Sintered Valve Seat Inserts - Microstructural Characterisation

E. S. Jesus Filho[1], E. R. B. Jesus[1], L. Salgado[1], S. L. Jesus[2], M. A. Colosio[3], J. C. Santos[3]
S. Yoshida[4], C. H. Sartori[4], J. L. Rossi[1]

[1] Instituto de Pesquisas Energéticas e Nucleares - IPEN
Av. Prof. Lineu Prestes, 2242 - Cidade Universitária, CEP 05508-000, São Paulo SP, Brazil
[2] Escola Superior de Agricultura Luiz de Queiroz - ESALQ
[3] General Motors do Brasil - Materials and Fastening Engineering Department
[4] Brasimet Comércio e Indústria - Application Engineering Department
esjfilho@usp.br

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Abstract: This work presents aspects related to new sintered materials for valve seat inserts application. Two types of materials were evaluated. The materials were made via powder metallurgy technique from a basic mixture of high-speed steel (AISI M3/2), iron and carbide powders. The microstructures of these materials before and after heat treatment are presented. Under the heat treatment condition, the activation of the diffusion mechanism among phases was promoted and a better distribution of the Cu phases along the matrix was achieved. The results indicate that the materials under development have a potential for commercial application as valve seat inserts.

Introduction

The valve seat inserts used for intake and exhaustion of gases in the engines combustion chambers, operate under severe work conditions. An important requirement for the valve-seat assembly is wear resistance, which must exist, at high temperature and in a chemically aggressive environment. This environment is characterised by high mechanical stresses, wear, corrosion, and erosion at high temperatures. Due to their good properties of thermal stability at high temperatures, the high-speed steels have been considered as an alternative material for this application. Others additional and important characteristics are good corrosion resistance (oxidation) and high thermal conductivity [1]. The high-speed steels present good machining after softening by means of annealing heat treatment. Therefore, the use of the powder metallurgy technique (PM) in this segment has growing constantly. The powder metallurgy process allows the production of parts and metallic components at low costs, high alloying flexibility and microstructure control improvement [2,3].

The present project was focused in the obtention of new materials by less complex processes and application of cheaper and less aggressive elements. This is the case of cobalt substitution due its high cost and the replacement of lead by other less toxic and non-pollutant element [4-6]. Another objective of this work was to reduce the sintering temperature and improve machining characteristics [4,7,8]. The decrease of the sintering temperature of the present alloy allowed the use of traditional sintering equipment commonly found in the PM industries that operates continually at 1150 ˚C maximum temperatures. The substitution of the cobalt in the alloy allowed a reduction of the cost still in the feedstock acquisition stage.

Z. Y. Liu et al. [9], comment about the difficulties to obtain the component containing high-speed steel by powder metallurgy techniques. According to them, the control during the sintering stage should be rigorous, under the risk of occur segregations and heterogeneities in the consolidation phase, associated with non uniform sintering and distortions. Besides, the sintering window of the high-speed steels is very narrow, no more than 10 °C for most of them, so, any small oscillation around this window can impair the properties and characteristics of the final product.

Additional heat treatments should only be used when is necessary to modify the properties of any material and not only to correct its microstructure. Additional process stages tend to increase the costs of the final product, reducing its competitiveness.

Experimental

Material

The materials were produced starting from a mixture of powders. The compacts were sintered at 1150 °C for 45 minutes in a hydrogen atmosphere. The chemical composition (nominal) of the powders mixture used is presented in Table 1.

Table 1. Chemical composition (nominal) of the powders mixture (mass %).

