M. MADEJ*

COPPER INFILTRATED HIGH SPEED STEEL BASED COMPOSITES WITH IRON ADDITIONS

INFILTROWANE MIEDZIĄ KOMPOZYTY NA OSNOWIE STALI SZYBKOTNĄCEJ Z DODATKIEM ŻELAZA

High hardness, mechanical strength, heat resistance and wear resistance of M3/2 grade high speed steel (HSS) make it an attractive material for manufacture of valve train components [1,2]. 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÷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. 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.

Attempts have been made to establish the influence of the production process parameters and amount of alloying additives, such as iron and electrolytic cooper, on the microstructure and mechanical properties of copper infiltrated HSS based composites.

Keywords: High speed steel, composites, sintering, infiltration

Nowoczesne metody wytwarzania stali szybkotnących i kompozytów na osnowie stali szybkotnących różnych gatunków oparte są na procesach metalurgii proszków. 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. Przez regulację liczby i udziału komponentów oraz ich wzajemnego oddziaływania można wpływać na strukturę i własności kompozytu, w celu uzyskania materiału o regulowanych własnościach, w szczególności o wysokiej odporności na zużycie cierne, dobrym przewodnictwie cieplnym, małym współczynniku tarcia i wysokich własnościach wytrzymałościowych. W artykule przedstawiono wyniki badań w zakresie wytwarzania i badania własności infiltrowanych kompozytów stal szybkotnąca – żelazo – miedź. Materiał badawczy stanowiły kształtki ze stali szybkotnącej gatunku M3/2 i stali szybkotnącej z dodatkiem 20% i 50% proszku żelaza gatunku NC 100.24. 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 niespiekane i spiekane infiltrowano miedzią, metodą nakładkową w piecu próżniowym w temperaturze 1150°C przez 15 minut .

Dodatek żelaza stosowano w celu oddziaływania na własności oraz obniżenia kosztów wytwarzania infiltrowanych kompozytów na osnowie stali szybkotnącej ze względu na niższą cenę proszku żelaza od proszku stali szybkotnącej. Dodatek proszku żelaza do proszku stali szybkotnącej powoduje zwiększenie zgęszczalności mieszanki, tym bardziej im większy jest dodatek żelaza. Gęstość kształtek M20Fe uległa nieznacznym zmianom podczas spiekania. Dodatek 50% Fe powoduje nieznaczne zwiększenie stopnia wypełnienia kapilar infiltrowanych kompozytów z wyprasek M50Fe w porównaniu do infiltrowanych kompozytów ze spieków M. Gęstość względna infiltrowanych komopozytów z wyprasek i spieków M20Fe jest nieznacznie mniejsza od gęstości względnej kompozytów z wyprasek i spieków M. Twardość infiltrowanych kompozytów z wyprasek i spieków M20Fe zmniejsza się ze wzrostem zawartości żelaza. Infiltrowane kompozyty z wyprasek mają mniejszą wytrzymałość na zginanie od kompozytów ze speków M20Fe i M50Fe, które odznaczają się większą wytrzymałością na zginanie od infiltrowanych kompozytów ze spieków M. Dodatek żelaza korzystnie wpływa na zwiększenie odporności na utlenianie

* AGH-UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF METALS ENGINEERING AND INDUSTRIAL COMPUTER SCIENCE, 30-059 KRAKÓW, 30 MICKIEWICZ AV., POLAND

infiltrowanych kompozytów z wyprasek M50Fe w podwyższonych temperaturach. Ubytek masy infiltrowanych kompozytów z wyprasek M20Fe podczas testu odporności na zużycie cierne jest nieznacznie mniejsze od ubytku masy infiltrowanych kompozytów z wyprasek M, natomiast ubytek masy infiltrowanych kompozytów ze spieków M20Fe i M50Fe jest większy w porównaniu do infiltrowanych kompozytów ze spieków M.

1. Experimental procedure

The POWDREX water atomised M3/2 grade HSS powder, finer than 160μm and Höganäs NC 100.24 grade iron powder, finer than 160μm were used in the experiments. The powders were delivered in the as-annealed condition. Chemical composition of the HSS powder is given in Table 1.

TABLE 1

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

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

Various amounts of iron powder were added to the HSS powder prior to compaction. The following compositions were investigated:

- 100% M3/2,
- M3/2 + 20% Fe,
- M3/2 + 50%Fe.

The starting powders are shown in Fig 1.

