological and economical considerations are equally important, infiltration of high-speed steel based skeleton with liquid cooper has proved to be a suitable technique whereby fully dense material is produced at low cost [1

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÷ 3]. An ability to press and sinter to near net shape requires good compressibility of the powder. Even after annealing, tool steel powders can be pressed to only about 80% of the theoretical density by most commercial facilities. On sintering and infiltration, little or no shrinkage can be tolerated and so the necessary strength and toughness may be achieved without removal of the remaining porosity. A reasonable compromise between all of these requirements may be achieved by using mixtures of high speed steel powders with softer low alloy or pure iron powder. During sintering and infiltration of such mixtures, interdiffusion of both carbon and metallic alloying elements occurs.

Infiltration is a process that has been practiced for many years. It is defined as "a process of filling the pores of a sintered or unsintered compact with a metal or alloy of a lower melting point" [6,7]. In the particular case of copper infiltrated iron and steel compacts, the base iron matrix, or skeleton, is heated in contact with the copper alloy to a temperature exceeding the melting point of copper, normally to between 1095 and 1150°C. Since technological and economical considerations are equally important, infiltration of high-speed steel skeleton with liquid cooper has proved to be a suitable technique whereby fully dense material is produced at low cost.

2. Experimental procedure

The Powdrex water atomised M3/2 grade HSS powder and Höganäs NC 100.24 iron powder, both finer than 160μm, were used in the experiments. The HSS powder was delivered in as-annealed condition. Its chemical composition is given in Table 1, whereas its morphology and microstructure are shown in Figure 1.

TABLE 1

Chemical composition of M3/2 HSS powder, wt-%

C	Cr	Co	Mn	Mo	Ni	Si	V	W	O	Fe
1.23	4.27	0.39	0.21	5.12	0.32	0.18	3.1	6.22	0.0626	balancc

Various amounts of iron, graphite and copper were added to the HSS powder prior to compaction. The additives are shown in Figure 2.

