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 55 2010 Issue 3

R. BIDULSKÝ**, M. ACTIS GRANDE*, A. ZAGO*, Z. BRYTAN*, J. BIDULSKÁ**

WEAR RESISTANCE OF VARIOUS TYPE SINTERED STEELS

ODPORNOŚĆ NA ZUŻYCIE ŚCIERNE WYBRANYCH GATUNKÓW STALI SPIEKANEJ

In this work, the influences of the processing conditions (applied load, cooling rate) on the wear resistance of sintered steels were presented. The wear behaviour of various sintered steels, including Astaloy LH, Astaloy CrL, Distaloy AE, PASC60, 316 L and 430 L were carried out by a pin-on-disk test. The effect of chemical composition and different applied loads in vacuum furnace related to a wear resistance (mass loss versus sliding distance) was investigated. The results showed that the microstructure constituents along with relevant hardness values represent an important parameter affecting the wear behaviour of sintered steels and the sinter hardening is suitable heat treatment for improving the wear resistance of sintered steels.
Keywords: Prealloyed sintered steel, Stainless steel, Sinter hardening, Sliding wear, Microstructure

W pracy przedstawiono wpływ parametrów wytwarzania (ciśnienia prasowania, szybkości chłodzenia) na zużycie ścierne stali spiekanych. Mechanizm zużycia ściernego różnych typów stali określono przy użyciu testu pin-on-disk. Zbadano wpływ składu chemicznego oraz ciśnienia prasowania podczas spiekania w próżni na odporność na zużycie ścierne (ubytek masy w funkcji drogi tarcia). Wyniki badań wykazały, że składniki strukturalne wraz z ich charakterystyczną twardością stanowią ważny czynnik wpływający na mechanizm zużycia ściernego, a zastosowanie obróbki cieplnej typu ”sinter hardening” jest właściwe dla polepszenia odporności na użycie ścierne stali spiekanych.

1. Introduction

The materials base in vehicle consist of: iron and cast iron (62%), non-ferrous metals (Al, Mg) and their alloys (8%), plastic (10%), rubber (4.5%), glass (3%), textile and isolation (4%), liquid and others material (7%). Demands for automotive industry force producers of metallic materials (steels, non-ferrous metals and their alloys and materials based on powder metallurgy – PM) to find new forms and facilities for appropriate properties of automotive parts [1, 2].

Controlling forming processes are an ineffective achieving of grain size (most important structural factor) under 1 μm; from point of view are exhausted opportunities to obtain favourable effects in properties area of produced parts [3-6].

Powder metallurgy (PM) is a well-established processing route for production near-net-shape components of complex geometry. The most important requirement of a successful production of sintered parts is a high and consistent quality of the powder from which the parts are to be made. The characteristics of the powder decide about its compacting and sintering behaviour and the properties of the finished product.

Another widely used PM manufacturing method for sintered steels is powder consolidation by uniaxial cold compaction and sintering of green compacts.

The powder consolidation process is still extensively used for the production of ferrous parts, especially for the automotive industry. Automotive industry, from whole production of PM parts, is produce in Europe 80%, in North America 70%, in Japan over than 80%. The powder consolidation process is still extensively used for the production of ferrous parts, especially for the automotive industry. Automotive industry, from whole production of PM parts, is produce in Europe 80%, in North America 70%, in Japan over than 80%. According to using of individual parts, especially in motors (40%) and gears (30%). According to [7] the typical vehicle produced in Europe and Japan is approximately 8 kg, on the other hand in the North America is about 18 kg. It is highly loaded application with require-

* POLITECNICO DI TORINO-ALESSANDRIA CAMPUS, VIALE T. MICHEL 5, 15100 ALESSANDRIA, ITALY
** TECHNICAL UNIVERSITY OF KOŠICE, FACULTY OF METALLURGY, LETNÁ 9, 042 00 SLOVAKIA

ments on their strength – plastic – degradation characteristics.