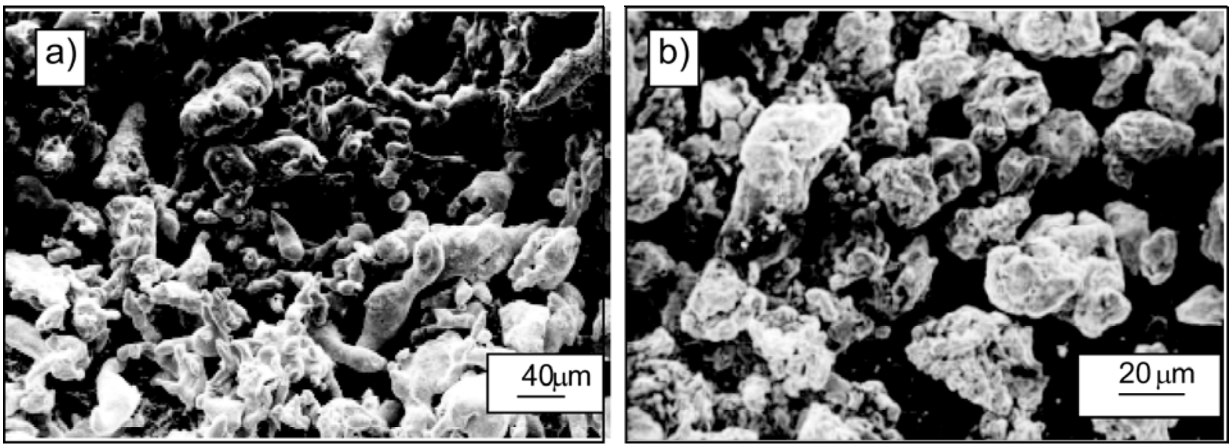

Fig. 1. EM micrographs of: a) M3/2 HSS powder, b) NC 100.24 iron powder

The mixtures were prepared by mixing for 30 minutes in the 3-D pendulum motion Turbula® T2C mixer. Then the powders were cold pressed in a rigid cylindrical die at 800 MPa.

The infiltration process was carried out in vacuum better than 10^{-3}hPa. Both green compacts and compacts pre-sintered for 60 minutes at 1150°C in vacuum were infiltrated with copper. Carefully pre-weighed preforms of copper 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 the room temperature.

The infiltrated specimens were then tested for hardness, by means of the Brinell test, and subjected to microstructural examinations by means of both light microscopy (LM) and scanning electron microscopy (SEM).

2. Results and discussion

The combined effects of iron powder content and powder processing route on the relative density of the porous skeleton are shown in Fig. 2.

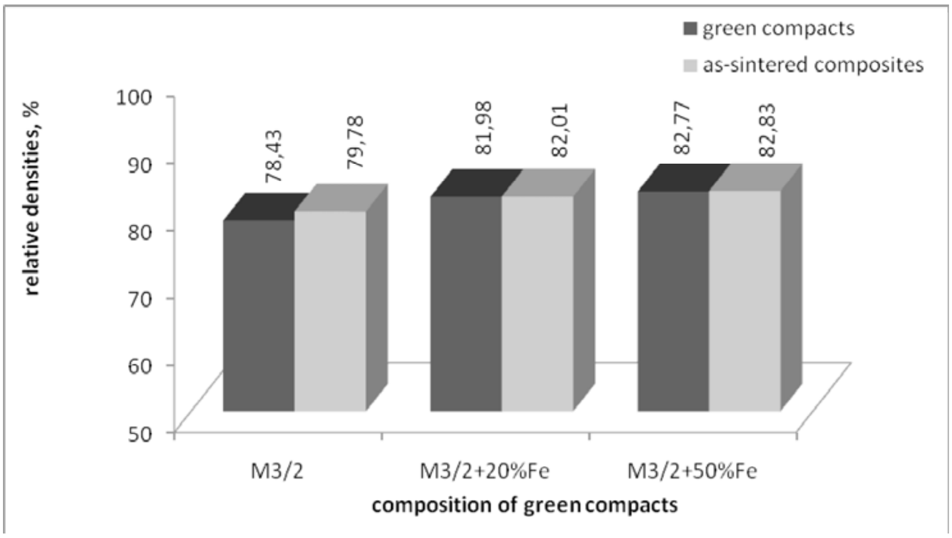

Fig. 2. Relative densities of green compacts and pre-sintered porous skeletons as a function of iron powder content

Fig. 2 shows that the M3/2 grade HSS cannot be fully densified at 1150°C, and that the as-sintered density is approximately equal to the green density [3,5]. Additions of 20 and 50% iron powder have a negligible effect on the as-sintered density.

Figs 3÷5 show the morphologies of capillaries in both the green compacts and pre-sintered skeletons.

