# High speed steel based composites with iron additions

M. Madej*

*AGH-University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Mickiewicz Ave 30, 30-059 Krakow, Poland*

Received 8 December 2010, received in revised form 15 September 2011, accepted 11 November 2011

**Abstract**

Attempts have been made to describe the influence of the production process parameters and additions of iron powders on properties of copper infiltrated HSS based composites. The powder compositions used to produce skeletons for further infiltration were M3/2, M3/2 + 20 % Fe and M3/2 + 50 % Fe. The powders were cold pressed at 800 MPa. The infiltration process was carried out in vacuum. Both green compacts and preforms sintered for 60 min at 1150 ℃ 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.

Key words: high speed steel, composites, infiltration, wear rate, friction coefficient

## 1. Introduction

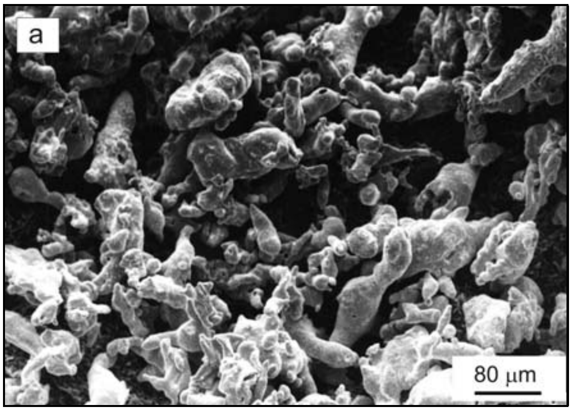
High hardness, mechanical strength, heat resistance and wear resistance of M3/2 high speed steel (HSS) make it an attractive material for manufacture of valve train components such as valve seat inserts and valve guides [1–3]. In this application, the material must exhibit resistance to oxidation, high 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 copper has proved to be a suitable technique whereby fully dense material is produced at low cost [1–3, 5]. 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 [6, 7]. 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.

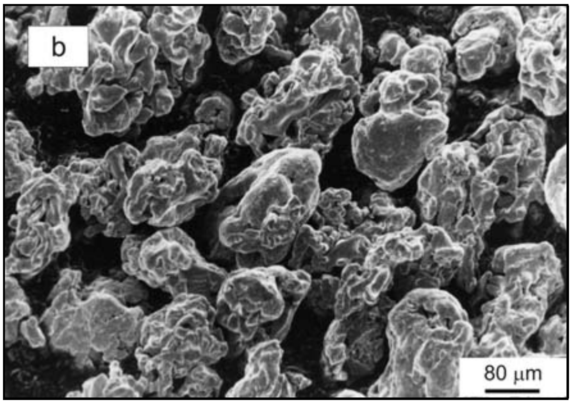
Infiltration is a process that has been practiced for many years. It is defined as "a process of filling the pores of a sintered or unsintered compact with a metal or alloy of a lower melting point" [4]. In the particular case of copper infiltrated iron and steel compacts, the base iron matrix, or skeleton, is heated in contact with the copper alloy to a temperature exceeding the melting point of copper, normally to between 1095 and 1150 ℃. Since technological and economical considerations are equally important, infiltration of high-speed steel skeleton with liquid copper has proved to be a suitable technique whereby fully dense material is produced at low cost.

* E-mail address: mmadej@agh.edu.pl

T a b l e 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 | balance |



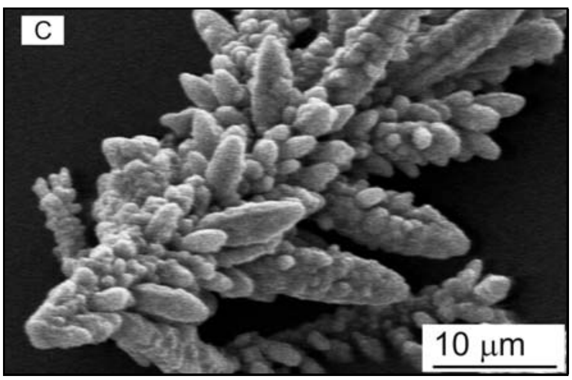




Fig. 1. SEM micrographs of: a) M3/2 HSS, b) NC 100.24 iron, c) copper.

