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THE STRUCTURE AND PROPERTIES OF COPPER INFILTRADET HSS HASED COMPOSITE

STRUKTURA I WŁAŚCIWOŚCI INFILTROWANYCH MIEDZIĄ KOMPOZYTÓW NA OSNOWIE STALI SZYBKOTNĄCEJ

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 [1,2,3]. In this application, the material must exhibit oxidation resistance, high hot strength and hardness, and superior wear resistance. Metal matrix composites were produced by powder metallurgy techniques and were composed by a infiltration high speed steel based material into which hard abrasive wear resistant carbide particles were incorporated at the powder compaction stage. 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 [1,2].

Infiltration is a process that has been practiced for many years. Infiltration is basically 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 above the melting point of the copper, normally within the range of 1095° to 1150°C.

Attempts have been made to describe the influence of the production process parameters and alloying additives, such as graphite and electrolytic cooper, on the microstructure and mechanical properties of copper infiltrated HSS based composites. The compositions of powder mixtures are 100% M3/2, M3/2 + 7.5%Cu, M3/2 + 0.3%C.

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

Stale manganowe, produkowane metodami metalurgii proszków, znajdują coraz szersze zastosowanie, z których wiele wskazuje na możliwość otrzymania wyrobów spiekanych o wysokich własnościach wytrzymałościowych w połączeniu z małymi tolerancjami wymiarowymi przy niskich nakładach kosztów. Własności mechaniczne spiekanych stali zależą od wielu czynników takich jak gęstość, temperatura i atmosfera spiekania oraz prędkość chłodzenia.

Infiltracja miedzią porowatych kształtek jest jednym ze sposobów wytwarzania kompozytów na osnowie stali szybkotnącej np. elementów silników spalinowych, takich jak gniazda zaworów i prowadnice zaworów. Infiltracja pozwala uzyskać wyroby lite lub prawie litych. Zastosowanie miedzi do infiltracji porowatych kształtek ze stali szybkotnącej wynika z jej dostępności, bliskiego zeru skrajnego kata zwilżania stali oraz dobrego przewodnictwa cieplnego, które jest szczególnie przydatne w wymienionych wyżej elementach silnika. Dodatek żelaza wprowadzono w celu obniżenia kosztów wytwarzania ze względu na niższą cenę proszku żelaza w stosunku do ceny stopowego proszku stali szybkotnącej. Stal szybkotnąca stanowi twardą osnowę odpowiedzialną za własności wytrzymałościowe i odporność na ścieranie a wprowadzona podczas infiltracji miedź ułatwia uzyskanie całkowitego zagęszczenia kompozytów oraz zwiększa przewodnictwo cieplne i elektryczne.

Celem pracy jest określenie wpływu parametrów wytwarzania oraz dodatku miedzi i grafitu na przebieg infiltracji, strukturę oraz niektóre własności infiltrowanych miedzią kompozytów na osnowie stali szybkotnącej.

Do wytwarzania porowatych kształtek zastosowano rozpylany wodą proszek stali szybkotnącej gatunku M3/2, elektrolityczny proszek miedzi ECu1 oraz proszek grafitu. Porowate kształtki do infiltracji wytwarzano z następujących mieszanek proszków: 100% M3/2, M3/2 + 7,5Cu i M3/2 + 0,3C. Mieszanie proszków wykonano w mieszalniku typu Turbula T2F. Czas mieszania wynosił 1 godzinę. Mieszanki poddano prasowaniu w matrycy o jednostronnym działaniu 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. Chłodzenie kształtek odbywało się wraz z piecem ze średnią szybkością ok. 4°C/min.