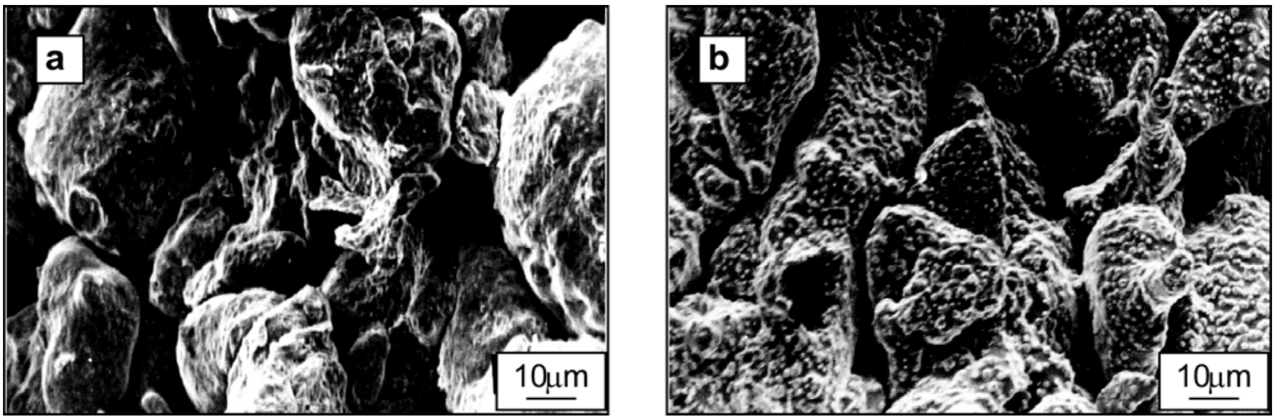

Fig. 3. The morphologies of capillaries in M3/2 grade HSS, SEM a) green compact, b) pre-sintered skeleton

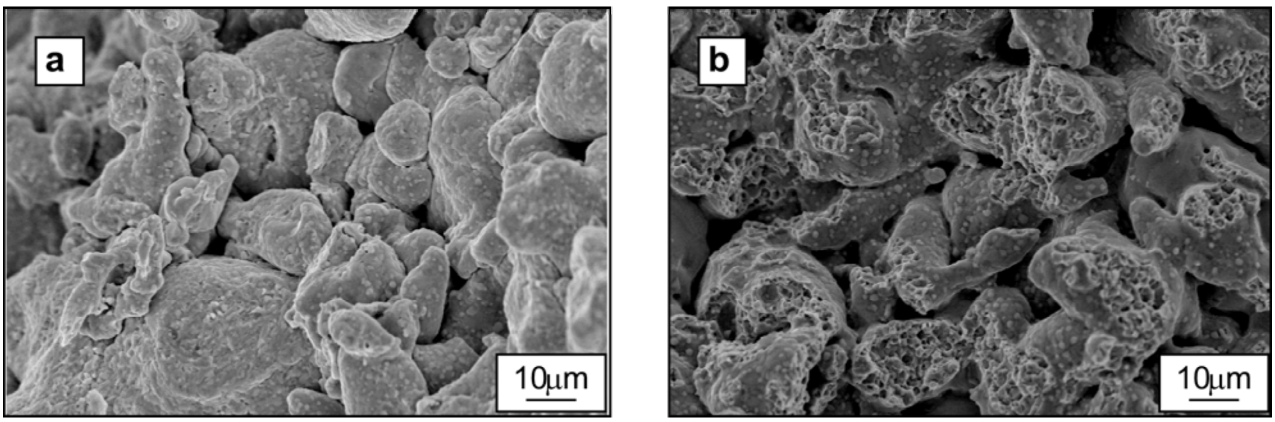

Fig. 4. The morphologies of capillaries in M3/2 HSS + 20% Fe , SEM a) green compact, b) pre-sintered skeleton

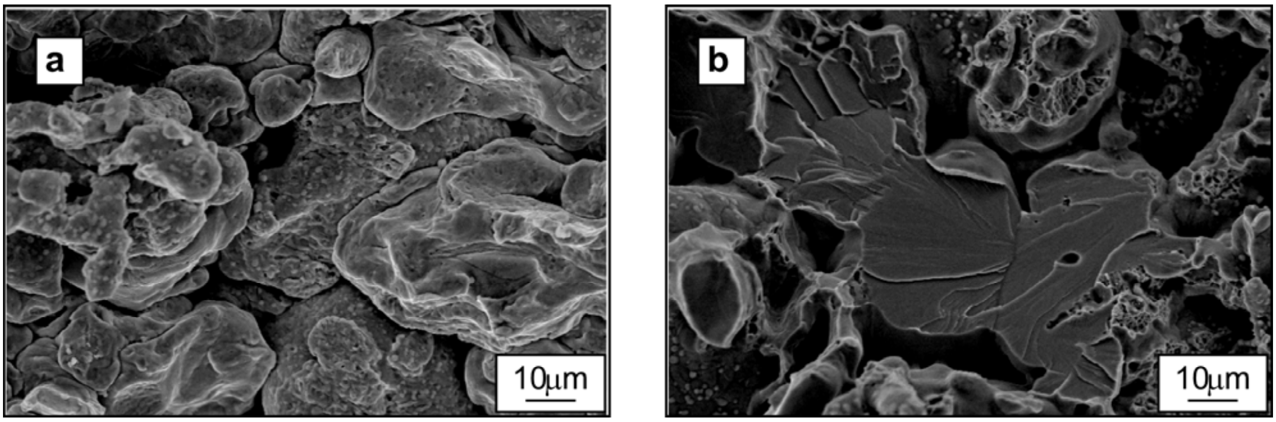

Fig. 5. The morphologies of capillaries in M3/2 HSS + 50% Fe , SEM a) green compact, b) pre-sintered skeleton