## 2. Experimental procedure

The Powdrex water atomised M3/2 grade HSS powder and Höganäs NC 100.24 iron powder, both finer than 160 μm, 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 Fig. 2.

Various amounts of iron were added to the HSS powder prior to compaction. The additives are shown in Fig. 1.

The following compositions were investigated:

1. M3/2,
2. M3/2 + 20 % Fe,
3. M3/2 + 50 % Fe.

The mixtures were prepared by mixing for 30 min 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 min at 1150 ℃ 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 ℃, held at temperature for 15 min, 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 (Fig. 3).

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: $20 \times 4 \times 4\ \mathrm{mm}^3$,
– rotating ring: heat treated steel, 55 HRC, ø $49.5 \times 8\ \mathrm{mm}^2$,
– rotational speed: 500 rev. $\mathrm{min}^{-1}$,
– 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

### *3.1. Characterisation of the porous skeletons*

A fully-dense material made of the M3/2 grade powder can be achieved by sintering at around 1250 ℃

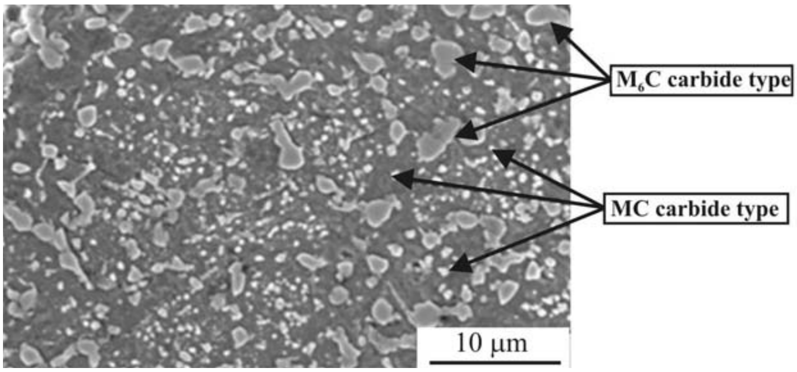



Fig. 2. M3/2 grade HSS powder: a) morphology, b) microstructure.

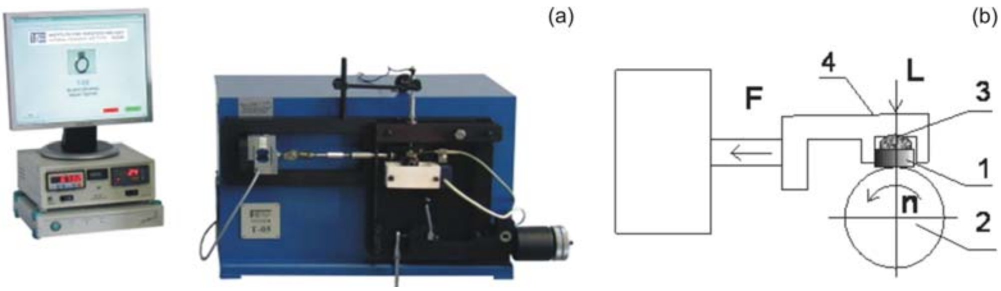



Fig. 3. Tribosystem T05: a) the tester components, b) wear test principle.