Wprowadzenie do proszku stali szybkotnącej M3/2 proszków miedzi lub grafitu powoduje zwiększenie zgęszczalności tych mieszanek względem zgęszczalności kształtek z proszku stali szybkotnącej. Pod wpływem spiekania w temperaturze 1150°C w czasie 60 minut, gęstość wszystkich rodzajów spieków ulega zwiększeniu. Przyrost gęstości względnej poszczególnych rodzajów spieków M3/2, M3/2+7,5Cu i M3/2+0,3C wynosi od 1 do 3 %. Wynika z tego, że dodatek miedzi lub grafitu w

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temperaturze spiekania 1150°C nie powoduje istotnej aktywacji procesów prowadzących do większego zagęszczenia spieków. Dodatek proszków miedzi i grafitu do proszku stali szybkotnącej powoduje nieznaczne zmniejszenie stopnia wypełnienia kapilar oraz gęstości względnej infiltrowanych kompozytów z wyprasek i spieków M3/2+7,5Cu i M3/2+0,3C w porównaniu do kompozytów M3/2. Największą twardość mają kompozyty z infiltrowanych wyprasek i spieków M3/2+0,3C. Dodatek miedzi powoduje zwiększenie wytrzymałości na zginanie infiltrowanych kompozytów z wyprasek i spieków M3+7,5Cu. z wyprasek i spieków M3, M3/2+7,5Cu oraz M3/2+0,3C składa się z ziarn stali szybkotnącej, z rozmieszczonymi wewnątrz węglikami typu M_6C i MC oraz obszarów miedzi.

1. Experimental

Water atomised M3 grade 2 powder of – 160 μm was obtained from POWDREX SA in the annealed condition. Chemical composition of this powder is given in the Table 1.

TABLE 1

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

compound	C	Cr	Co	Mn	Mo	Ni	Si	V	W	Fe	O
composition	1.23	4.27	0.39	0.21	5.12	0.32	0.18	3.1	6.22	bal	626ppm

Copper powder ECu1 of – 63μm was obtained from Euromat. The compositions of powder mixtures are:

- 100% M3/2,
- M3/2 + 7.5%Cu,
- M3/2 + 0.3%C.

The powders morphologies are shown in fig 1.

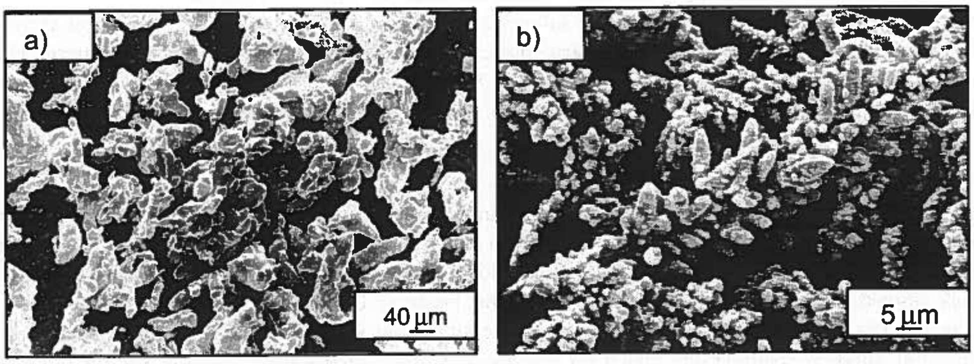

Fig. 1. SEM morphology of powder particles: (a) high speed steel M3/2 class, (b) electrolytic copper ECu1.

Composite mixtures were prepared in a Turbula® mixer for 30 min. The M3/2 powder and composite powders were uniaxially cold compacted in a cylindrical die at 800 MPa.

The infiltration process is subdivided into two fundamental methods: single step or double step. In the single step the unsintered (green) high speed steels or composite mixtures and copper alloy compacts were placed in contact prior to vacuum furnace entry. The copper alloy infiltrant compacts were placed on the top surface of the green compacts. The double step infiltration method consists of pre-sintering of only the green compacts. After the first sintering process, the infiltrant compacts were placed on the top surface of the sintered composites and placed in a vacuum furnace entry.

Half of the green compacts were sintered in vacuum at 1150°C for 60 minutes. Both sintered specimens and green compacts were analysed before infiltration. Density measurements by the Archimedes method were used to evaluate the level of porosity.