From the microstructural observations (Figs 3÷5) it may be concluded that the morphologies of capillaries are mainly affected by the manufacturing route and powder characteristics (Fig. 1), such as the powder particle size and morphologies of powder particles.

The properties of the as-infiltrated composites are given in Figs 6÷8.

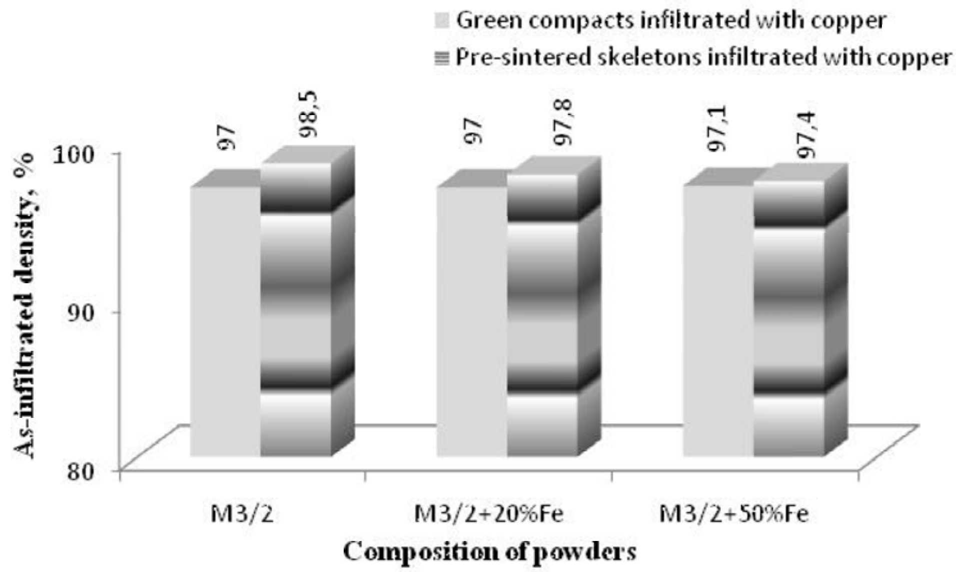

Fig. 6. As-infiltrated density as a function of iron powder content and manufacturing route

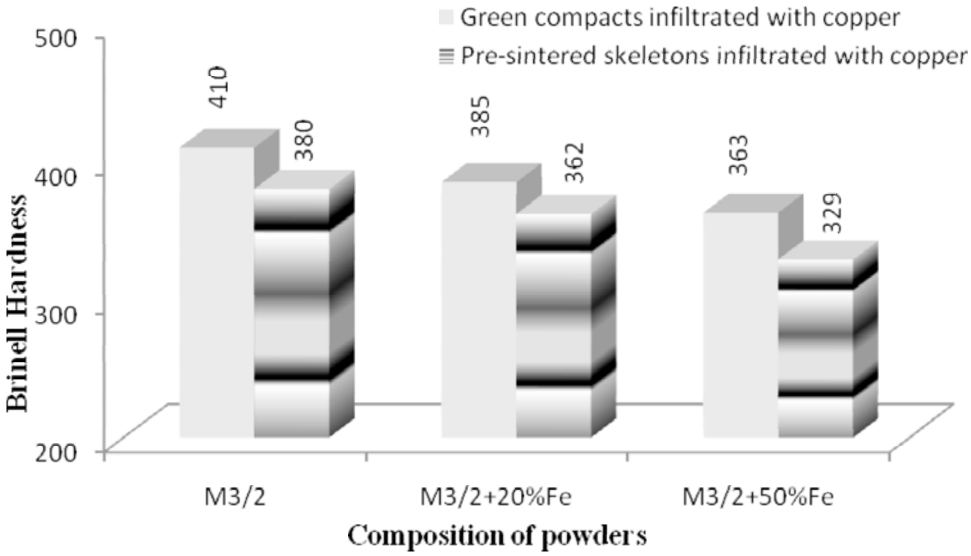

Fig. 7. As-infiltrated Brinell hardness as a function of iron powder content and manufacturing route