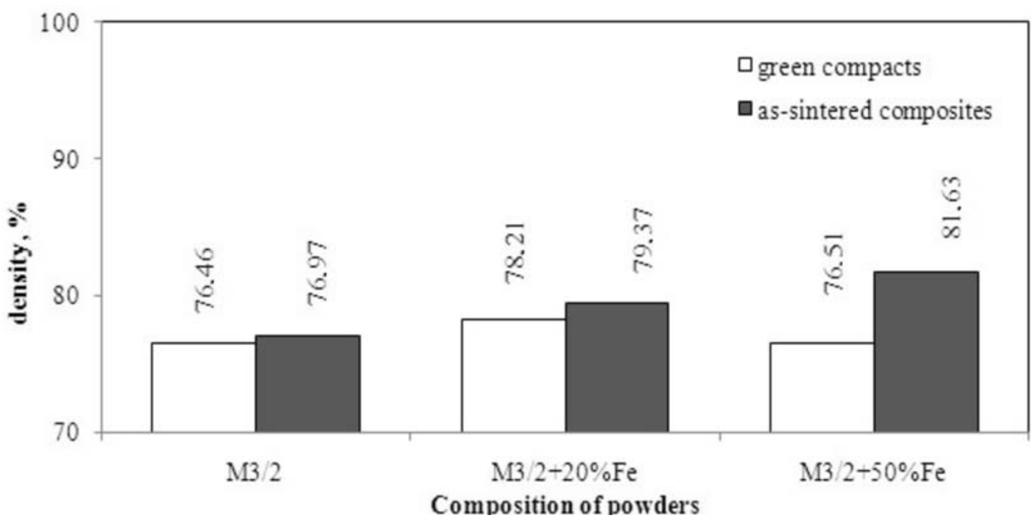



Fig. 4. Relative densities of green compacts and pre-sintered porous skeletons.

[5], therefore to produce porous preforms the compacts were sintered at 1150 ℃. The combined effects of the powder mix composition and its processing route on relative densities of the porous skeletons are shown in Fig. 4.

From Figs. 4 and 5 it is evident that the as-sintered densities of M3/2 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.

Figures 6–8 show the morphologies of capillaries in both green compacts and pre-sintered skeletons.

It may be concluded from the microstructural observations (Figs. 6–8) that the morphologies of capillaries are mainly affected by the manufacturing route and powder characteristics (Fig. 1), such as powder particle size and morphologies of powder particles.

### *3.2. The properties of copper infiltrated HSS based composites*

The properties of the as-infiltrated composites are shown in Figs. 9–11.

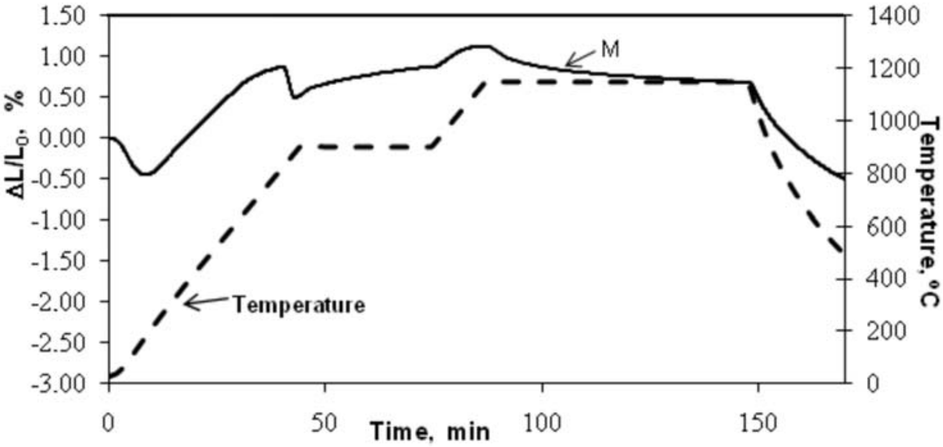



Fig. 5. Dilatometric curves recorded during heating of the HSS M3/2 material to the sintering temperature.