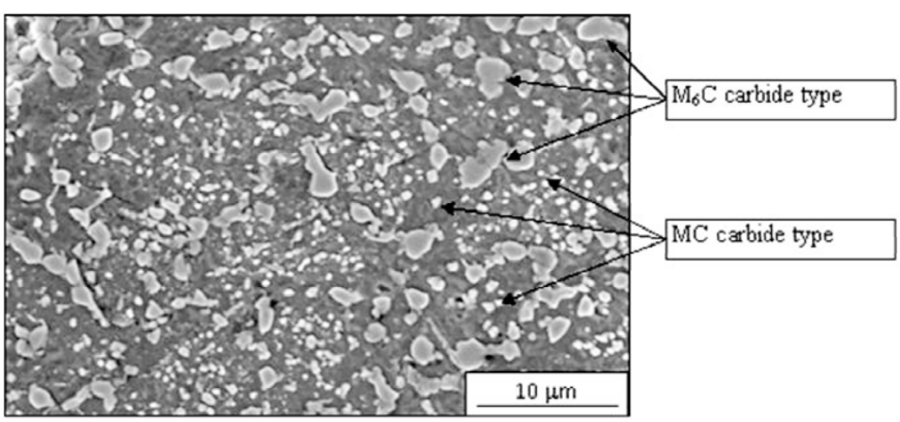

Fig. 1. M3/2 grade HSS powder: a) morphology, b) microstructure

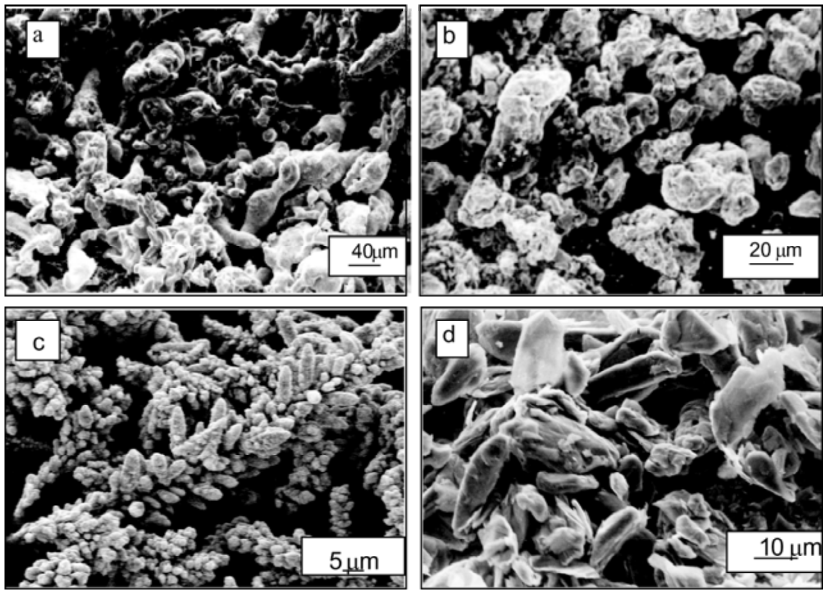

Fig. 2. Powders added to M3/2 HSS: a) NC 100.24 iron, b) copper, c) graphite. SEM

The following compositions were investigated:

1. M3/2
2. M3/2 + 20% Fe
3. M3/2 + 50% Fe
4. M3/2 + 7.5% Cu
5. M3/2 + 0.3% C (graphite).

The mixtures were prepared by mixing for 30 minutes in a chaotic motion Turbula® T2C mixer and cold pressed in a rigid cylindrical die at 800 MPa.

The infiltration process was carried out in vacuum better than 10^{-3}Pa. Both green compacts and performs sintered for 60 minutes at 1150°C in vacuum were infiltrated with copper. Carefully pre-weighed pieces of copper infiltrant were placed on top of the rigid skeletons of predetermined porosity, heated to 1150°C, held at temperature for 15 minutes, and cooled down with the furnace to room temperature.

The infiltrated specimens were subsequently tested for Brinell hardness, bending strength and resistance to wear, and subjected to microstructural examinations by means of both light microscopy (LM) and scanning electron microscopy (SEM). The wear tests were carried out using the block-on-ring tester (Figure 3).

a)

b)

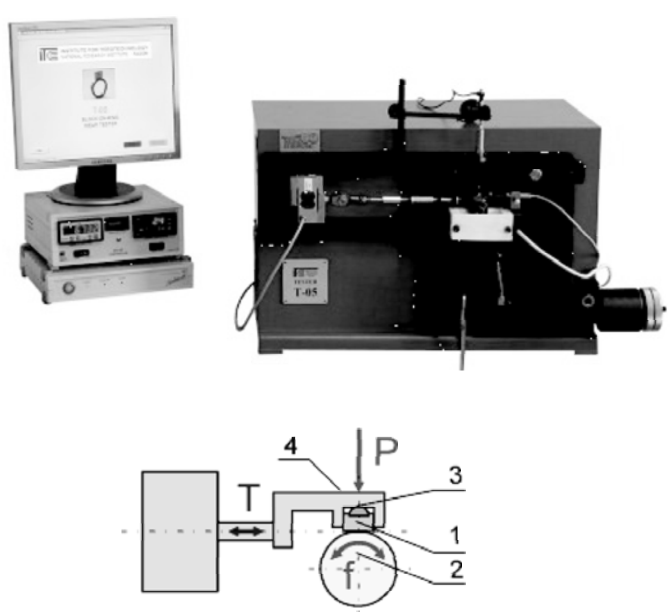

Fig. 3. Tribosystem T05: a) the tester components, b) wear test principle

During the test a rectangular wear sample (1) was mounted in a sample holder (4) equipped with a hemispherical insert (3) ensuring proper contact between the test sample and a steel ring (2) rotating at a constant speed. The wear surface of the sample was perpendicular to the loading direction. Double lever system was used to force the sample towards the ring with the load accuracy of ±1%.

The wear test conditions were:

- test sample dimensions: 20 x 4 x 4 mm,
- rotating ring: heat treated steel, 55 HRC, ø49,5 x 8 mm,
- rotational speed: 500 rev./min.,
- load: 165 N,
- sliding distance: 1000 m.

The measured parameters were:

- loss of sample mass,
- friction force *F* (used to calculate the coefficient of friction).

3. Results and discussion

Characterisation of the porous skeletons. A fully-dense material made of the M3/2 grade powder can be achieved by sintering at around 1250°C [4÷7], therefore to produce porous preforms the compacts were sintered at 1150°C. The combined effects of the powder mix composition and its processing route on relative densities of the porous skeletons are shown in Figure 4.

