EFFECT OF NEW TYPE HEAT TREATMENT ON WEAR CHARACTERISTICS OF HIGH-STRENGTH SINTERED STEELS

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Abstract
The main aim of the paper is to study the influence of new type heat treatment - sinter hardening - on the wear characteristics of high-strength sintered steels. The wear behaviour of the chromium pre-alloyed sintered steels was investigated through pin-on-disk tests. Two different processing conditions have been used, involving different cooling rates from the sintering temperatures of 1180 °C, the first of which, identified as slow, implied a cooling rate of 0.05 °C/s. The later cooling rate obtained applying a process called sinter hardening determined an average cooling of 6 °C/s. The role of the different chemical compositions has also been evaluated. The microscopic investigations reveal deformed layers and tracks along the direction of sliding during wear. Particular attention has also been paid to the friction coefficient and to the role of porosity on wear. The results showed that the microstructure characteristics represent an important parameter affecting the wear behaviour of sintered steels and sinter hardening is a suitable heat treatment for improving the wear resistance of sintered steels.

Keywords: high-strength steel, heat treatment, sinter hardening, sliding wear.

1 Introduction

Porous ferrous alloys, obtained via powder metallurgy (PM), are currently used in the production of structural parts, such as gears, cams and automotive valve seat applications, which undergo sliding, rolling or abrasive wear loading in service.

To achieve the production of sintered parts with high-performance applications it is therefore necessary to apply a further optimization of the processing conditions or some new approaches are necessary [1-5], as well as mathematical and computer simulation [6, 7].

Secondary operations are successfully used in the PM processing to achieve the desired wear and fatigue resistance as well improved material properties (strength and hardness) [8-11]. Coating, heat treating and steam treating are among the secondary operations that are successfully applied in the fabrication of finished PM parts. Sinter hardening in vacuum furnaces has been shown to be an alternative to more traditional processing, offering cost savings and better part properties [12-15]. The tempering operations, which can be carried out within the same sintering cycle, allow reducing internal stresses that influence mechanical properties as well as crack initiation and propagation.

This work is focused on the role of the different sintering processes on the wear mechanisms of Fe (Cr - Mo) - C sintered steels and on the understanding of the wear mechanisms.

2 Material and experimental methods

Powder mixtures were homogenised in a Turbula mixer using Astaloy CrL powder, graphite powder and commercial AW wax powder as lubricant.

Specimens with a green density of ~7.0 g/cm^3 were obtained using a 2000 kN hydraulic press, in a disc-shaped mould (ϕ 40 mm) applying a pressure of 600 MPa. Sintering was carried out in the TAV vacuum furnace with argon back filling at 1180 °C. Two different cooling rates have been used: the first of which, identified as slow, implied a cooling rate of 0.05 °C/s; the later cooling rate obtained applying a process called sinter hardening determined an average cooling of 6 °C/s. Densities were evaluated using the water displacement method. The processing conditions are recorded in **Table 1**.

Table 1 The chemical composition and type of uses powder for studied alloys

Type of used powder	Composition [wt. %]
AstaloyCrL, graphite	Fe-1.5Cr-0.2Mo-0.65C
AstaloyCrL, electrolic Cu, graphite	Fe-1.5Cr-0.2 Mo-0.65C-1Cu
AstaloyCrL, electrolic Cu, graphite	Fe-1.5Cr-0.2 Mo-0.65C-2Cu

Wear test was carried out by means of pin-on-disc procedure. 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 3 mm. 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. The applied loads were 25 N. The distances of the pin position from the disc centre were 34 mm. 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 during each test.

The wear characterization of the chromium pre-alloyed sintered steels containing copper were carried out by means of optical microscopy, also determining the volume mass and the interconnected (open) porosity, wear tracks features observations were carried out using SEM JEOL 7000F.