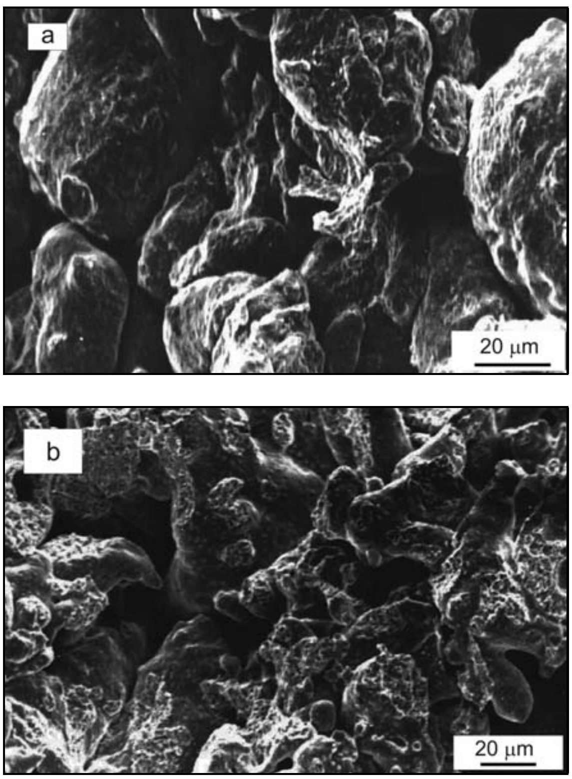



Fig. 6. The morphologies of capillaries in M3/2 grade HSS, SEM: a) green compact, b) pre-sintered skeleton.

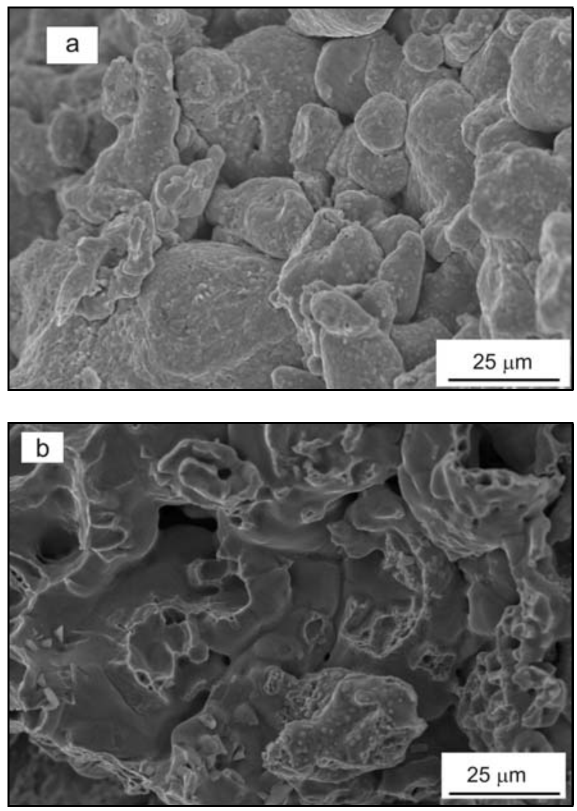



Fig. 7. The morphologies of capillaries in M3/2 HSS + 20 % Fe, SEM: a) green compact, b) pre-sintered skeleton.

As seen in Fig. 9 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. For pre-sintered samples an increase of bending strength occurs, this can be explained by the diffusion of carbon and alloying of iron particles during sintering. 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.