The porous skeletons were subsequently infiltrated with copper, by the gravity method, in vacuum at 1150°C for 15 minutes. The infiltrated composites were cooled with the vacuum furnace.

Specimens for microstructural examination by optical microscopy and SEM, were prepared by the standard metallographic methods. Brinell hardness numbers were obtained from polished samples.

2. Results and discussion

2.1. Characteristic of porous skeletons

The effects of the amount contents of copper and graphite and sintering conditions on the density of porous skeletons are shown in figure 2.

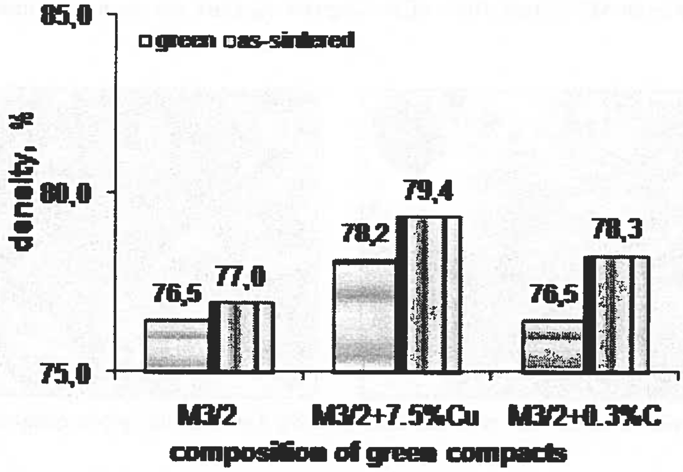

Fig. 2. Relative densities of green compacts and pre-sintered porous skeletons

The increase in copper content renders the powder mixture better compressible. For example the M3/2 powder without copper compacted at 800 MPa attains a density of 76 % theoretical, while the samples prepared from M3/2 HSS with 7.5% copper gives 78.2% theoretical density. Figure 2 shows that the M3/2 grade HSS cannot be fully densified at temperature as low as 1150°C, and as-sintered density is approximately equal to the green density [3, 5]. Additions of 7.5% copper increase the as-sintered density presumably due to occurrence of a liquid phase. Additions of 0.3graphite increase the as-sintered density presumably as a result of chemical reaction between the steel matrix and graphite powder. Figure 3 shows a dilatometric curve of the M3/2 HSS.

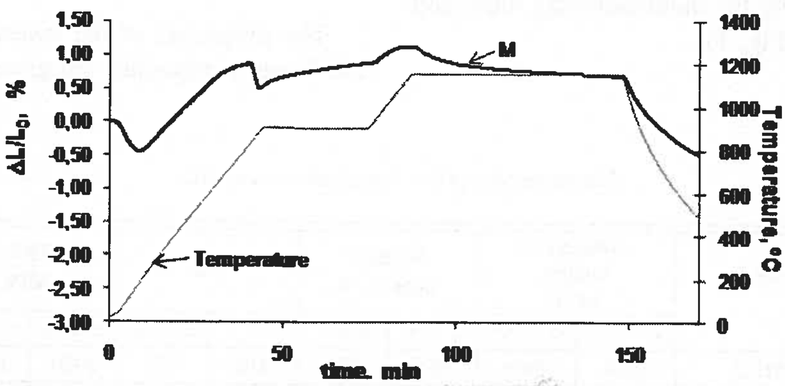

Fig. 3. Dilatometric curves recorded on heating the HSS M3/2 material to the sintering temperatur

Figures 4÷6 show the morphologies of capillaries in green compacts and as-sintered materials.