The key role for automotive produces is knowledge about the knowledge of material performance in dry conditions to understand their behaviour in severe tribological conditions. In addition dry sliding tests provide information on the material ability to face surface plastic deformations, being responsible for all forms of wear concerned of sintered parts. The present investigation focused on the frequently powders using in industrial practice and especially only wear characteristics. Certainly, the other phenomena such as corrosion resistance, mechanical properties, fatigue and fracture characteristics are not included in this investigation. Three iron base alloys (Astaloy LH, Astaloy CrL and Distaloy AE), and PASC60, which represent such as components requiring good soft magnetic properties. Moreover, stainless steels are suited in automotive exhaust components to increase automotive performance and also wear resisting components such as valve parts. Automotive usage of all stainless steel products represented about 23 kg per vehicle according to [8] and it is assumed that a growth of 37% in 10 years [9, 10]. The requirement for low price and possible dimensional tolerances are an aim of solution to consider demands of the automotive designers, but high performance and comfort also represent strong market needs as underline Tengzelius [11]. Austenitic stainless steel of 316 L grade exhibit superior corrosion resistance and significantly lower machinability compared to ferritic stainless steels of 430 L grade.

Sinter hardening treatment is a progressive method which to combine sintering and heat treatment in one single step process. When sinter hardening at elevated temperature is realized in vacuum type furnace, than very useful to prevent problems related to decarburization and oil (before tempering is necessary to remove it from the open porosity), as well as an inert atmosphere used in sintering process enables to eliminate problem with adequate dew point which it is demand for producing sintered steels including chromium.

The main aim of paper is shown the influence of sinter hardening along with different applied load on the wear resistance of sintered steels by a pin-on-disk test under vacuum in inert atmosphere in correlation to the microstructural characteristics of the investigated specimens.

2. Materials and experimental methods

Powder mixes used for research are summarised in the following Table 1.

TABLE 1

Processing conditions and chemical composition of investigated materials

System	Chemical composition	Sintering
A	Astaloy LH + 0.65% C	1120°C/60 min (vacuum, SH*) + tempering 200°C/60min
B	Astaloy CrL + 0.65% C	1120°C/60 min (vacuum, SH*) + tempering 200°C/60min
C	Distaloy AE + 0.5% C	1120°C/60 min (vacuum, SH*) + tempering 200°C/60min
D	316L	1250°C/60 min (vacuum)
E	43	1250°C/60 min (vacuum)
F	PASC 60	1120°C/60 min (vacuum, SH*) + tempering 200°C/60min

Mixes (added with Acrawax as lubricant) were homogenized using a laboratory Turbula mixer for 20 minutes. Specimens' disc-shaped moulds (with diameter of 40 mm) were obtained using a 2 MN hydraulic press, applying a pressure of 650 MPa. Sintering was carried out in the TAV vacuum furnace with argon back filling at 1120°C and 1250°C for 60 minutes with an integrated final tempering at 200°C for 1 hour for specimens sintered at 1120°C. The measured cooling rate was 8°C/s. Specimens were dewaxed before sintering in a batch furnace type nabertherm MINIJET-HP S/N 235. Densities were evaluated using the water displacement method. Pin-on-disc wear test was carried out by means of a tribometer entirely developed in the Alessandria Campus of Politecnico di Torino. The disc was made of the investigated material. As a counter face, a WC-Co pin was used, having a rounded shape on top with ϕ 3mm. The counter-pin was changed after the end of each test, in order to preserve the roundness of its top. All wear tests were performed in air and without any lubricant. According to that the pin-on-disk it is generally used for low normal pressures and small sliding velocities [12], the applied loads were 5, 10 and 25 N. The rotation speed of the disc was 140 rpm. The distances of the pin position from the disc centre were 34 mm. During experiments, the friction coefficient was continuously recorded.

The tested surface was polished with abrasive papers in order to determine a medium surface roughness equal (or less) to 0.8 μm, as specified in the ASTM G99-95a. Each test was interrupted after 300, 600, 900, 1200 and 2000 meters sliding distance and discs were weighed, using a precision scales with a sensitivity of 10-5 to determine the evolution of wear loss during each test. Microstructures observations were carried out using light and SE microscopy (LEICA and LEO with EDS microprobe). Polished samples were etched using Nital and Vilella (stainless steels). The apparent Rockwell hardness HRB (measured on the tested specimen surfaces) was determined by means of digital tester EMCOTEST according to the standards ASTM E 18 for Rockwell hardness.

3. Results and discussion

3.1. Microstructure

The microstructures of investigated sintered alloys based on powder mixtures are complex and heterogeneous.

The microstructures of iron base (Astaloy LH, Astaloy CrL and Distaloy AE) sintered specimens were depends on diffusivity on elements such as Ni, Mo, Cr, due to rapid cooling conditions (sinter hardening), dominant amounts of martensite was investigated, **Figs. 1-3**.