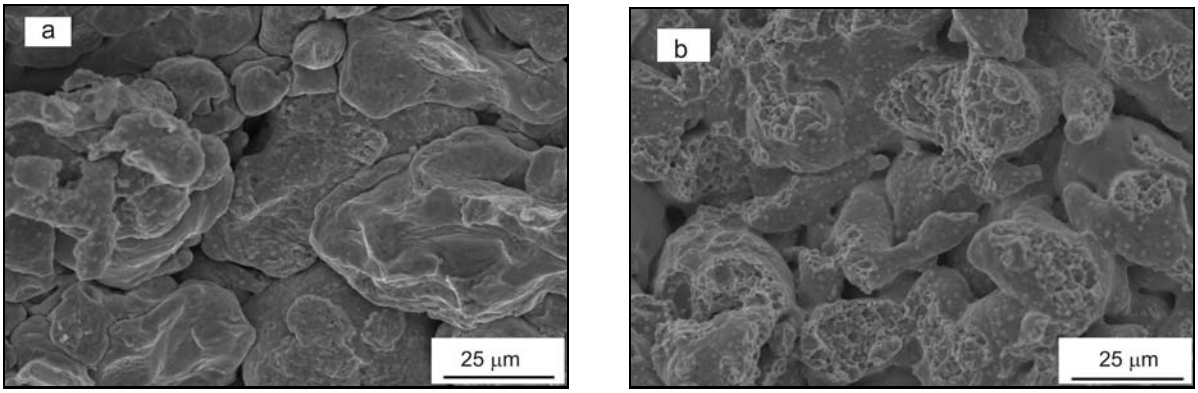



Fig. 8. The morphologies of capillaries in M3/2 HSS + 50 % Fe, SEM: a) green compact, b) pre-sintered skeleton.

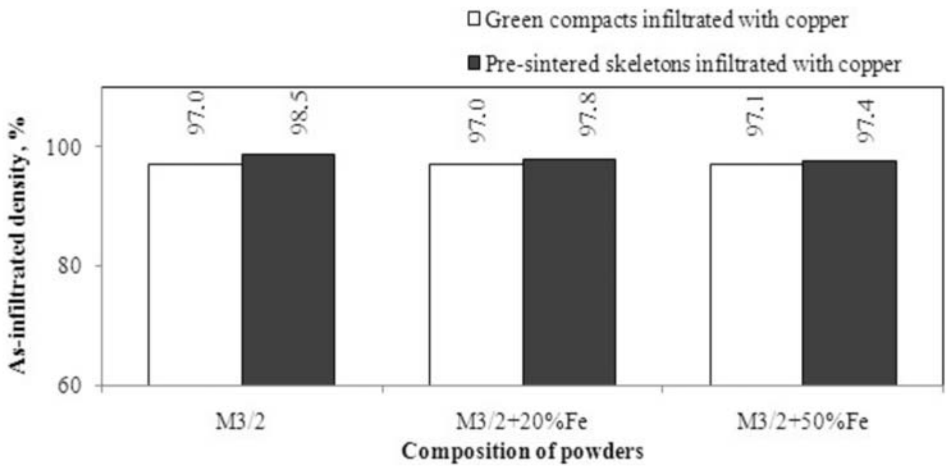



Fig. 9. Relative densities of as-infiltrated composites.

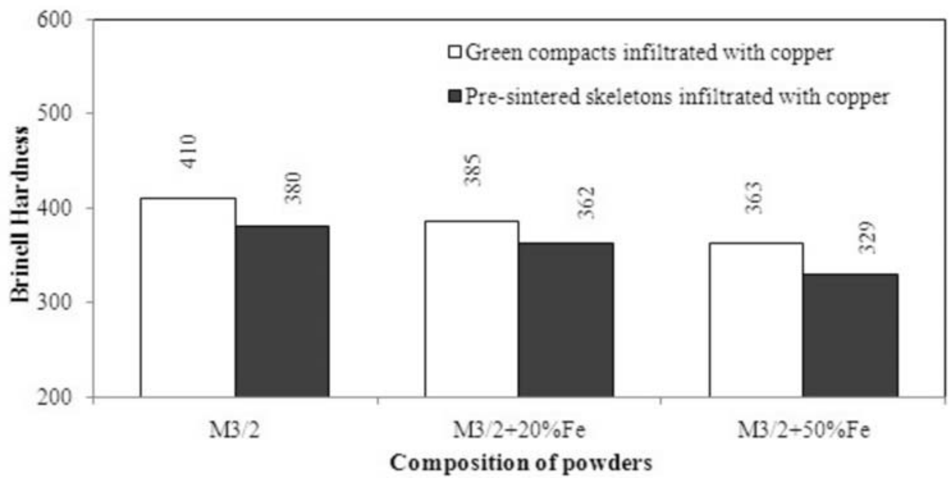



Fig. 10. The Brinell hardness of as-infiltrated composites.

