A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 50 2005 Issue 4

M. MADEJ*, J. LEŻAŃSKI*

COPPER INFILTRATED HIGH SPEED STEEL BASED COMPOSITES

KOMPOZYTY STAL SZYBKOTNĄCA-WĘGLIK WOLFRAMU-MIEDŹ

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, 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, 2].

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 the copper, normally to between 1095 and 1150°C.

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

Keywords: High speed steel, composites, sintering, infiltration.

W artykule przedstawiono wyniki badań w zakresie wytwarzania i badania własności oraz struktury infiltrowanych kompozytów stal szybkotnąca — węglik wolframu — miedź.

Do wytwarzania porowatych kształtek stosowano: rozpylany wodą proszek stali szybkotnącej gatunku M3/2 oraz proszek węglika wolframu WC. Porowate kształtki do infiltracji wytwarzano z następujących mieszanek proszków: 100%M3/2, M3/2 + 10% WC, M3/2 + 30% WC. Mieszanki poddano prasowaniu w matrycy o działaniu jednostronnym stempla pod ciśnieniem 800 MPa. Część wyprasek poddano spiekaniu w piecu próżniowym w temperaturze 1150°C przez 1 godzinę. Następnie niespiekane i spiekane kształtki poddano infiltracji metodą nakładkową. Infiltrację prowadzono w piecu próżniowym w temperaturze 1150°C przez 15 minut.

* WYDZIAŁ METALURGII I INŻYNIERII MATERIAŁOWEJ, AKADEMIA GÓRNICZO-HUTNICZA, 30-059 KRAKÓW, AL. MICKIEWICZA 30

Celem pracy jest określenie wpływu dodatku proszku węglika wolframu WC do proszku stali szybkotnącej gatunku M3/2 oraz parametrów wytwarzania na morfologię kapilar w porowatych kształtkach przeznaczonych do infiltracji i wpływu morfologii kapilar na przebieg infiltracji, i na własności infiltrowanych kompozytów.

1. Experimental procedure

The POWDREX water atomised M3/2 grade HSS powder, finer than 160μm, was used in the experiments. The powder was delivered in the as-annealed condition. Its chemical composition 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 fine tungsten carbide powder (FSSS=3μm) were added to the HSS powder prior to compaction. The following compositions were investigated:

- 100% M3/2,
- M3/2 + 10% WC,
- M3/2 + 30%WC.

The starting powders are shown in Fig 1.

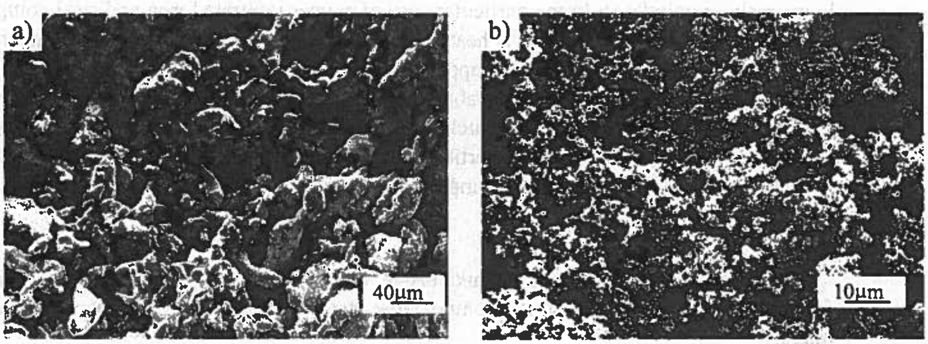

Fig. 1. SEM micrographs of: (a) M3/2 HSS powder, (b) tungsten carbide powder

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}Pa. 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

