COMPARATIVE STUDY OF TOUGHNESS AND WEAR RESISTANCE OF HIGH SPEED STEELS PM SINTER 23 AND CONVENTIONAL AISI M2

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Abstract. High speed steels (HSS) produced by powder metallurgy (PM) techniques present several advantages over conventionally produced ones. PM route allows the achievement of more isotropic materials with finer microstructures and more homogeneous carbide distribution, increasing the mechanical properties and notably the toughness. The objective of this study is to investigate the correlation of microstructure with toughness and wear resistance of PM SINTER 23 and AISI M2 HSS. The steels were hardened using austenitizing temperatures of 1190 and 1180ºC, respectively for PM SINTER 23 and AISI M2. Tempering was performed at two different temperatures, 570/600ºC for PM SINTER 23; and 550/580ºC for AISI M2. Microstructural characterization of all samples was performed using light optical microscopy (LOM) and scanning electron microscopy with X-ray microanalysis (SEM/EDS). Toughness was evaluated using the bend test method developed for hard tool materials. The wear tests were carried out in a pin-on-disc wear-test machine. Results show that both the austenite grain sizes and the carbide morphology are finer in the PM steel. The conventional AISI M2 has coarse carbide bands. Carbide distribution is much more homogeneous in PM SINTER 23, which contributes to better mechanical properties. PM SINTER 23 is tougher than conventional AISI M2. Bend fracture strength results are closely related to the microstructure of materials, as PM material has a more homogeneous and finer distribution of primary carbides. The wear results show that for a given hardness level SINTER 23 presents greater wear resistance.

Keywords*: high speed steels, toughness, wear resistance, microstructure.*

1. Introduction

Powder metallurgy (PM) has played an important role in the development of high speed steels (HSS). HSS produced by this route present several advantages over conventionally produced ones (Roberts and Cary, 1998). The microstructure of conventional HSS is characterized by the presence of coarse carbide arrangements. Hot-working results in finer and largely spaced carbide particles, arranged in bands or cells parallel to the working direction. This microstructure presents anisotropic properties, which may result in tool distortion after heat treatment (Roberts and Cary, 1998; Pinedo and Barbosa, 1994).

The manufacturing process of HSS by PM techniques usually involves the production of atomized powders, which are subsequently placed in vacuum-sealed mild steel cans and cold isostatically pressed to improve heat conductivity. The encapsulated powders are pre-heated and hot-isostatically pressed (HIP). After HIP process, the material is hot-worked in order to close and heal remaining porosities, break sulphide clusters formed during the heating process and improve mechanical properties (Hellman, 1992).

As a result of the high cooling rates involved in the powder atomization process, PM HSS present a microstructure consisting of finer primary carbides, smaller grains sizes and absent of carbide bands. After heat treating, PM HSS present higher toughness and hardness and more isotropic properties in comparison with conventionally produced ones (Pinedo and Barbosa, 1994; Kumar *et al.*, 1991a; Kumar *et al.*, 1991b). This combination of properties allows the safer heat treating of tools and leads to better performances in service (Pinedo and Barbosa, 1994; Hellman, 1992).

In the present work we have investigated the correlation of microstructure with toughness and wear resistance of PM SINTER 23 and conventional AISI M2 high speed steels. The microstructures of steels were characterized using light optical microscopy (LOM) and scanning electron microscopy with X-ray microanalysis (SEM/EDS). Toughness was evaluated using the bend test method developed for hard tool materials. The wear resistance was studied by the pin-on-disc technique.