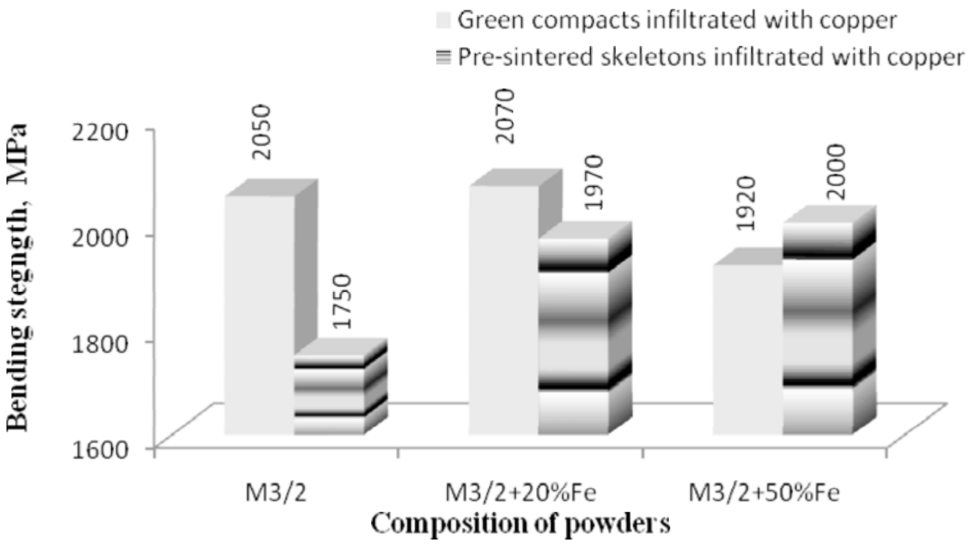

Fig. 8. As-infiltrated bending strength as a function of iron powder content and manufacturing route

From Figs 6÷8 it is evident that the as-infiltrated properties of the investigated composites are a complex function of the manufacturing route and tungsten carbide content. The molten copper is drawn into the interconnected pores of the skeleton, through a capillary action, and fills 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 powder, whereas the bending strength seems not to be affected by the addition of iron powder. Marked differences in hardness between the materials obtained from the two infiltration routes have been observed, with higher hardness numbers achieved with direct infiltration of green compacts.

The as-infiltrated composites were used for wear tests performed by block-on-ring wear tester (Fig. 9).

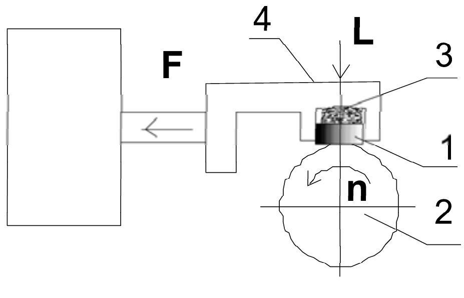

Fig. 9. Schematic view of block-on-ring wear tester

The sample (1) was mounted in a sample holder (4) equipped with a hemispherical insert (3) ensuring proper contact between the sample and a rotating ring (2). The wear surface of the sample was perpendicular to the pressing direction. Double lever system forced the sample against the ring with the load accuracy of ±1%. The ring rotated with a constant rotating speed.

The wear tests conditions chosen for the current investigations were:

- tested samples – rectangular as-infiltrated specimens 20 × 4 × 4 mm,
- counterpart (rotating ring) – φ 49,5 × 8 mm, heat treated steel, 55 HRC,
- dry sliding,
- 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).

The wear test results are given in Figs 10 and 11.