The microstructure of the A and B alloys based on the prealloyed type powders consists of a dominant martensite microstructure with 90% and 85% areas, **Figs. 1-2**. The microstructure of the C system basically consists of a mixture of predominantly

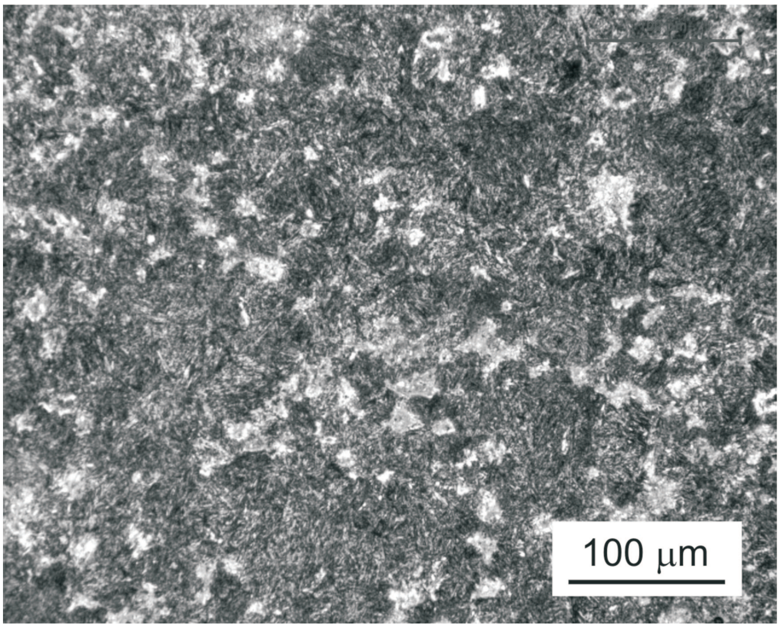

Fig. 1. The typical microstructure of the A steel

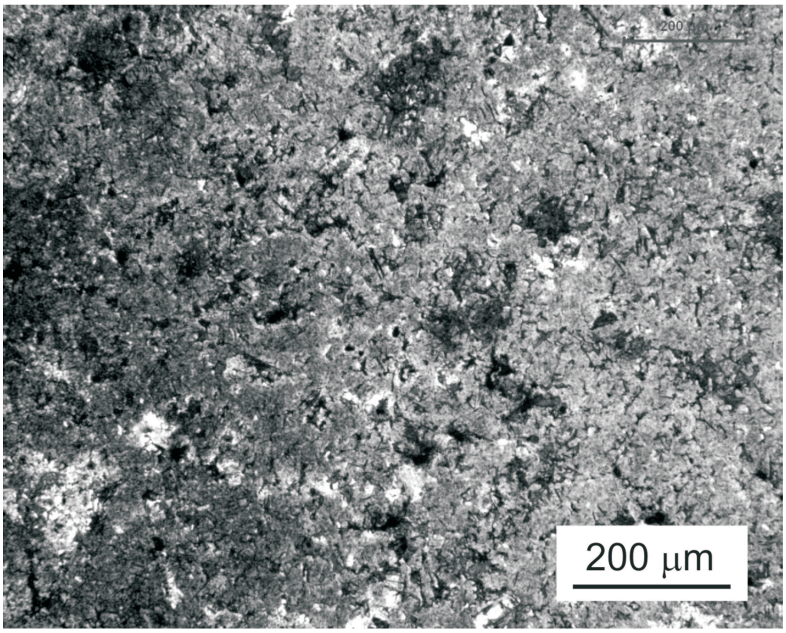

Fig. 2. The typical microstructure of the B steel

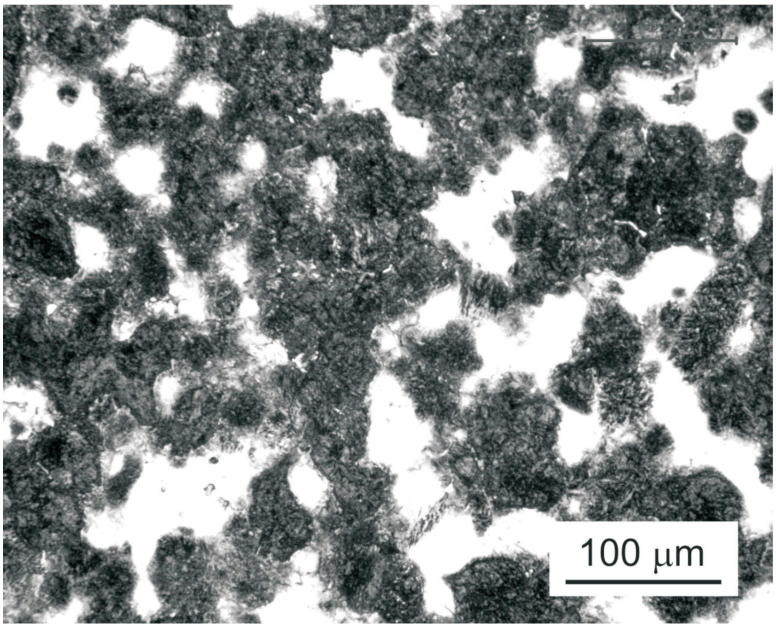

Fig. 3. The typical microstructure of the C steel

martensite areas with 70% and carbide mixtures of pearlite/bainite with 30% areas, **Fig.3**. The highest percentage amount of martensite for system A on the base of Astaloy LH is not striking. A new lean hardening grade is most suited for sinter hardening applications. On the other system, also B (on the base of Astaloy CrL powder) is widely used for sinter hardening treatment [13], when Astaloy CrL system is doped by Cu, the results is very promising, mainly in requirements of wear properties [14-16]. The microstructures of stainless steels systems D and E consist of austenitic and ferritic microstructure, respectively (**Fig. 4 and 5**).