2.1. Characterisation of the porous skeletons

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

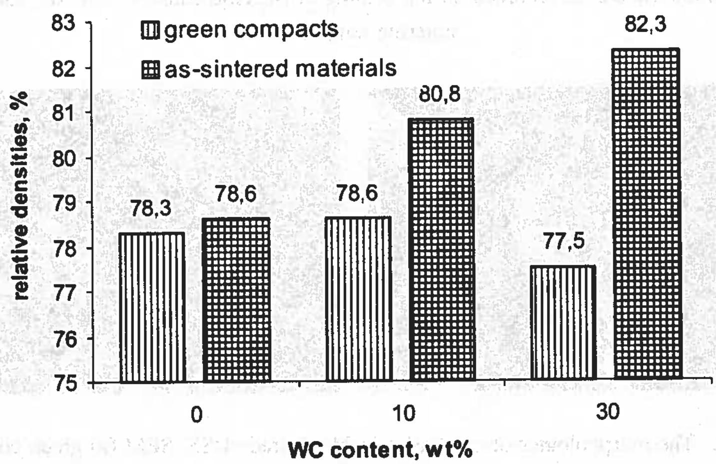

Fig. 2. Relative densities of green compacts and pre-sintered porous skeletons as a function of tungsten carbide content

Figure 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]. Addition of 30% tungsten carbide increase the as-sintered density presumably due to the occurrence of a liquid phase resulting from a chemical reaction occurring between the HSS matrix and tungsten carbide particles. As exemplified in Fig. 3, marked specimen expansion followed by its rapid contraction has indicated that the chemical reaction takes place at temperatures between 1080 and 1110°C.

Figures 4 and 5 show the morphologies of capillaries in both green compacts and pre- sintered skeletons.

It may be concluded from the microstructural observations (Figs 4 and 5) that the morphologies of capillaries are mainly affected by the manufacturing route and powder characteristics (Fig. 1).

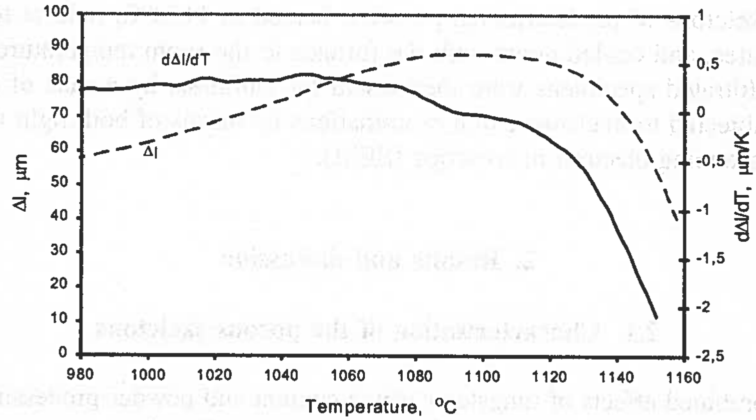

Fig. 3. Dilatometric curves recorded during heating of the HSS M3/2 + 30% WC material to the sintering temperature

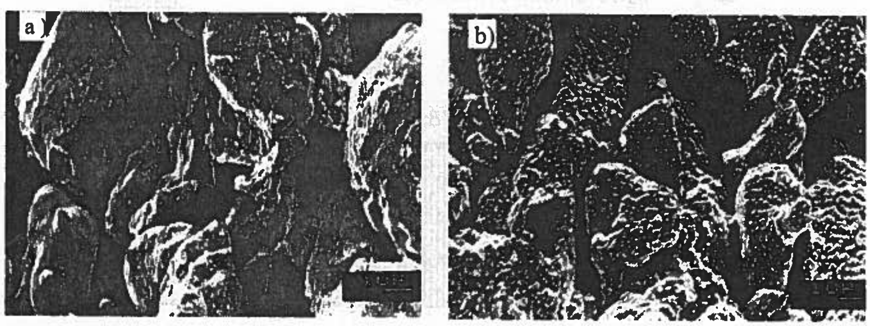

Fig. 4. The morphologies of capillaries in M3/2 grade HSS, SEM (a) green compact, (b) pre-sintered skeleton