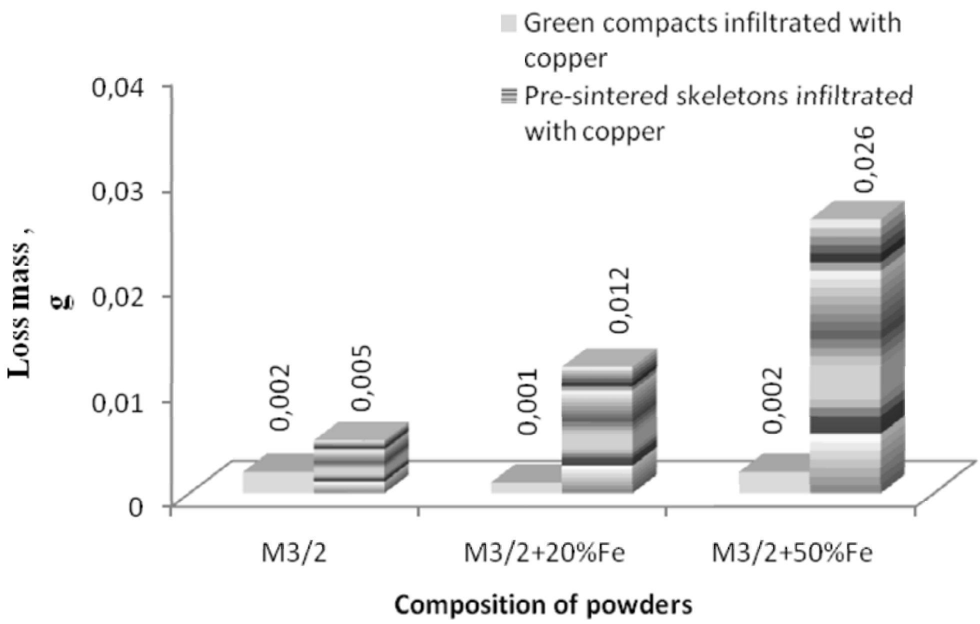

Fig. 10. Loss of mass of as infiltrated composites

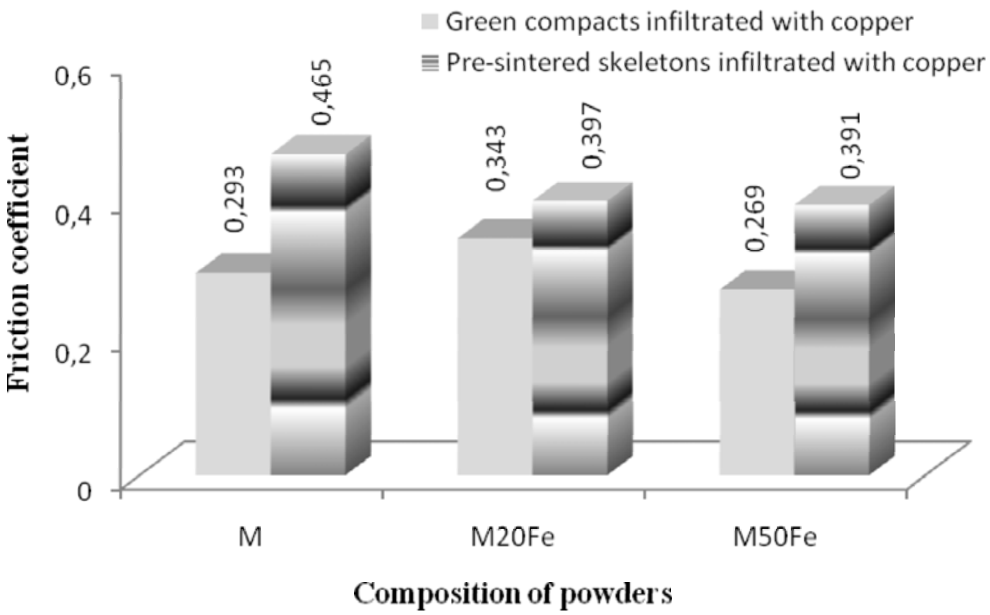

Fig. 11. Friction coefficients of as infiltrated composites

The measurements of the wear resistance and friction coefficient permit classification of the as-infiltrated composites with respect to their wearability. Direct infiltration of green compacts with copper results in the highest wear resistance and higher friction coefficient of the as-infiltrated composites. The addition of 20÷50% iron does not lower the wearability of the composites produced by direct infiltration of green compacts with copper. Comparing the wearability of composites received through direct infiltration of green compacts and infiltration of pre-sintered skeletons it is evident that that the pre-sintered, iron containing specimens show 11÷12 times higher loss of mass than the iron containing green compacts infiltrated with copper. It is possible to explain the substantial loss of mass of as-infiltrated composites by the diffusion of carbon to iron particles during sintering.

Typical microstructures of copper infiltrated green compacts and pre-sintered skeletons are shown in Figs 12÷14.

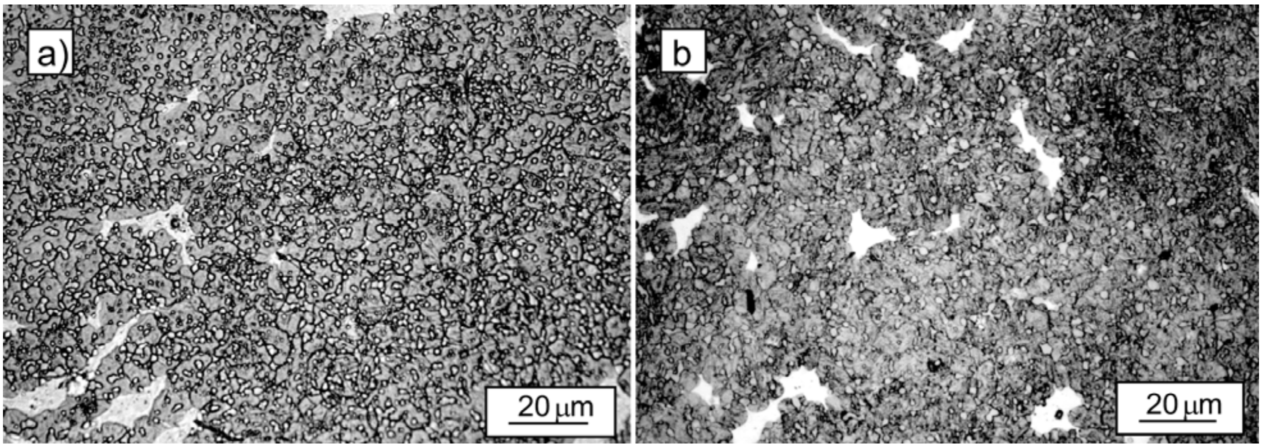

Fig. 12. Microstructures of M3/2 HSS based composites: a) green compact infiltrated with copper, b) pre-sintered skeleton infiltrated with copper