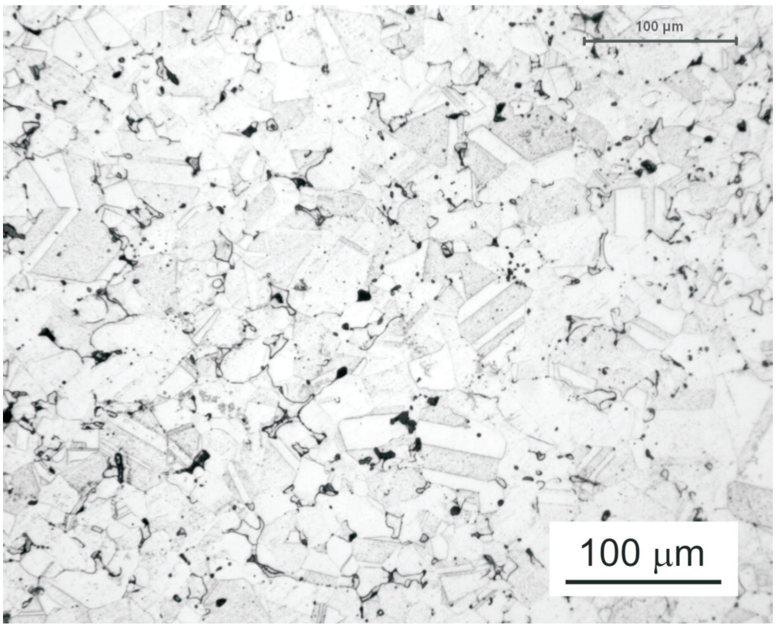

Fig. 4. The typical microstructure of the D steel

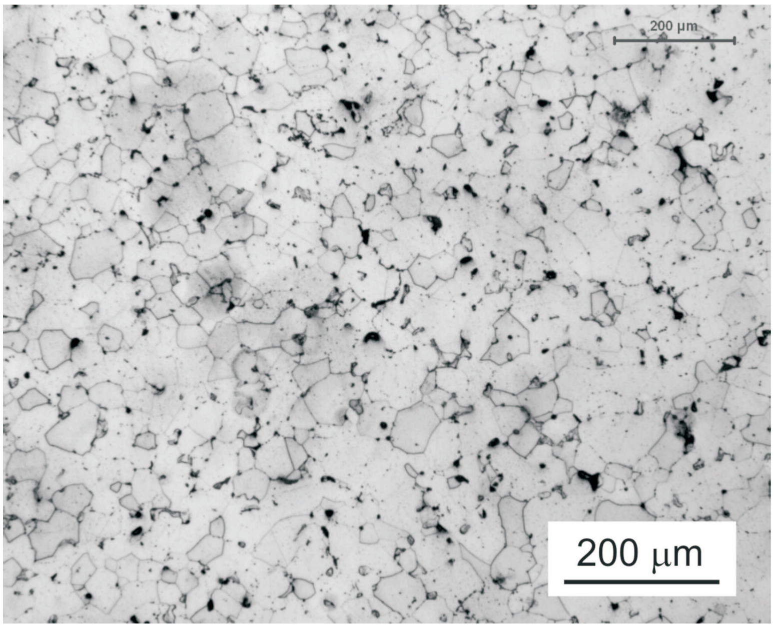

Fig. 5. The typical microstructure of the E steel

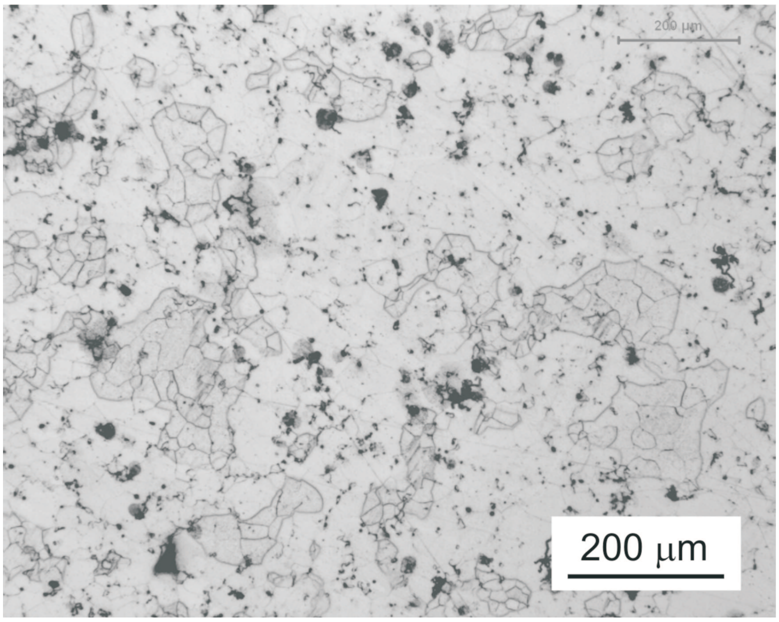

Fig. 6. The typical microstructure of the F steel

The presence of liqid phase, in sintering of system F, promotes homogeneously distributed (transport of both phosphorous and iron atoms in the liquid phase is faster than in solid phase) of phosphorous in the Fe matrix. The ferritic microstructured was revealed, **Fig. 6**.

3.2. Friction coefficient

Typical variation of coefficient of friction measured during the dry sliding tests conducted at the varied applied normal load is shown in **Fig. 7** (only for 5N). **Fig. 7** shows the initial friction coefficient at the beginning of the test varies between 0.1 and 0.25 for all the materials investigated. Within a short period, the coefficient of friction steeply raises to about 0.6-0.85 depending upon the composition of pin and applied normal load. Next sliding shows reducing of the coefficient of friction