Mass losses were expressed as material removal during the test and were recorded as function of the sliding distance. The wear of sintered materials is more complicated than that of wrought steels and depends on some factors related to the sintered microstructures such as plasticity and strength of the different phases, as well as porosity. Hence, the evaluation of the wear resistance (as the reciprocal value of the amount of wear) is better expressed in terms of wear rate. The wear rate has been calculated using the following equation:

$$W_s = \frac{\Delta m}{\rho \cdot L \cdot F_N} \qquad (1)$$

where:

W_s is the wear rate [mm^3/Nm],

Δm is the mass loss of test samples during wear test [g],

ρ is the density of test materials [g/cm^3],

L is total sliding distance [m],
F_N is the normal force on the pin [N].

3 Results and discussion

Table 2 reports the steady-state value of friction coefficient and shows how the porosity content influences the steady-state value of friction coefficient in investigated Fe-1.5Cr-0.2Mo-0.65C steel.

Table 2 The density, porosity and friction coefficient values of investigated Fe-1.5Cr-0.2Mo-0.65C steel

Processing conditions Temperature / cooling rate	**Pressing density**	**Sintering density**	**Total porosity**	**Friction coefficient**
[°C / °C·s^{-1}]	[g/cm^3]	[g/cm^3]	[%]	[%]
1180 / 0.05	6.987	7.002	8.64	0.7397
1180 / 6	6.983	6.973	9.01	0.7200

The results show that the steady-state value of friction coefficient decreases with the increasing amount of porosity. Using traditional PM methods, cold die pressing and following sintering operations usually attain porosity value of 8-10% are obtained in dependence with the sintered steel characteristics such as alloying additions and microstructure constituents. The friction properties are strongly dependent with the sintered steel characteristics.
Fig. 1 shows the wear rates of investigated steels.

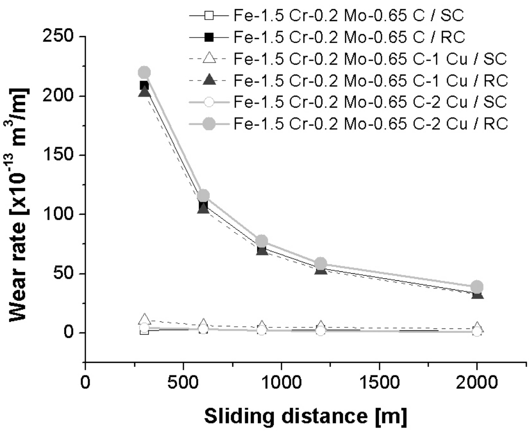

Fig.1 Wear rates of studied sintered steels at 1180 °C using both cooling rates

The lowest wear rate values were recorded for the specimens sintered at slow cooled condition than rapid cooled. Wear resistance of chromium pre-alloyed sintered steels using higher cooling rate (sinter hardening) was improved due to the shifting of ferrite - bainite (**Fig. 2a**) to dominant martensitic microstructure with some areas of bainite (**Fig. 2b**).
Useful information on the wear mechanisms of the sintered steels were obtained by SEM analyses of the worn surfaces. The worn surfaces were characterized by the presence of fine grooves parallel to the sliding direction and flake-like fragments (**Fig. 3a**), typical of delamination wear, observed in the wear debris. As well as mild oxidation wear, in detail microstructure analyses were observed (**Fig. 3b**).