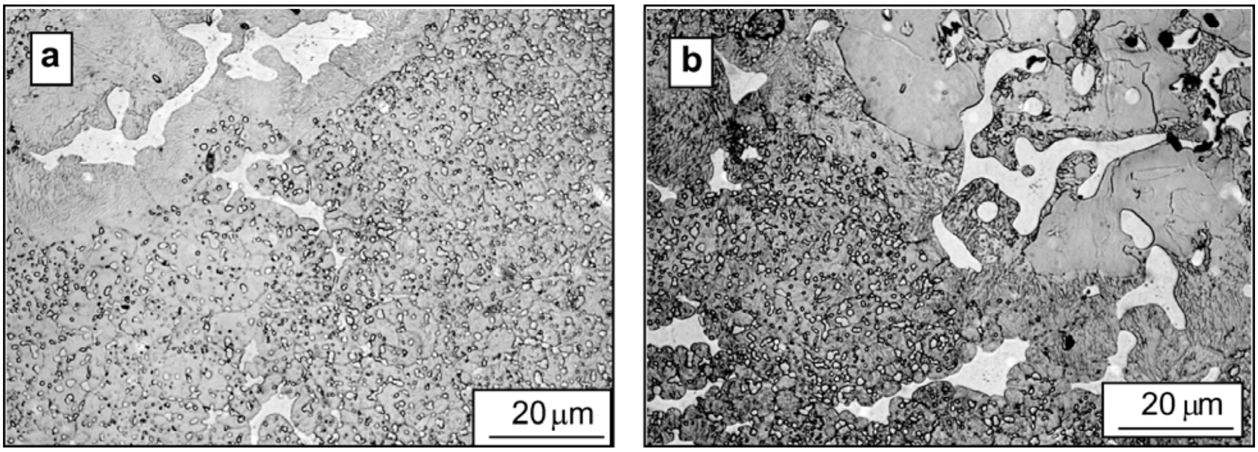

Fig. 13. Microstructures of M3/2 HSS + 20%Fe composites: a) green compact infiltrated with copper, b) pre-sintered skeleton infiltrated with copper

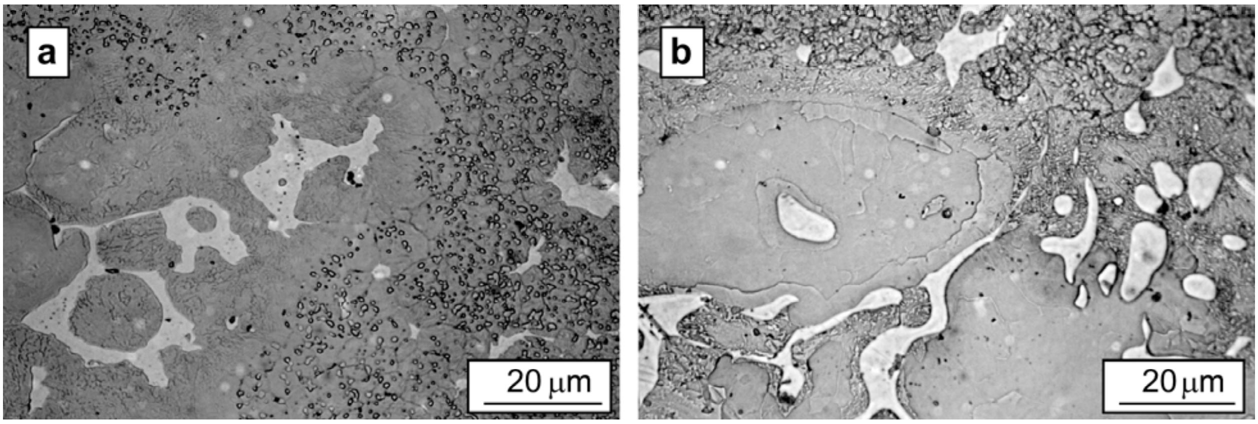

Fig. 14. Microstructures of M3/2 HSS + 50%Fe composites: a) green compact infiltrated with copper, b) pre-sintered skeleton infiltrated with copper

It can be seen that the microstructure of the M3/2 grade HSS based composites consists of a steel matrix with finely dispersed carbides and islands of copper (Fig. 12). Figs 13 and 14 show uniform distribution of HSS, iron, copper, and residual porosity in the as-infiltrated microstructures of the composites.