### *3.3. Tribological properties*

The wear test results are given in Figs. 12 and 13.

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.

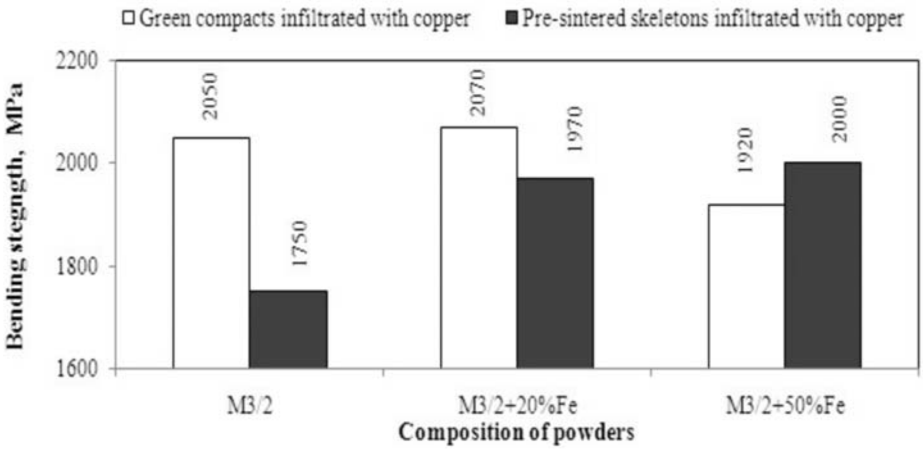



Fig. 11. The bending strength of as-infiltrated composites.

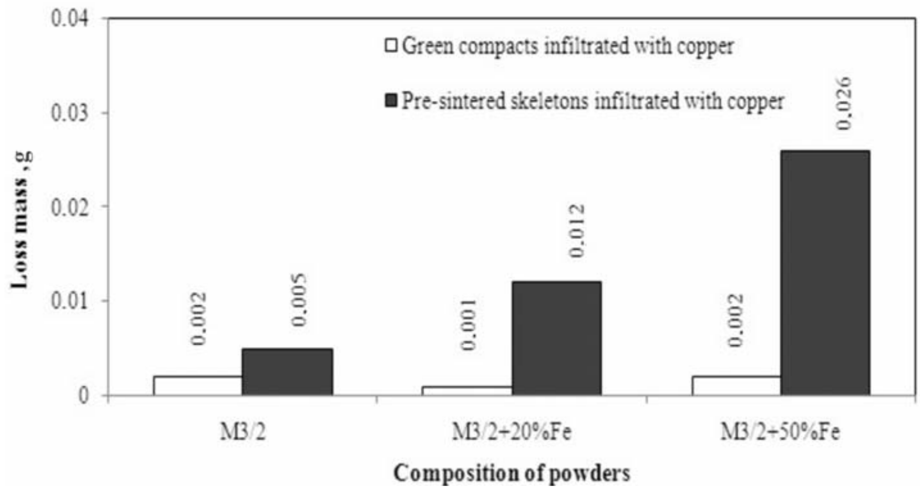



Fig 12. Loss of mass of as-infiltrated composites.