Material	Fe	AISI M 3/2	C	Cu (infiltration)	NbC	MnS
Alloy 1	44.0	44.0	0.45	9.3	1.8	0.45
Alloy 2	43.5	43.5	0.74	10.0	1.8	0.45

Heat treatment

The heat treatment process was performed in a vacuum furnace. The cycle consisted to austenitization at 1150 ºC by 20 minutes followed by quickly cooling with nitrogen at 6 bar pressure. The tempering was made in two stages at 180 ºC by two (2) hours each stage. In spite of the literature [10] that recommends a strip austenitization temperature among 1170-1240 °C for high-speed steel series M, it was decided, in this work, to use 1150 °C equal to the sintering temperature. Besides, its well known that some manufacturers of high-speed steels use temperatures below 1170 °C, as in the case of IMI - Industrial Metal India [11], that works in the range of 1140-1180 °C, and of Böhler-Uddeholm Specialty Metals [12], 1050-1180 °C.

Results and discussion

Table 2 presents the mechanical and physical properties of the obtained inserts materials, in the condition as sintered.

Table 2. Mechanical and physical properties of the inserts as sintered.

Material	Specific mass (g/cm^3)	Hardness (HRC)	Radial transversal strength (MPa)
Alloy 1	7.33	37.0 ± 2.5	1268 ± 83
Alloy 2	7.29	29.0 ± 6.0	816 ± 130

After sintering, it was detected an undesirable high standard deviation for alloy 2 hardness, and hardness and radial transversal strength variation between the two obtained alloys. Thus, characterizing the presence of microestructural heterogeneities. Based on this observation, it was determined to do a cycle of heat treatment in the obtained materials, to try correct or minimize these heterogeneities and to improve the hardness profile. Therefore, quenching and tempering was required in order to make the parts somewhat tougher and to revert some retained austenite. In this the case, it may result in uneven hardness. For valve seat inserts it is not desirable to have retained austenite since it can transform to martensite in the engine. This can lead to size changes and the possible drop out of the seat into the cylinder.

After the heat treatment process, the mechanical properties were measured and are presented in Table 3.

Table 3. Mechanical and physical properties of the inserts after heat treatment.

Material	Hardness (HRC)	Radial transverse strength (MPa)
Alloy 1	41.0 ± 3.0	869 ± 64
Alloy 2	36,0 ± 3.0	708 ± 109

The chosen heat treatment was effective in improvement the hardness profile, or at least keep the same standard deviation, for both alloys. However, for alloy 1 it has induced a decrease in the radial transverse strength. The analysis of the images obtained by scanning electron microscopy (SEM) of the samples of the alloys 1 and 2 in the as sintered and after heat treatment Fig. 1 to 4, did not show a very significant microestructural change when compared with the same alloys in the as sintered condition. However, the heat-treated alloys tended to present a better distribution of the Fe phases along the microstructure. It is possible to notice more evident indications of the Fe diffusion for the high-speed steel islands (light contrast) characterized by the light grey tones around of the darkest grey (Fe).

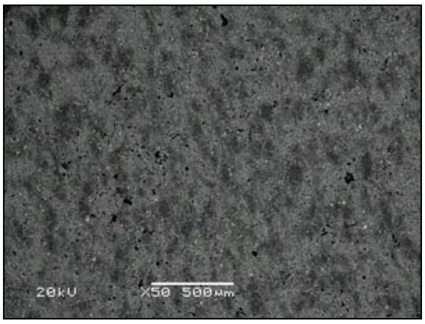


Figure 1 – SEM micrography of alloy 1 in the as sintered condition.

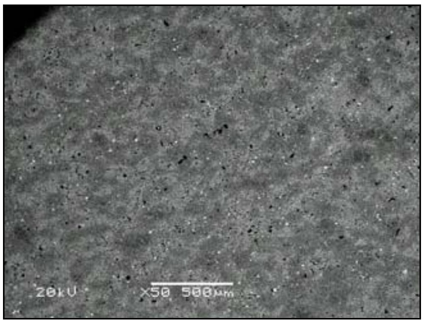


Figure 2 – SEM micrography of alloy 1 in the as sintered and heat treated condition.

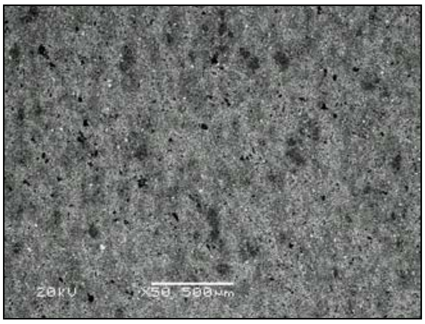


Figure 3 – SEM micrography of alloy 2 in the as sintered condition.