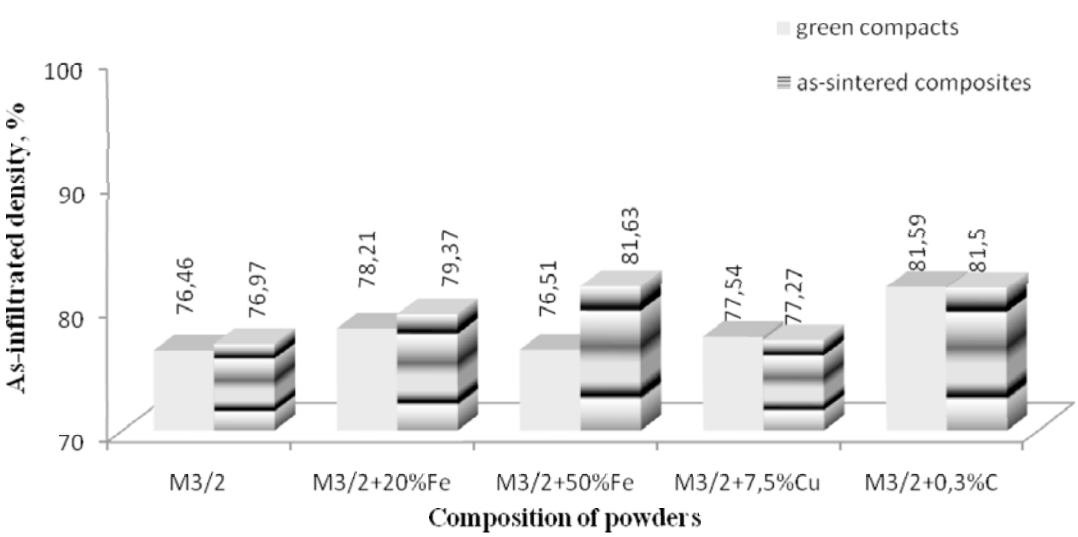

Fig. 4. Relative densities of green compacts and pre-sintered porous skeletons

From Figure 4 it is evident that the as-sintered densities of M3/2, M3/2+7.5%Cu and M3/2+0.3%C are approximately equal to their green densities, whereas the addition of 20% iron to M3/2 has a negligible effect on the as-sintered density. The addition of 0.3% graphite apparently exerts a lubricating effect on the powder thus increasing the green density of cold pressed compacts.

4. The properties of copper infiltrated HSS based composites

The properties of the as-infiltrated composites are shown in Figures 5÷7.