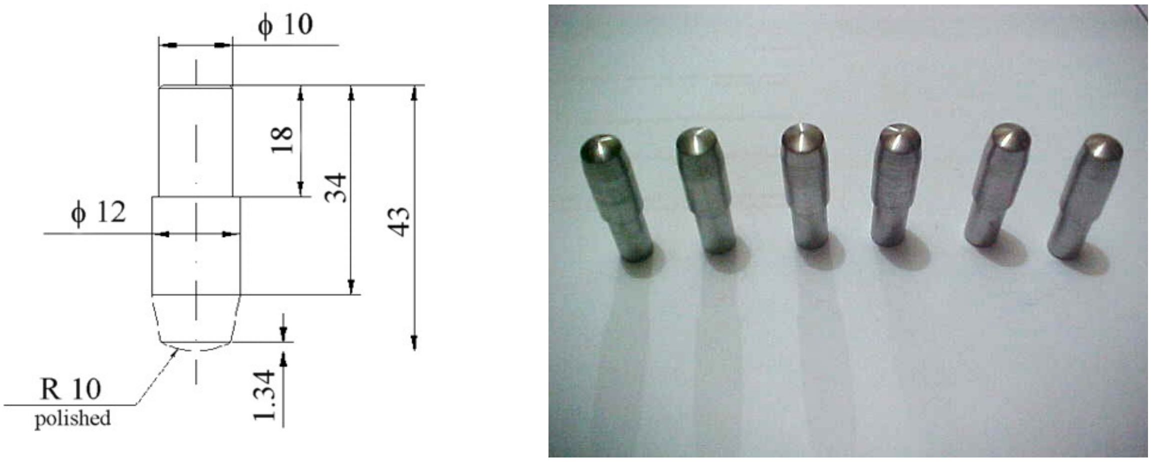
2. Experimental procedure

The nominal chemical compositions of PM SINTER 23 and conventional AISI M2 are presented in Tab. 1. SINTER 23 is similar to AISI grade M3:2, UNST11323.

Table 1. Nominal chemical compositions of PM SINTER 23 and AISI M2 (in wt %).

Material	Fe	C	Mn	Si	Cr	Ni	Mo	W	V
SINTER 23	bal.	1.28	-	-	4.2	0.3	5.0	6.3	3.1
AISI M2	bal.	0.78-0.88	0.15-0.40	0.20-0.45	3.75-4.50	0.3	4.50-5.50	5.50-6.75	1.75-2.20

The starting materials were supplied by Villares Metals S.A., in bars of approximately 76 mm in diameter. Specimens for bend and wear tests were machined from the bars and subsequently heat-treated. The specimens of AISI M2 were cut from the central region of the bars, due to the greater microstructural homogeneity in these regions. Rectangular specimens with dimensions of 70mm x 7mm x 5mm were used in bend tests. The pin specimens used in the wear tests are shown in Fig. 1.



(a) (b)

Figure 1. Dimensions of pin specimens used in wear tests.

The specimens were heat-treated in order to obtain two different standard hardness levels for each material, as follows: a) 60-62 HRC and 62-64 HRC for AISI M2; b) 62-64 HRC and 64-66 HRC for SINTER 23. The heat treatment of AISI M2 consisted in heating to 1180°C (austenitizing temperature), followed by triple tempering treatments during 2 h at 580 and 550°C, respectively for 60-62 HRC and 62-64 HRC levels. SINTER 23 was heated to 1190°C and tempered at 600°C (62-64 HRC) and 570°C (64-66 HRC), also during 2 h. Table 2 summarizes the heat treatment conditions used in this work.

Table 2. Heat treatment conditions of M2 and SINTER 23 HSS steels.

Material	Heat treatment temperature (°C)		Standard hardness (HRC)
	Austenitizing	Tempering (2 h)	
AISI M2	1180	580	60-62
		550	62-64
PM SINTER 23	1190	600	62-64
		570	64-66

Samples for metallographic examination were cut from the as-received bars and heat-treated specimens. They were ground and polished using conventional techniques. Microstructural characterization was performed using light optical (LOM), scanning electron microscopy with X-ray microanalysis (SEM/EDS) and Rockwell C hardness tests.