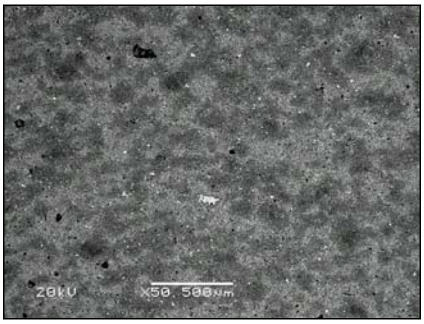


Figure 4 – SEM micrography of alloy 2 in the as sintered and heat treated condition.

It is possible to notice that the hardness increase lightly and the radial strength decrease in both cases when compared with the material in the as sintered condition. This is due to the presence of the martensitic phase in the microstructure of these materials that promotes the hardening but make the materials brittle.

The attempt to correct or minimize the heterogeneities observed in the materials in the as sintered condition was not successful, because is still possible to notice high standard deviations in the hardness values even after heat treatment.

The Fig. 5 and 6 show more clearly the contrast differences, evidencing the diffusion mechanism previously commented. The microestructural analyses for EDS in the heat-treated alloy 1 (Fig. 7, points a, b and c), characterise better the phenomenon, showing the evolution of the diffusion mechanism that starts of the darkest area (point b) containing larger amounts of Fe, and it advances to point c (high-speed steel islands). In the transition region between the two areas, it was found the point a, that presents a decrease in the Fe content, and a increase of other elements amounts as Cr and Cu. On the same micrographs it is still possible to verify a better accommodation and distribution of the Cu phases after heat treatment. In Fig. 5, a great concentration of the element Cu is verified mainly in the proximities of the phase rich in Fe; after heat treatment (Fig. 6), it is noticed a better distribution of the Cu phase, along the microstructure of the material.

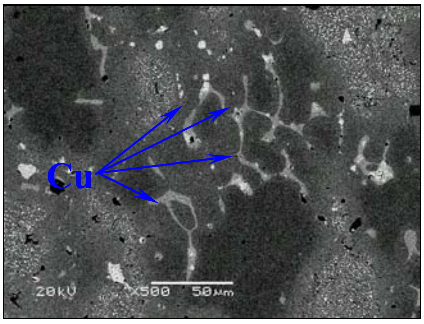


Figure 5 – SEM micrography of alloy 1 in the as sintered condition.

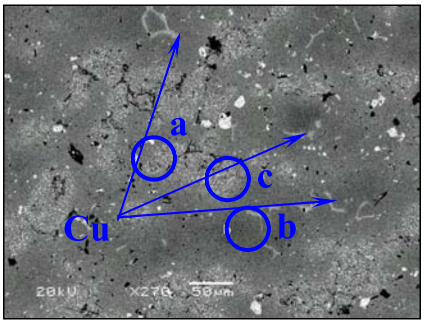
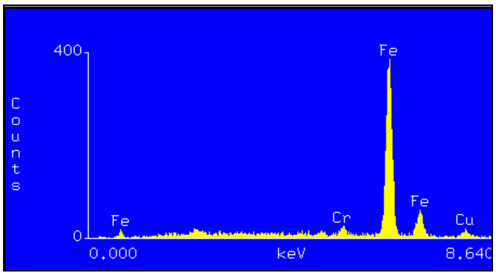
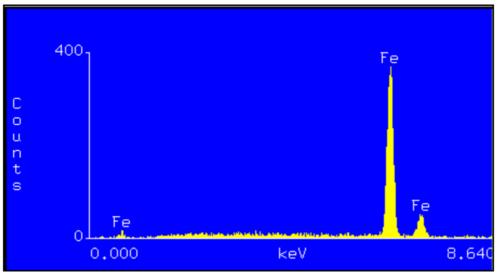


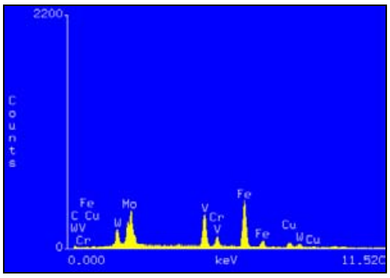
Figure 6 – SEM micrography of alloy 1 in the as sintered and heat treated condition.