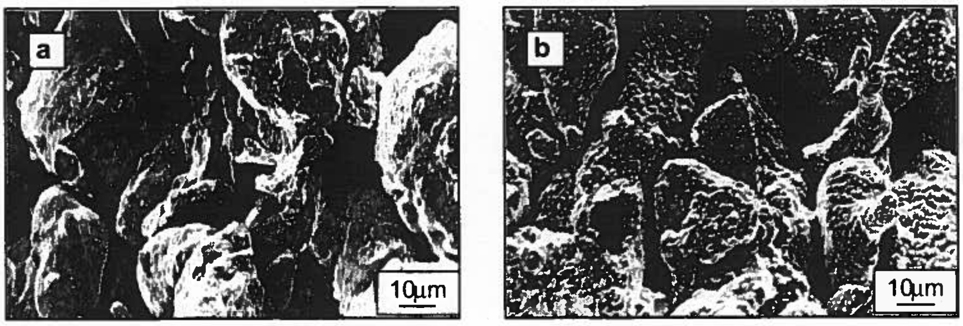

Fig. 4. The morphologies of capillaries in M3/2 grade HSS, SEM (a) green compact, (b) as-sintered material

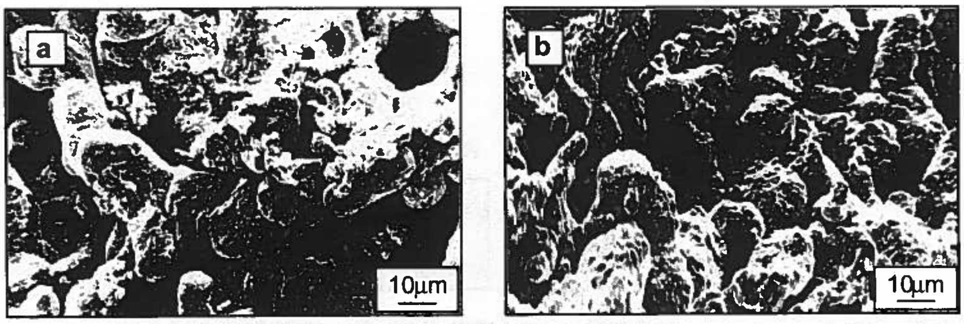

Fig. 5. The morphologies of capillaries in M3/2 HSS with additions of 7.5% Cu, SEM (a) green compact, (b) as-sintered material

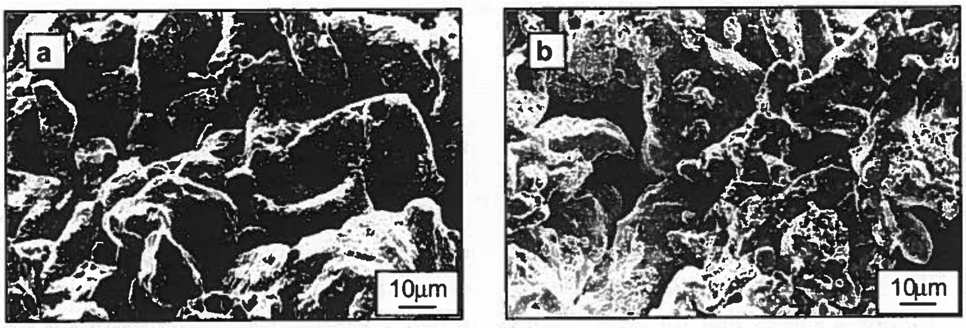

Fig. 6. The morphologies of capillaries in M3/2 HSS with additions of 0.3% C, SEM (a) green compact, (b) as-sintered material

From the microstructural observations (Figs 3 and 4) it may be concluded that the morphologies of capillaries is mainly affected by the manufacturing route and powders characteristics (Fig. 1).

2.2. The properties of copper infiltrated HSS based composites

The properties of the investigated copper infiltrated HSS based composites are given in table 2.