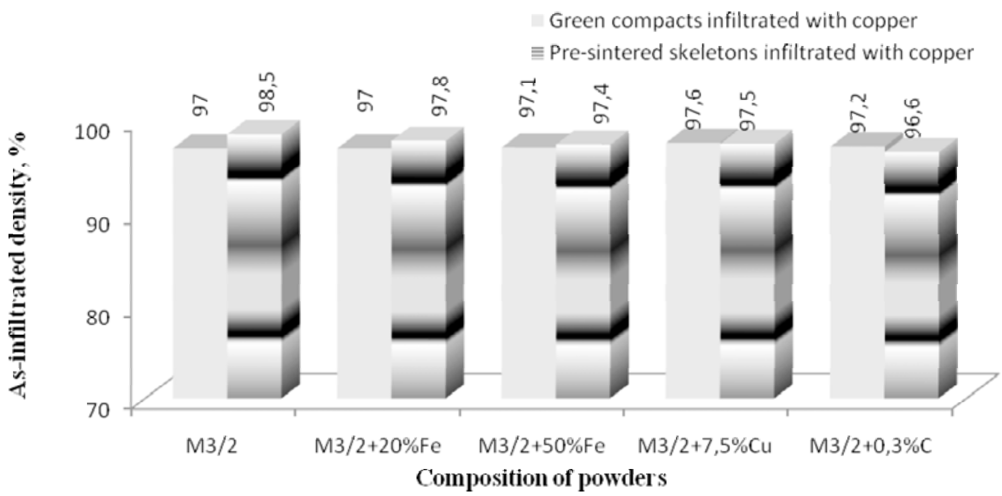

Fig. 5. Relative densities of as-infiltrated composites

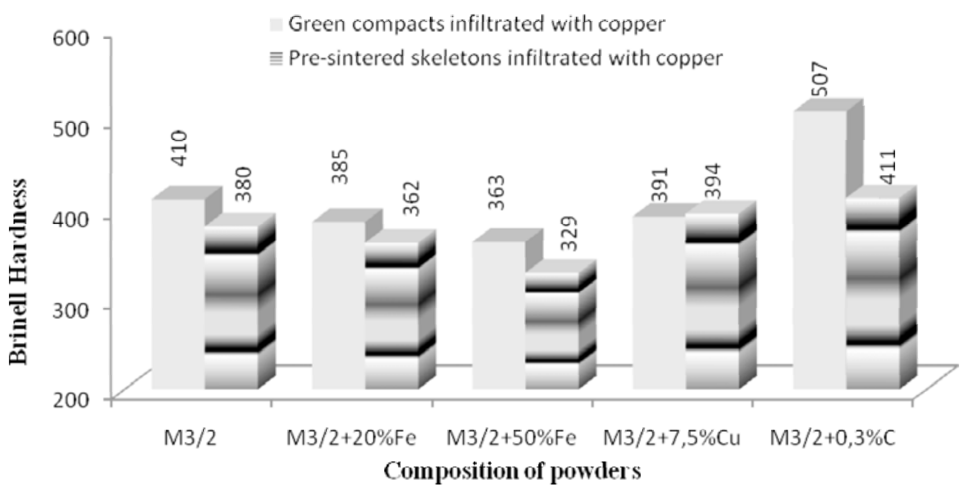

Fig. 6. The Brinell Hardness of as-infiltrated composites

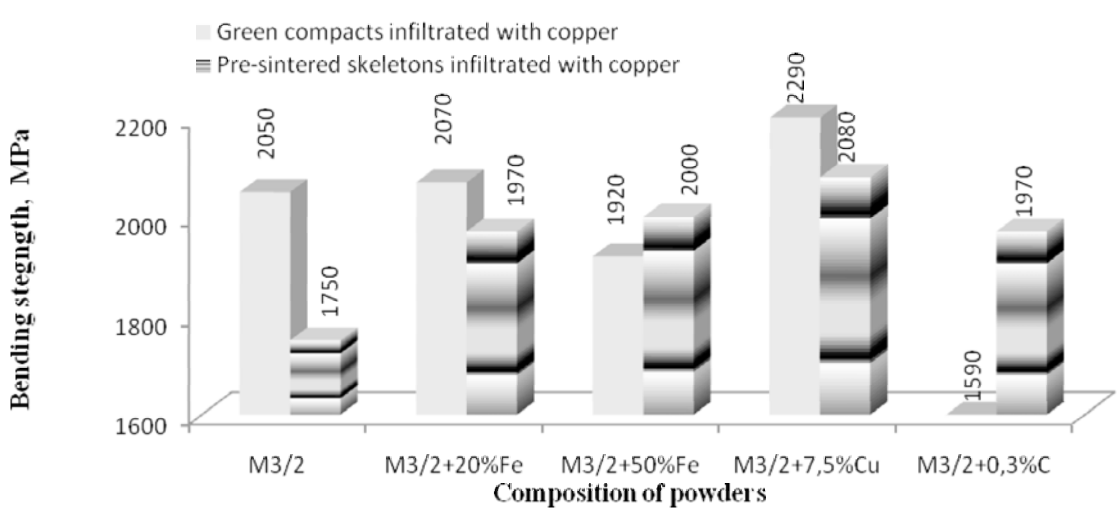

Fig. 7. The Bending Strength of as-infiltrated composites

As seen in Figure 5 the molten copper was drawn into the interconnected pores of the skeletons, through a capillary action, and filled virtually the entire pore volume to yield final densities exceeding 97% of the theoretical value.

The Brinell hardness of the as-infiltrated composites decreases with the increased content of iron in the starting powder mix, whereas the bending strength does not seem to be affected. Substantial differences in hardness are observed between the materials obtained from the two infiltration routes. Markedly higher hardness numbers were achieved after direct infiltration of green compacts. It is seen in Figures 6 and 7 that the addition of 0.3% C to M3/2 increases hardness, and decreases the bending strength of composites obtained by direct infiltration of green compacts.

5. Tribological properties

The wear test results are given in Figures 8 and 9.