(a)



(b)



(c)

Figure 7– Spectra obtained by EDS of the areas a, b and c, of Fig. 6.

Similar behaviour as previously related for alloy 1, wads also verified for alloy 2 (Fig. 8 and 9). It is possible to verify that the better Cu phase distribution occurred after the heat treatment. Before the heat treatment (see Fig. 8) the Cu phases were observed in Fe matrix in a more concentrated manner.

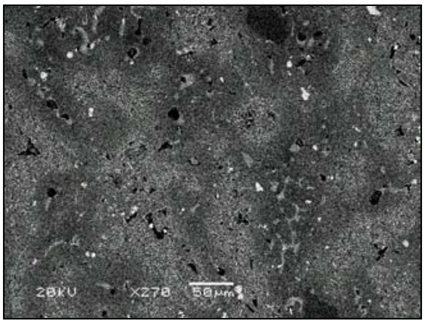


Figure 8 – SEM micrography of alloy 2 in the as sintered condition.

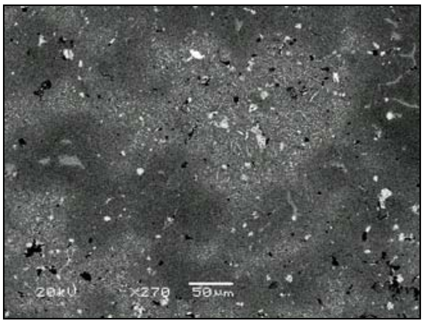


Figure 9 – SEM micrography of alloy 2 in the as sintered and heat treated condition.

A general characterisation by EDS of alloys 1 and 2 after sintering and heat-treating, allowed the identification, besides the Cu phases previously illustrated (Fig. 5, 6, 8 and 9), of the main elements added in the alloys, in a simple form or combined. Fig. 10 shows the microstructure of alloy 2 heat-treated, served as illustrative microstructure example, for alloys 1 and 2 before and after the heat treatment.

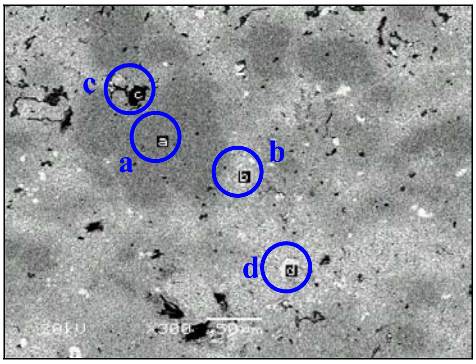
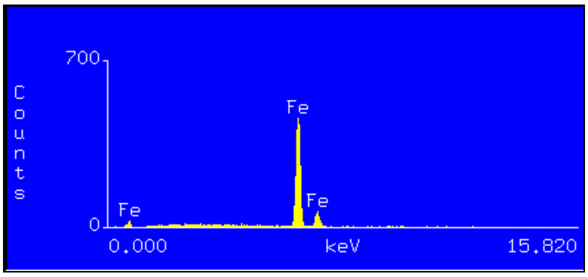
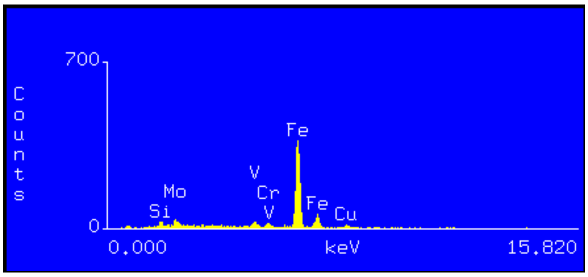


Figure 10– SEM micrography of alloy 2 in the as heat-treated condition.