TABLE 2

The properties of the investigated composites

Alloy	Amount of copper, wt %,		Relative density, %		HB		TRS, MPa	
	o. s. i.[1]	d. s. i.[2]	o. s. i.	d. s. i.	o. s. i.	d. s. i.	o. s. i.	d. s. i.
M3/2	20.8	19.9	98.0	97.1	413	377	2050	1750
M3/2+7,5%Cu	26.5	26.2	97.6	97.5	391	394	2290	2080
M3/2+0,3%C	20.1	18.9	97.2	96.6	507	411	1590	1970

[1]o. s. i. – one step infiltration

The properties of copper infiltrated M3/2 grade HSS based composites were a function of the manufacturing route and copper and graphite content. Through the capillary action, the molten copper alloy is drawn into the interconnected pores of the skeleton and fills the entire pore volume. Filling of the pores with higher density copper can result in final densities exceeding 97% of the composite theoretical value. Although non-infiltrated high densities are obtainable through multiple pressing and sintering operations, the extraordinary cost of machine/labor time may exceed the cost of the infiltrating materials required. Attempts show that we can achieve full density by the copper infiltration HSS based composites. Table 2 gives the variation of hardness and TRS with the content of copper and graphite. It is seen that the hardness increases with addition of 0.3%C but the TRS decreases on addition of graphite to the o.s.i. composites. Considerable differences in hardness and in the TRS existed between the two routes of infiltration. Better results we can achieve after the one step infiltration.

2.3. Microstructures

Figures 6÷8 show micrographs of one step and double step infiltrated composites.

The microstructure resulting from infiltration of green compacts and as-sintered materials of M3/2 grade HSS based composites consists of a steel matrix with a dispersion of carbides and islands of the infiltrated copper. Figure 6 shows carbides dispersed within the grains and on grain boundaries. Qualitative EDX analysis of the carbides (Fig 9) shows V-rich MC type carbides, and W and Fe rich M6C carbides. For comparison, the microstructures obtained after one step infiltration and after double step infiltration of M3/2 grade HSS are show in Fig. 6a and 6b.

From the microstructural observations (Fig. 6÷9) and obtained results (Table 2) it may be concluded that the infiltration with Cu infiltrant almost completely eliminates porosity.

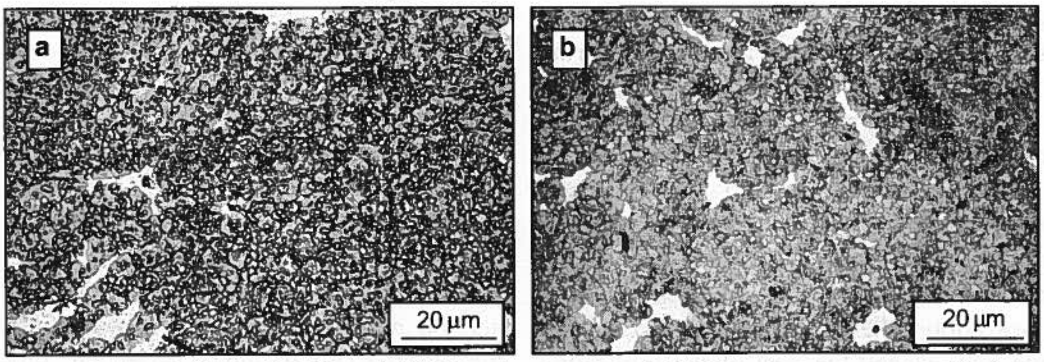

Fig. 7. Microstructures of copper infiltrated M3/2 grade HSS based composites: (a) infiltrated green compact, (b) sintered and infiltrated materiall