Toughness was studied using the bend test method, where bend rupture strength may be directly related to toughness. Bend tests were performed in the transverse direction. Wear tests were performed in a pin-on-disc wear-test machine, according to ASTM G99-95. The disc specimens were manufactured in SAE 1020 carbon steel with 62 mm in diameter and surface finished by polishing with 1µm diamond paste. The wear tests were carried out by the application of a 30 N load through the pin to the disc spinning at a friction speed of 0.6 m/s. Load was applied during 1 min for all

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samples. The wear in pins was measured by the accumulated mass loss after the tests. At least three specimens of each material and condition were tested in order to verify de reproducibility of the results.

3. Results and discussion

The microstructures of AISI M2 and PM SINTER 23 are shown in Fig. 2. Coarse primary carbides can be observed in the microstructure of M2 steel in the as-received condition (Fig. 2a). Coarse carbides arranged in bands or stringers are often observed in HSS produced by conventional casting (Roberts and Cary, 1998; Kumar *et al.*, 1991a). These bands are parallel to the working direction. In contrast, PM HSS like SINTER 23 presents a refined microstructure with fine and uniformly dispersed carbide particles (Fig. 2b). In this case, the spherical morphology is predominant. Note the absence of carbide bands in the microstructure of SINTER 23.

X-ray microanalysis results show that primary carbides are mainly of M_6C (Mo and W-rich) and MC (V-rich) types, in both materials. SINTER 23 presented a higher fraction of MC type (V-rich) carbides. This finding can be explained by the higher V and C contents of SINTER 23, as depicted in Tab. 1.

Figures 2c and 2d show the microstructures of heat-treated specimens. It is noticeable the presence of carbide bands (working direction) in the M2 steel even after heat treatment (Fig. 2c). Figure 2d shows the presence of a higher volume fraction of particles in SINTER 23, in comparison with the as-received condition (Fig. 2b). This is due to secondary carbide precipitation during heat treatments.