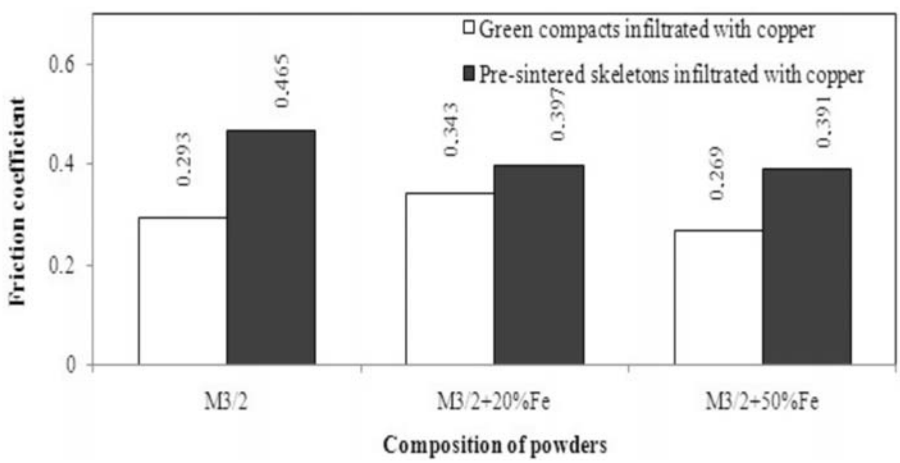



Fig. 13. Friction coefficient of as-infiltrated composites.

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

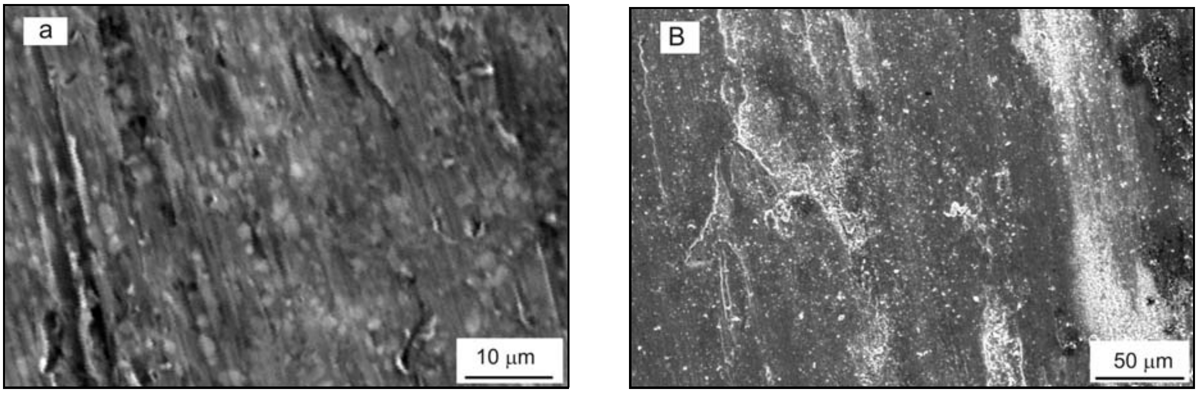



Fig. 14. The surface of the as-infiltrated composites after examining the wear resistance: a) M3/2, b) M3/2 + 50 % Fe.

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.

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 Fig. 14.

The surface topographies of M3/2 and M3/2 + 50 % Fe specimens indicate occurrence of different wear mechanisms (Fig. 14). 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 14a provides evidence of ploughing and sideways displacement of material in M3/2. Figure 14b shows smearing of iron over the surface of the as-infiltrated M3/2 + 50 % Fe composite which implies marked contribution of adhesive wear, whereas the extensive formation of iron oxides may account for the lowest friction coefficients.

## 4. 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 11–12 times higher loss of mass than the iron containing green compacts infiltrated with copper.

– 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.

## Acknowledgements

This work was done in frame of the project No 11.11.110.788, which was financed by the Ministry of Science and Higher Education.

## References

[1] Greetham, G.: Powder Metallurgy, *2*, 1990, p. 112.
[2] Palma, R. H.: The International Journal of Powder Metallurgy, *37*, 2001, p. 29.
[3] Wright, C. S.: Powder Metallurgy, *3*, 1994, p. 937.
[4] Leżański, J.: Metalurgia i Odlewnictwo, 1988, p. 100.
[5] Torralba, J. M.: Powder Metallurgy Progress, *36,* 1993, p. 55.
[6] Bała, P., Pacyna, J.: Archives of Metallurgy and Materials, *53,* 2008, p. 795.
[7] Madej, M.: Archives of Metallurgy and Materials, *53,* 2008, p. 839.