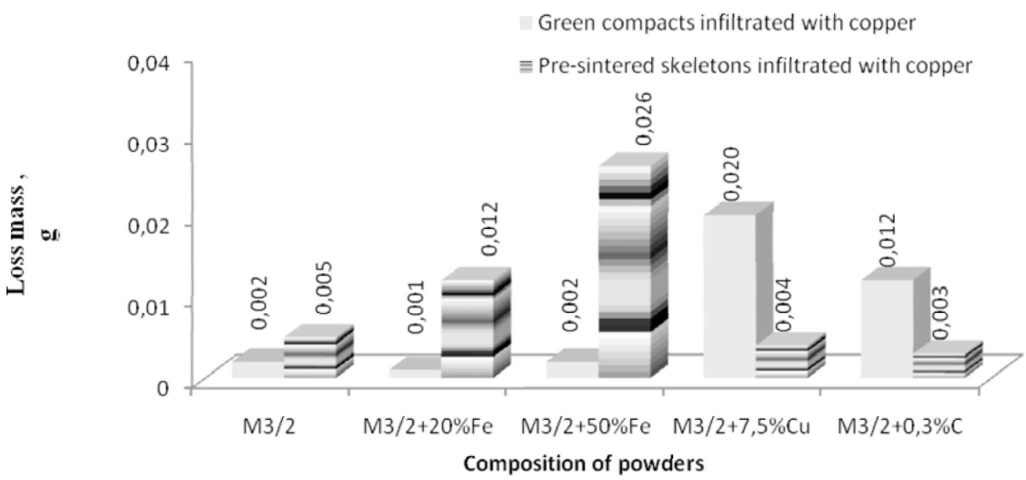

Fig. 8. Loss of mass of as infiltrated composites

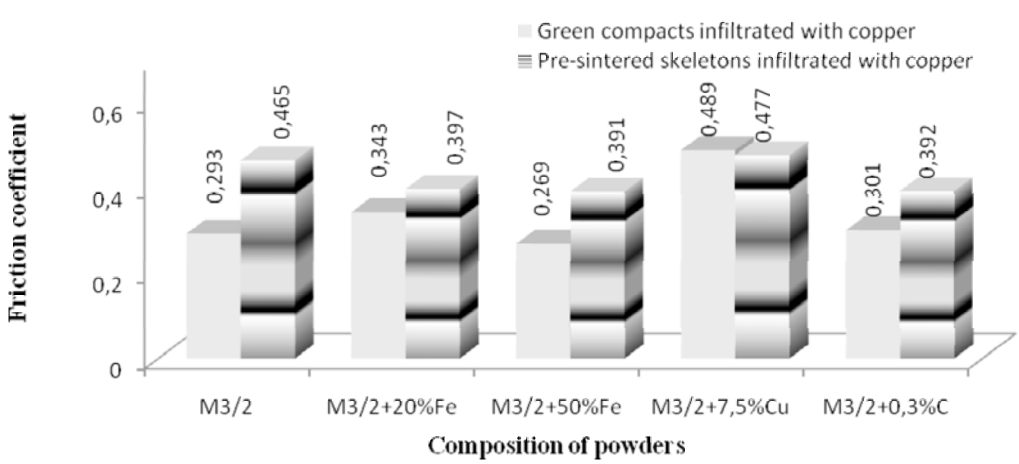

Fig. 9. Friction coefficient of as infiltrated composites

The measurements of the wear resistance and friction coefficient permit classification of the as-infiltrated composites with respect to their tribological properties. Direct infiltration of green compacts with copper results in the highest wear resistance and lower friction coefficient of the as-infiltrated M3/2, M3/2+20%Fe and M3/2+50%Fe composites. By comparing the wear resistance of composites received through direct infiltration of green compacts and infiltration of pre-sintered skeletons it is evident that the pre-sintered M3/2+Fe compositions show 12÷13 times higher loss of mass than the iron containing green compacts infiltrated with copper. This can be explained by the diffusion of carbon and alloying of iron particles during sintering. Infiltration of the pre-sintered skeletons results in the highest wear resistance of the as-infiltrated M3/2+7,5Cu and M3/2+0,3C composites.

Addition of 50% iron powder decreases the friction coefficient of composites received from direct infiltration of green compacts. It could be explained by the presence of iron inclusions in the microstructure of as-infiltrated composites, which impart good sliding properties. Characteristic surface topographies after the wear test are exemplified in Figure 10.