and reaches to steady state. The steady state stage were observed after 700 m of sliding aproximately, but the distance is more or less the same for the investigated sintered steels without stainless steel grades, where steady state stage were revealed after 400 m without a reduction zone observening at iron steel grades. According to higher values of the friction coeffient for applied normal force of 5 N for stainless steels grade, higher applied force do not applied for stainless steels grade. This results is not suprisingly, due to poor wear resistance of austenitic stainless steels, their use may result in material transfer between sliding bodies, mechanical mixing and oxidation [17, 18].

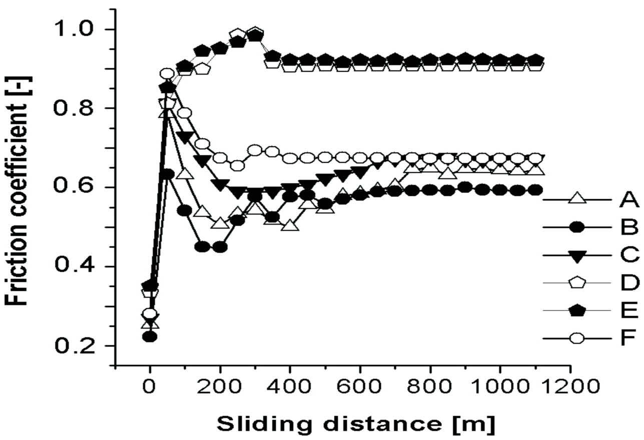

Fig. 7. The variation of friction coefficient measured during the dry sliding tests conducted at the applied normal load of 5 N

It is clear, the friction coefficients of investigated sintered steels in steady state stage continually raises with applied normal load. The friction coefficients were ranging between 0.6-0.9 at steady state stage.