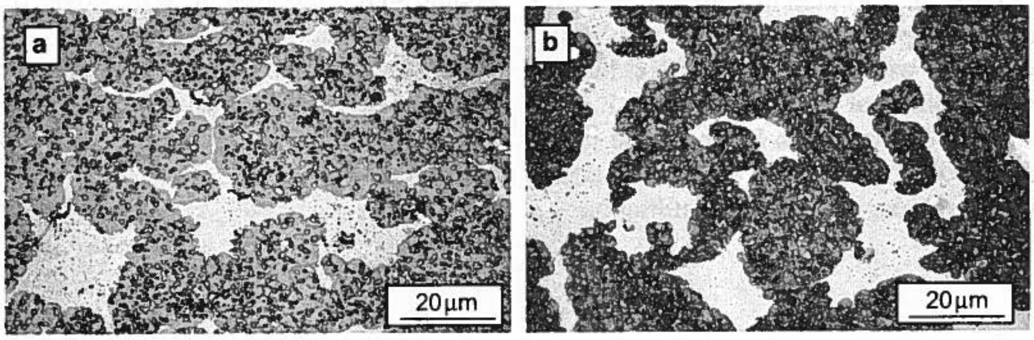

Fig. 8. Microstructures of copper infiltrated M3/2 grade HSS based composites with addition of 7.5% Cu: (a) infiltrated green compact, (b) sintered and infiltrated material

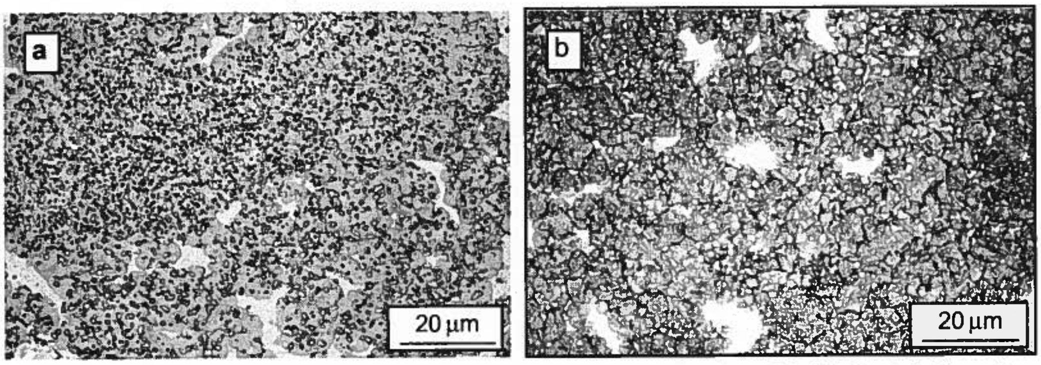

Fig. 9. Microstructures of copper infiltrated M3/2 grade HSS based composites with addition of 0.3% C: (a) infiltrated green compact, (b) sintered and infiltrated material

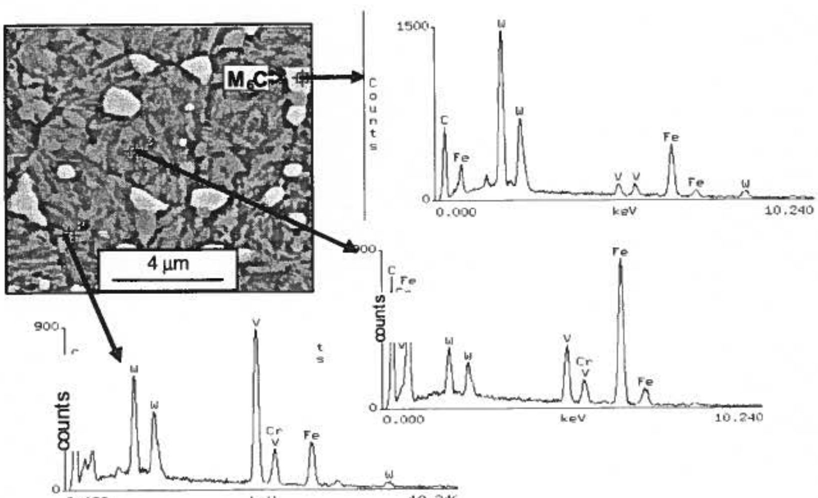

Fig. 10. SEM microstructure of sintered and infiltrated M3/2 material and point analysis of elements

3. Conclusions

- Infiltration of HSS porous 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 HSS based composites strongly depend on the contents of copper and graphite. Copper additions decrease the hardness of HSS based composites, but increase the TRS of infiltrated composites. Graphite additions increase the hardness of HSS based composites, but decrease the TRS of o.s.i. infiltrated composites.
- One step infiltration results in higher hardness of composites and reduce production costs.

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