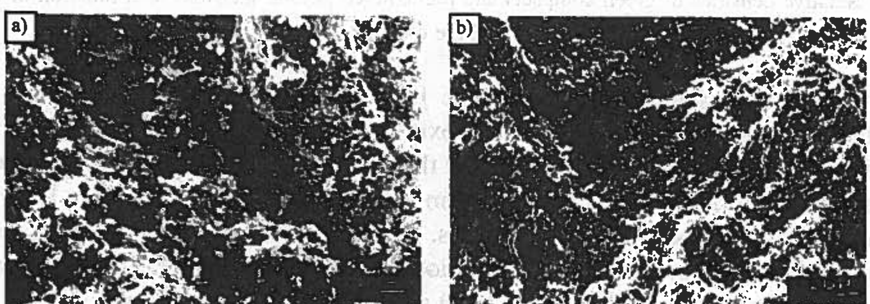

Fig. 5. The morphologies of capillaries in M3/2 HSS + 30% WC , SEM (a) green compact, (b) pre-sintered skeleton

2.2. The properties of copper infiltrated HSS based composites

The properties of the as-infiltrated composites are given in Table 2.

TABLE 2

Properties of the investigated composites

Alloy	Copper content, wt %,		As-infiltrated density, %		Brinell Hardness		Bending strength, Mpa	
	GC[1)]	PS[2)]	GC	PS	GC	PS	GC	PS
M3/2	21.7	15.4	97.0	98.5	410	380	2050	1750
M3/2+10%WC	20.5	16.0	97.7	98.2	470	460	1300	1450
M3/2+30%WC	20.5	15.3	98.2	98.2	575	560	1170	1380

[1)] GC — green compacts infiltrated with copper
[2)] PS — pre- sintered skeletons infiltrated with copper

From Table 2 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 increases with the increased content of tungsten carbide, whereas the bending strength seems to be adversely affected by the addition of the tungsten carbide powder. Considerable 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.

2.3. Microstructures

Typical microstructures of a copper infiltrated green compact and pre-sintered skeleton are shown in Figures 6 and 7, respectively.

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. Figure 5 shows tungsten carbides located within the grains and on the grain boundaries as well. The SEM and EDX analysis performed on the specimens containing 30% tungsten carbides is presented in Fig. 1. The qualitative EDX analysis revealed the presence of both MC type vanadium-rich carbides and M_6C type tungsten and iron rich carbides.

The SEM and EDX analysis performed on the specimens containing 10 and 30% tungsten carbide have revealed the carbide phase evenly distributed within the copper-rich regions. As it is apparent from Fig. 8, WC reacts with the surrounding HSS matrix and forms a tungsten and iron-rich M_6C carbide grain boundary network.

From the microstructural observations (Figs 4-6) and obtained results (Table 2) it may be concluded that the infiltration with copper almost completely eliminates porosity.

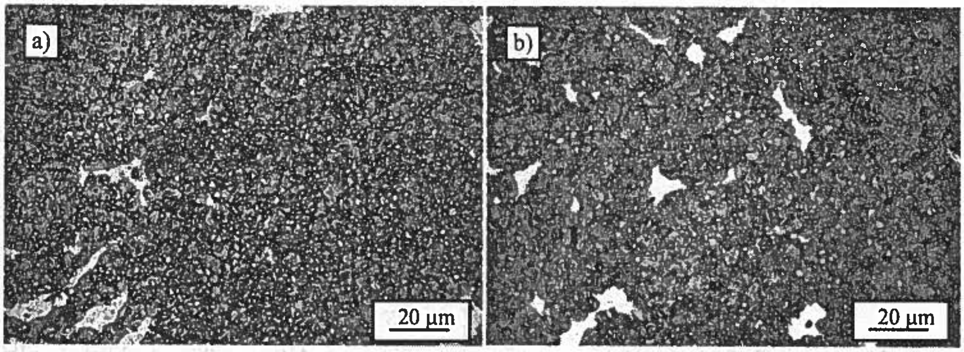

Fig. 6. Microstructures of M3/2 HSS based composites: (a) green compact infiltrated with copper, (b) re-sintered skeleton infiltrated with copper