The present results of friction coefficent (**Table 2**) is coresponded with previous investigations of sintered steels, reported in [19]. The friction coefficient of sintered steels ranges from 0.7 to 0.9 under untreated condition [19]. The friction coefficient raises with increasing applied load.

TABLE 2

The range of friction coefficients of investigated steels at the varied applied normal load of 5, 10 and 25 N

Load [N] / Friction coef. [-]	A	B	C	D	E	F
5	0.6471	0.5932	0.6703	0.9083	0.9219	0.6732
10	0.6502	0.6387	0.6781	–	–	0.6844
25	0.6531	0.6531	0.7219	–	–	0.6916

3.3. Wear characteristics

Material removal is expressed as loss of length, area, volume or mass and is termed as the amount of wear and wear rate relates to the path or duration of load [20].

Fig. 8 shows the mass loss obtained for all tested conditions in a steady state wear. It may be seen that the mass loss increase with increase in applied load.

The wear rate was calculated using the following equation:

$$W_s = \frac{\Delta m}{\rho \cdot L \cdot F_N} \tag{1}$$

where

Ws – the wear rate (mm^3/N·m),

Δm – the mass loss of test samples during wear test (g),

ρ – the density of test materials (g/cm^3),
L – total sliding distance (m) and
FN – the normal force on the pin (N).

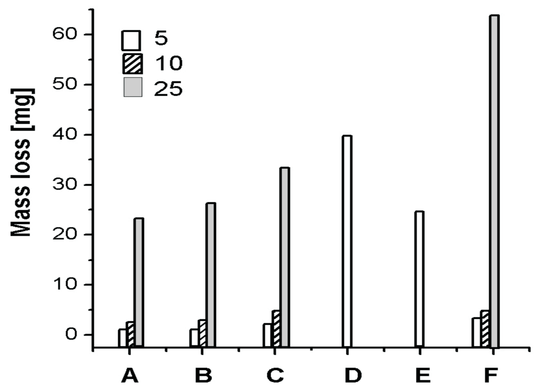

Fig. 8. The mass loss in a steady state wear

Fig. 9 and **Fig. 10** shows the wear rate obtained for all tested conditions.

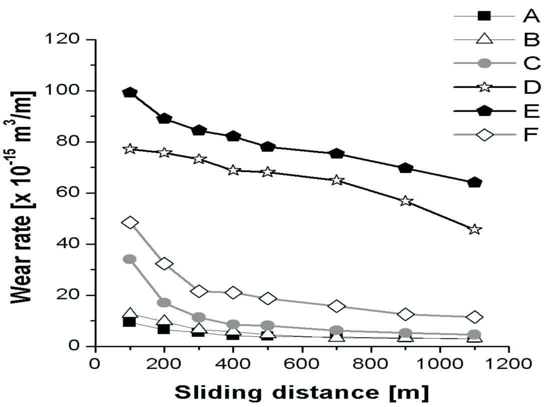

Fig. 9. The wear rate at the applied normal load of 5 N

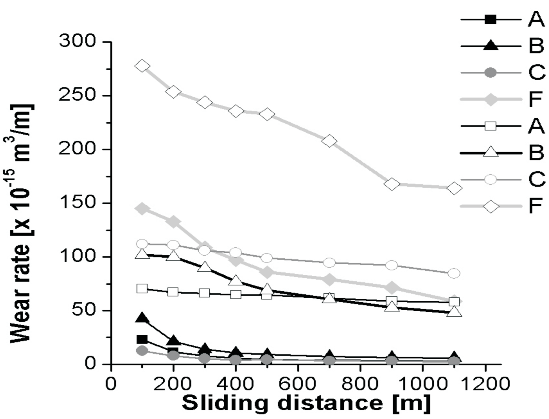

Fig. 10. The wear rate at the applied normal load of 5 N and 10 N

In general, the wear rate decreased initially and remained almost constant with the increase in sliding distance. The wear rate was found to increase with increase in applied load, as is clearly presented in Fig. 10. The wear rate of the specimens decreased in the order: D, E, F, C, B and A. It is interesting that microstructured characteristics are follow: D system has austenitic microstructure with 40 HRB, E system has ferritic microstructure with 55 HRB, F system has ferritic (homogeneously distributed P) microstructure with 65 HRB, C system has 70% martensite and 30% carbide mixtures of pearlite/bainite with 98 HRB, B system has 85% martensite and 15% bainite with 102 HRB, A system has 90% martensite and 10% bainite with 105 HRB. It is very clear from these observations that microstructures and hardness of the material had a significant influence on the wear behaviour in the investigated PM material.