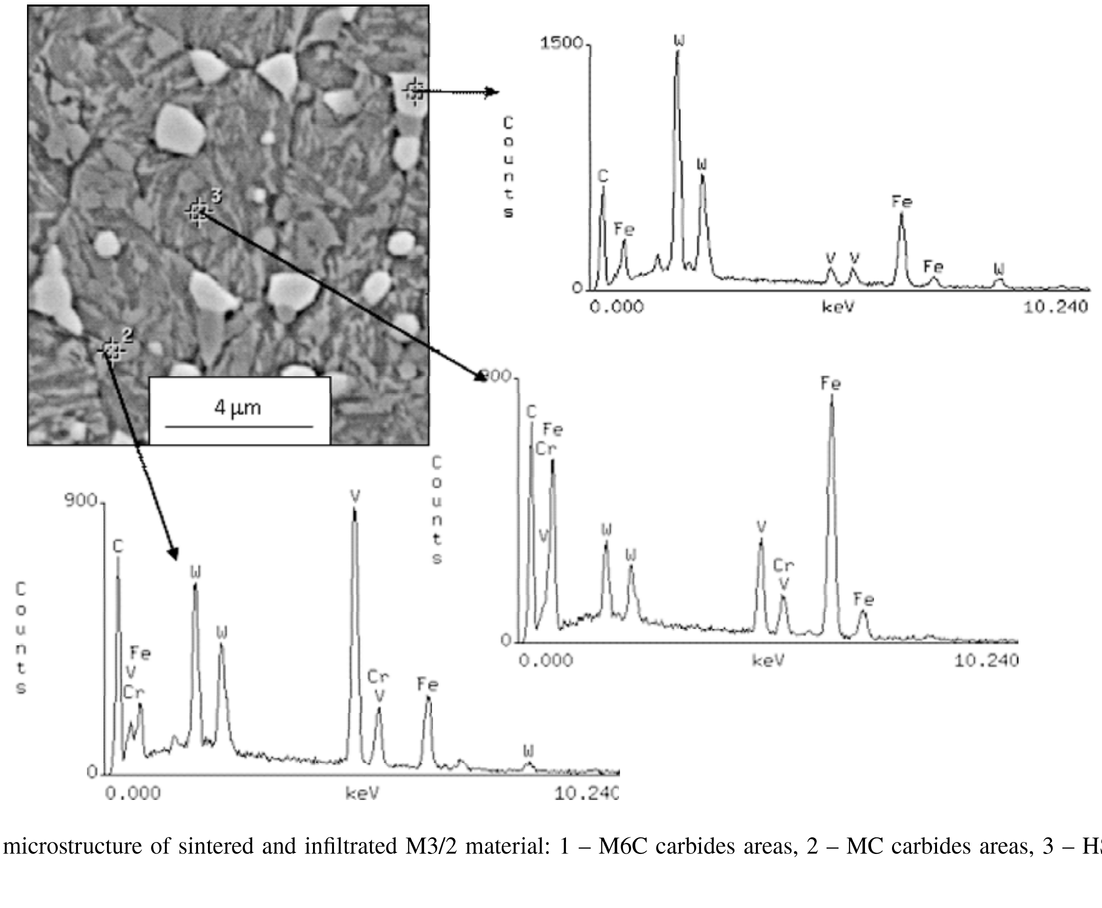

Fig. 15. SEM microstructure of sintered and infiltrated M3/2 material: 1 – M6C carbides areas, 2 – MC carbides areas, 3 – HSS matrix

The qualitative EDX analysis (Fig. 15) revealed the presence of both MC type vanadium-based carbides and M_6C type tungsten and iron rich carbides.

From the density measurements (Fig 6) and microstructural observations (Figs 12÷14) it is evident that the infiltration with copper almost completely eliminates porosity.

3. Conclusions

- Infiltration of porous HSS skeletons with liquid copper has proved to be a suitable technique whereby fully dense HSS based materials are produced at low cost.
- The mechanical properties of the examined composites depend on the iron content. The presence of iron decreases the hardness and increases the bending strength (with the exception of copper infiltrated M3/2+50%Fe green compacts).
- The additions of iron powder doesn't change the wear rate of HSS based composites produced by direct infiltration of green compacts with copper, but the pre-sintered, iron containing specimens show 2.4÷5.2 times higher loss of mass than the iron containing green compacts infiltrated with copper.
- Direct infiltration of green compacts with copper results in the highest hardness of the composites and allows to cut the production cost.
- Direct infiltration of green compacts with copper results in the lower friction coefficient of the as-infiltrated composites.

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