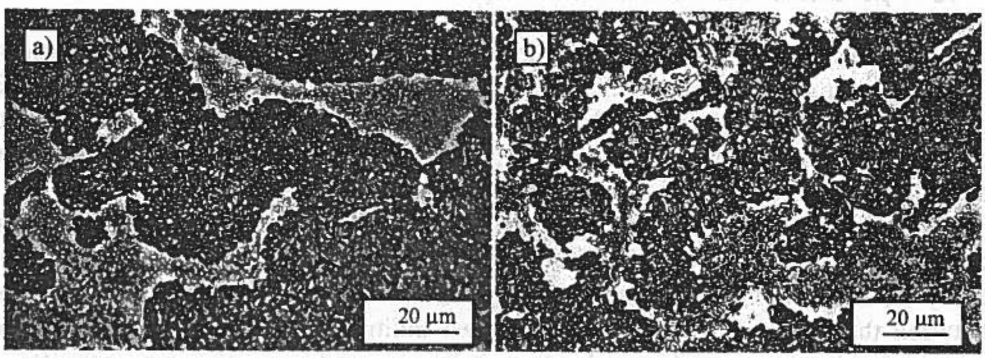

Fig. 7. Microstructures of M3/2 HSS + 30%WC composites: (a) green compact infiltrated with copper, (b) pre-sintered skeleton infiltrated with copper

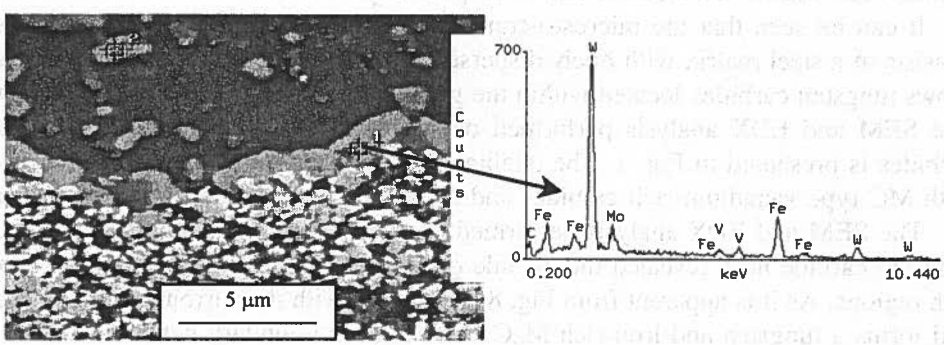

Fig. 8. SEM micrograph of a pre-sintered and copper infiltrated M3/2+30%WC composite (left) and EDX spectrum emitted from the M_6C type carbide layer (right)

3. 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.
- The mechanical properties of the HSS based composites are strongly dependent on the tungsten carbide content. The additions of tungsten carbide increase the hardness of HSS based composites, but decrease their bending strength.
- Tungsten-rich M_6C type carbide is formed as a result of the chemical reaction between the tungsten monocarbide and HSS matrix.
- Direct infiltration of green compacts with copper results in the highest hardness of the composites and allows to cut the production cost.

This work was done in frame of the project No 11.11.110.491, which was financed by KBN

REFERENCES

[1] G. G r e e t h a m, Development and performance on infiltrated and non- infiltrated valve seat insert materials and their performance. Powder Metallurgy, 3, 2, 112-114 (1990).

[2] R o d r i g o H. P a l m a, Tempering response of copper alloy- infiltrated T15 high- speed steel, The International Journal of Powder Metallurgy.

[3] C.S. W r i g h t, The production and application of PM high-speed steels. Powder Metallurgy **3**, 937-944 (1994).

[4] J. L e ż a ń s k i, Infiltracja cieczy w porowatych materiałach. Metalurgia i Odlewnictwo, 118 (1988).

[5] J.M. T o r r a l b a, Sinterability study of PM M2 and T15 HSS reinforced with tungsten and titanium carbides **36**, pp. 55-66 1993.

Received: 20 October 2004.