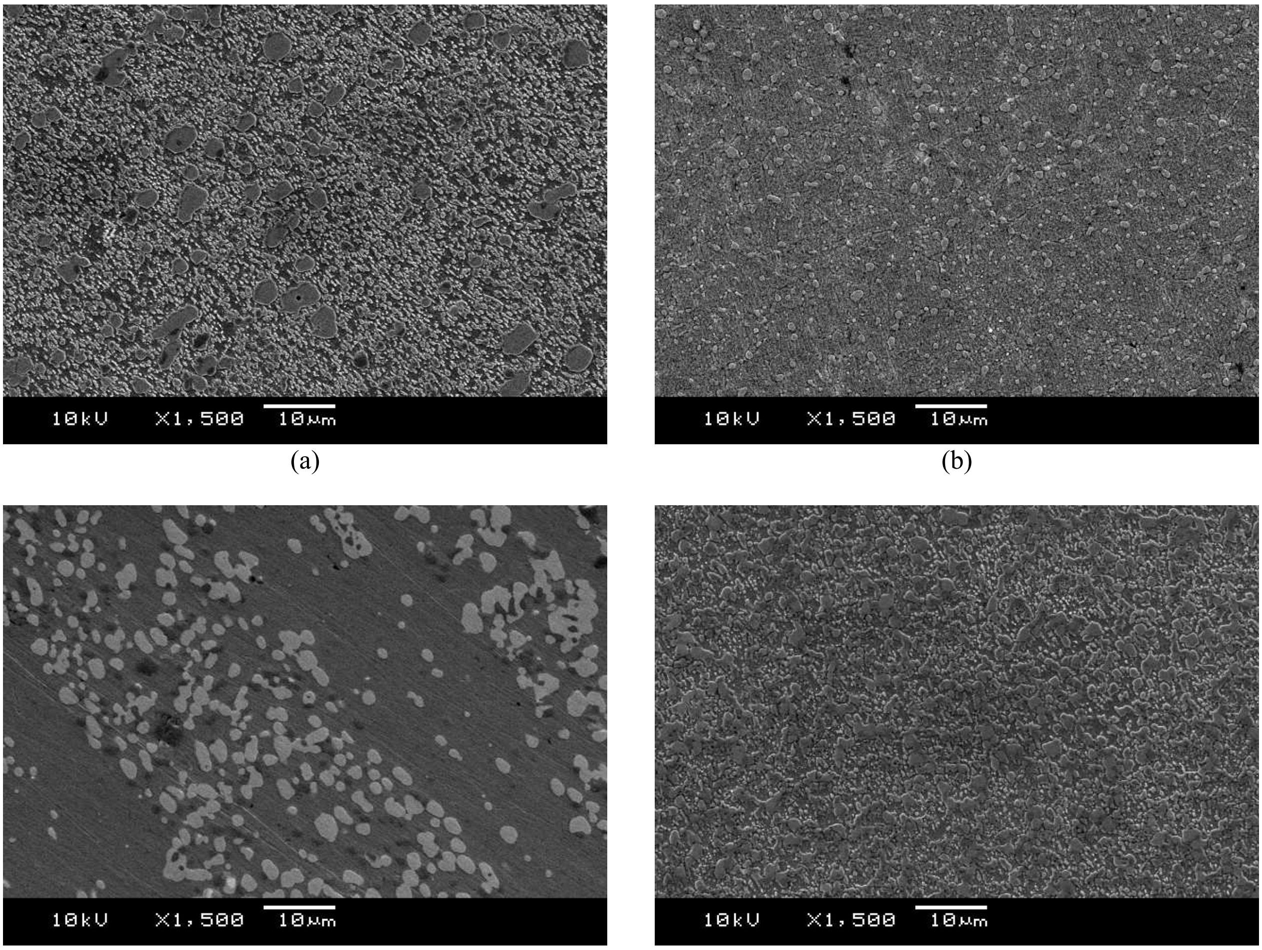

Figure 2: Microstructures of AISI M2 and PM SINTER 23 steels in the longitudinal direction: a) M2 as-received condition (SEM-SE); b) SINTER 23 as-received condition (SEM-SE); c) M2 after hardening at 1180^{o}C and tempering at 580^{o}C (SEM-BSE); d) SINTER 23 after hardening at 1190^{o}C and tempering at 600^{o}C (SEM-SE).

The PM process creates a refined carbide structure when compared with conventionally produced HSS. During the powder atomization process the small droplets solidify rapidly, which gives a fine and uniform distribution of carbides in the microstructure. This fine microstructure can be maintained after the hot isostatic pressing and hot working operations, resulting in a segregation-free, uniform and isotropic microstructure (Hellman, 1992; Kasak and Dulis, 1978 Takigawa *et al.*, 1981).

Figure 3 shows the bend fracture strength for M2 and SINTER 23 in the transverse direction. Considering the bend strength average values, SINTER 23 is tougher than M2. As expected, bend strength of M2 decreases with increasing hardness. It is worth mentioning that for the same hardness level (63HRC), the superior toughness of SINTER 23 becomes evident. HSS exhibits high toughness and fracture resistance due to the special characteristics of its microstructure. Toughness, in particular, is basically dependent on matrix fracture toughness and carbides morphology and distribution. According to Yanaba and Hayashi (1999), cracking of carbides leads to formation of subcritical cracks, which grow with increasing of applied strain. Failure occurs when the crack size exceeds a critical length. The improved toughness of SINTER 23 results directly from its refined and more homogeneous microstructure.