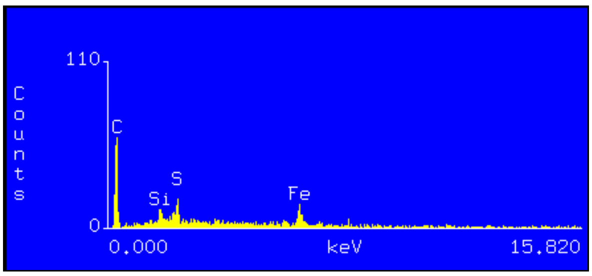
The EDS spectra (Fig. 11), shows the presence of typical high-speed steel alloy elements (see point b). In the points a and d, Fe and Nb were detected respectively, while in the point c, was detected the presence of C, Fe and S; this late was arising probably from the MnS, once the presence of S in the high-speed steel is considered as a by-product.

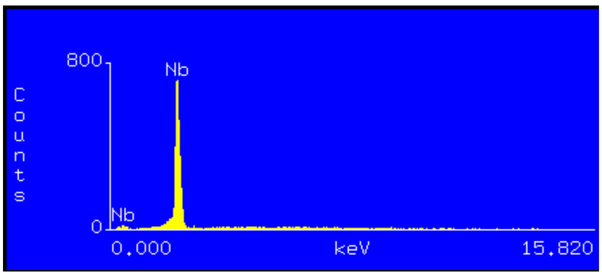


(a)



(b)





(c) (d)

Figure 11 – Spectra obtained by EDS, of the areas a, b, c and d, of Fig. 10.

In general the micrographs indicate that the thermal treatment aided in a better Cu phase distribution as well as in the diffusion mechanism of the Fe to the high-speed steel islands, where the microstructures were completely consolidated in a sintering operation.

Conclusions

Care should be taken in the sintering stage of the components with high-speed steel phases, to avoid defects as non-uniform sintered regions.

In general the heat treatment promoted the activation of the diffusion mechanism among phases and a better distribution of the Cu phases along the matrix.

In spite of the heterogeneities detected in the materials that can be minimized during sintering stage, the results indicate that the materials under development have a potential commercial application as valve seat inserts.

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References

[1] K. Myers. Materials World, December (1999) 755-6.
[2] The PM structural parts industry - past growth and future prospects, Metal Powder Report, December (1999), p. 14-2.
[3] D Whittaker. The International. Journal of Powder Metallurgy, 34 (1998) 53-62.
[4] L Salgado, F Ambrozio Filho, J L Rossi, R M Leal Neto, C R Herrmann Filho, M A Colosio. Journal of Materials and Manufacturing, USA, 110 (2002) 261-4.
[5] M Sakai. SAE International Paper Series n. 2000-01-0395 (2000) 1-5.
[6] F M Johnson. Mutation Research, 410 (1988) 123-410.
[7] E S Jesus Filho, L Salgado, S L Jesus, J L Rossi, M A Colosio, J C Santos. Materials Science Forum, in print (2005) 1-6.
[8] E S Jesus Filho, L Salgado, S L Jesus, J L Rossi, M A Colosio, J C Santos. SAE International Paper Series n. 2005-01-0717 (2005) 1-5.
[9] Z Y Liu, N H Loh, K A Khor, S B Tor. Materials Letters, 45 (2000) 32-8.
[10] R Wilson. Metallurgy and Heat Treatment of Tool Steels, Mc Graw-Hill, 1st Edi. (1975) 173.
[11] Industrial Metal (India) - IM 3 CL2 - http://business.vsnl.com/industrialmetal/hss.html. Assessed 20/09/2005.
[12] BÖHLER-UDDEHOLM Specialty Metals, - VANADIS 23 - super clean high performance powder metallurgical cold work tool steel™ - http://www.busmi.com/pdfs/data_sheet_van23.pdf. Assessed 20/09/2005.