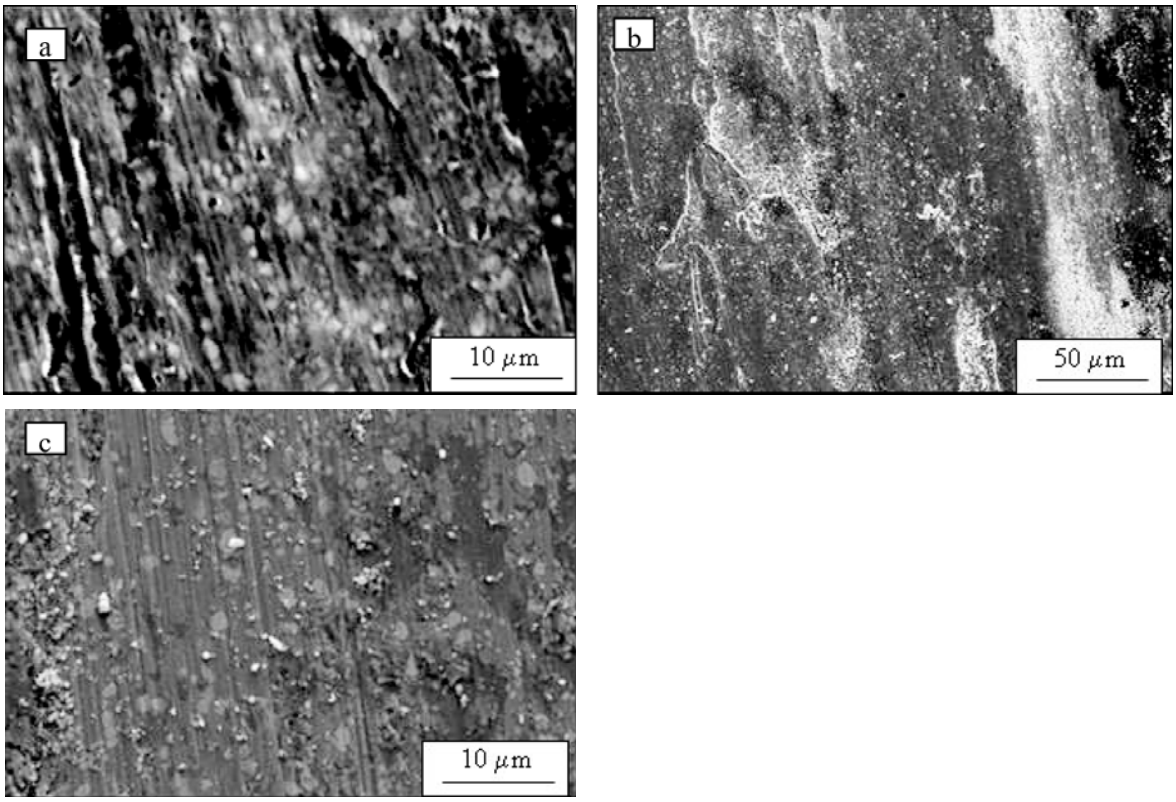

Fig. 10. The surface of the as-infiltrated composites after examining the wear resistance. a) M3/2, b) M50Fe, c) M7,5Cu

The surface topographies of M3/2, M3/2+50Fe and M3/2+7,5Cu specimens indicate occurrence of different wear mechanisms (Figure 10). The carbides seen on the wear-surfaces are being crushed and pulled out of the matrix to act as abrasive particles which increase the coefficient of friction. Figure 10a provide evidence of ploughing and sideways displacement of material in M3/2. Figure 10b shows smearing of iron over the surface of the as-infiltrated M3/2+50Fe composite which implies marked contribution of adhesive wear, whereas the extensive formation of iron oxides may account for the lowest friction coefficients. Copper additions to M3/2 (Figure 10c) increase the contribution of micro-cutting and, presumably, adhesion wear which results in the highest friction coefficients.

6. Conclusions

- Infiltration of porous HSS skeleton with liquid copper has proved to be a suitable technique whereby fully dense HSS based materials are produced at low cost.
- Direct infiltration of green compacts with copper results in the higher hardness and higher resistance to wear of the M3/2, M3/2+20%Fe and M3/2+50%Fe composites, and allows to cut the production cost.
- The pre-sintered, iron containing specimens show 12÷13 times higher loss of mass than the iron containing green compacts infiltrated with copper.
- Direct infiltration of as-sintered materials with copper results in the higher resistance to wear of the M3/2+7,5%Cu and M3/2+0,3%C composites.
- The carbides seen on the wear-surfaces of as infiltrated composites are being crushed and pulled out of the matrix to act as abrasive particles which increase the coefficient of friction.

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