The present work focused on the frequently powders using in automotive industrial practice. Considering that in the present time the requirement for low price is over striking by financial crisis and along with high performance in terms of wear resisting, PM components represents possible solution. Sinter hardening treatment, as a one single step process, enables to eliminate problem with adequate dew point, shorten processing time, elimination of oil quenching as well as provides adequate mechanical properties along with wear resistance.

4. Conclusion

1. Wear rate increases with increasing the hardness of specimens along with type of microstructure. Specimen which exhibits austenitic or ferritic structure shows less specific wear resistance than specimens containing martensite and mixture of martensite and bainite.

2. Presented results show that microstructure constituents along with relevant hardness values represent an important parameter affecting the wear behaviour of sintered steels.

3. Sinter hardening offers an alternative method to through hardening powder metal components in protective vacuum atmosphere enables to attain promising results and also is very useful economical method to manufacture structural parts for application in components like gears, piston and connecting rods, where is it necessary to determine wear resistance.

Acknowledgements

R. Bidulská thanks the Bilateral Project SK-PL-0011-09. Technical assistance of Enrico James Pallavicini and Elena Piccardo are gratefully acknowledged.

Received: 10 February 2010.

REFERENCES

[1] T. Kvačkaj, Acta Metallurgica Slovaca, **8**, 2, 100-108 (2002).
[2] C. H. Caceres, Metallurgical and Materials Transactions A, **38**, 7, 1649-1662 (2007).
[3] J. Bidulská, T. Kvačkaj, R. Bidulský, M. Actis Grande, High Temperature Materials and Processes **27**, 3, 203-207 (2008).
[4] T. Kvačkaj, I. Pokorný, Metalurgija **41**, 1, 37-42 (2002).
[5] J. Kusnierz, M.H. Mathon, J. Dutkiewicz, T. Baudin, Z. Jasienski, R. Penelle, Archives of Metallurgy and Materials **50**, 2, 367-377 (2005).
[6] T. Kvačkaj, L. Sokolová, M. Vlado, V. Vrchovinský, High Temperature Materials and Processes **24**, 2, 139-144 (2005).
[7] D.L. Schaefer, C.J. Trombino, In: Advances in Powder Metallurgy & Particulate Materials, Metal Powders Industries Federation, Princeton, NJ **1**, 11-17 (2003).
[8] http://www.ametekmetals.com/metal-powder/ automotive.cfm_1.12.2008.
[9] I. Cremer, In: Proceedings EURO PM 2007, plenary presentation, Toulouse, EPMA, Shewsbury, 1-28 (2007).
[10] A. Danielson, In: Proceedings EURO PM 2007, plenary presentation, Toulouse, EPMA, Shewsbury, 1-11 (2007).
[11] J. Tengzelius, Metal Powder Report **62**, 5, 20-21 (2007).
[12] S. Philippon, G. Sutter, A. Molinari, Wear **257**, 7-8, 777-784 (2004).
[13] M. Sulowski, K. Faryj, Archives of Metallurgy and Materials **54**, 1 121-127 (2009).
[14] R. Bidulský, M. Actis Grande, High Temperature Materials and Processes **27**, 4, 249-256 (2008).
[15] R. Bidulský, M. Actis Grande, J. Bidulská, M. Vlado, T. Kvačkaj, High Temperature Materials and Processes **28**, 3, 175-180 (2009).
[16] R. Bidulský, M. Actis Grande, J. Bidulská, T. Kvačkaj, Materiali in Tehnologije **43**, 6, 303-307 (2009).
[17] Z. Yang, M. G. S. Naylor, D. A. Rigney, Wear **105**, 1, 73-86 (1985).
[18] G.D. Straffelini, A. Trabucco, A. Molinari, Metallurgical and Materials Transactions A **33**, 3, 613-624 (2002).
[19] N. Candela, R. Plaza, M. Rosso, F. Velasco, J.M. Torralba, Journal of Materials Processing Technology **119**, 1-3, 7-13 (2001).
[20] K.V. Sudhakar, P. Sampathkumaran, E.S. Dwarakadasa, Wear **242**, 1-2, 207-212 (2000).