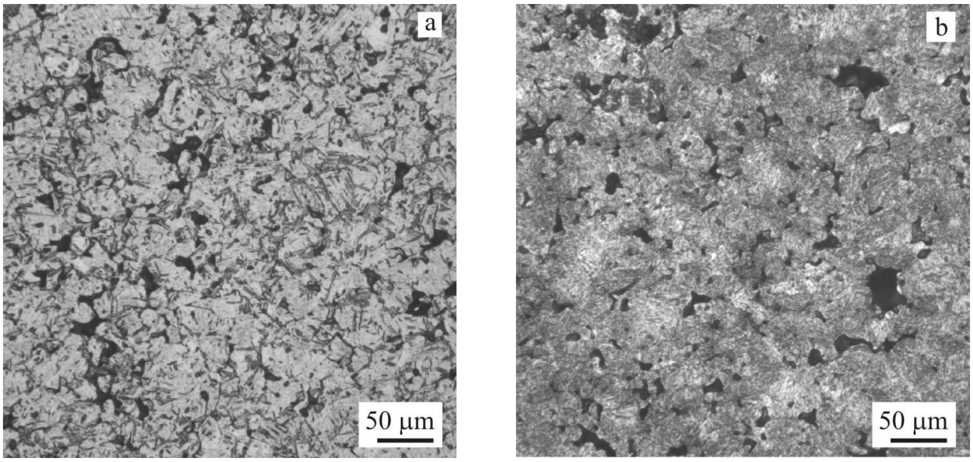

Fig.2 The typical microstructure of studied sintered steels in slow cooling (a) and rapid cooling (b) conditions

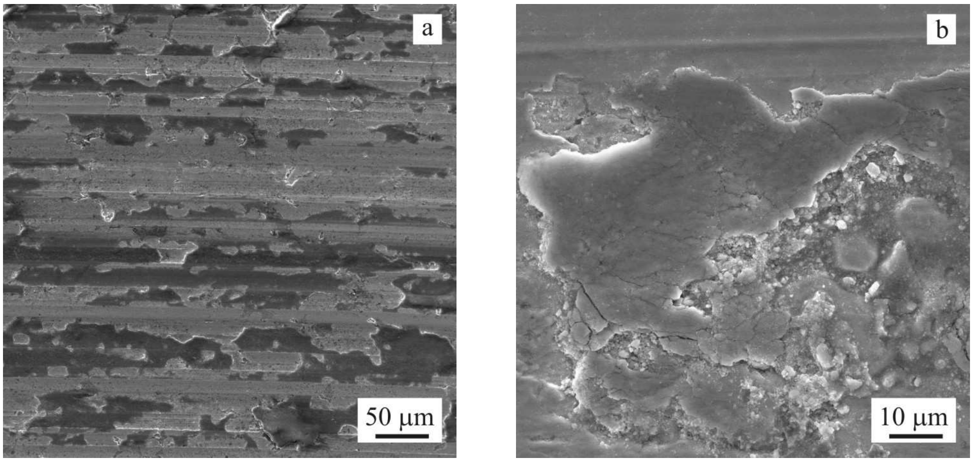

Fig.3 The typical delamination wear of studied sintered steels with fine grooves parallel to the sliding direction and flake-like fragments (a) and with mild oxidation wear (b)

The delamination wear mechanism postulates the consecutive steps [16] of gross plastic deformation of the subsurface along the sliding direction, the subsequent nucleation of voids and cracks (in porous materials, the voids pre-exist in the form of pores; pores act as stress and strain concentrators, then the nucleation of cracks may be rather favoured), the propagation of the cracks nearly parallel to the wear surface and the formation of wear sheets when cracks reach the surface. Therefore, plastic deformation took place on wear surfaces during wear tests. Contact pressure of wear surfaces increased with the increasing amount of porosity [17]. When the pores are filled with debris particles during wear, therefore enhances the wear resistance of the samples by increasing the real contact area and decreasing the contact pressure. The small wear debris can be trapped inside the open pores on the sliding surface, and this may lead to the main difference between the wear rate obtained from the depth loss and from the weight loss. Nevertheless, porosity is to be beneficial for enhancing the wear resistance by entrapping the wear debris and preventing the formation of large abrasive agglomerates.

4 Conclusions

1. Wear resistance of investigate sintered steels using cooling rate were improved due to shifting ferrite - bainite to dominant martensitic microstructure.
2. The results of friction coefficient show that the steady-state value of friction coefficient decreases with the increasing amount of porosity, as well as pores play an important role representing the potential sites of the first microcracks forming and positively influencing the wear process by entrapping the wear debris and preventing the formation of large abrasive agglomerates.
3. The microscopic investigation reveals that delamination and oxidation wear are the main wear mechanisms in wear tests.

Acknowledgements

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