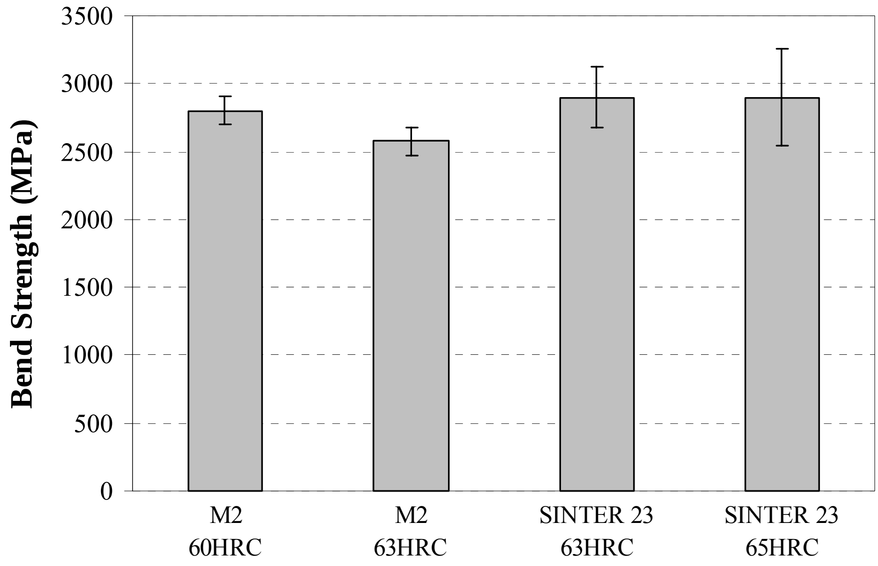

Figure 3. Bend fracture strength of M2 and SINTER 23 steels. Error bars indicate standard deviation.

Figure 4 shows the pin wear results for M2 and SINTER 23 specimens. The M2 steel shows similar wear for the two hardness levels studied, considering the standard deviations. The same is not valid for SINTER 23, which presents a significant improvement in the wear resistance with increasing hardness. It is worth noting, however, that for a similar hardness value (63HRC), SINTER 23 presented greater wear resistance than M2, in average 38% higher. The large amount of MC type carbides could be the main cause of this behavior (Roberts and Cary, 1998; Kumar *et al.*, 1991a; Horton and Child, 1983).

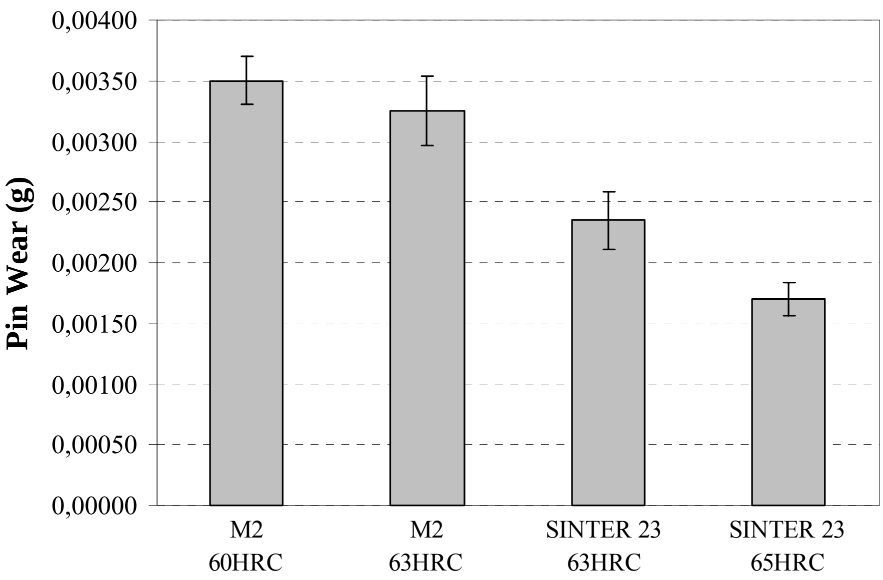

Figure 4. Pin wear for M2 and SINTER 23 HSS steels. Error bars indicate standard deviation.

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4. Conclusions

Based on the results presented in this paper, the following main conclusions are drawn:

a) Conventional AISI M2 in the as-received condition displays a microstructure consisting of coarse primary carbides, arranged in bands parallel to the working direction. PM SINTER 23 has a finer and homogeneous microstructure with fine and uniformly dispersed carbide particles. Carbide bands remain in the microstructure of M2 steel after heat treatment.

b) The refined and homogeneous microstructure improves the mechanical properties of SINTER 23 after heat treatment, which presented higher toughness and greater wear resistance in comparison with M2 steel. The large amount of MC type carbides could be the major responsible for the enhanced wear resistance of SINTER 23.

5. References

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