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RESEARCH

Abrasive Wear Resistance of the Iron- and WC-based Hardfaced Coatings Evaluated with Scratch Test Method

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A B S T R A C T

Abrasive wear is one of the most common types of wear, which makes abrasive wear resistance very important in many industries. The hardfacing is considered as useful and economical way to improve the performance of components submitted to severe abrasive wear conditions, with wide range of applicable filler materials. The abrasive wear resistance of the three different hardfaced coatings (two iron-based and one WC-based), which were intended to be used for reparation of the impact plates of the ventilation mill, was investigated and compared. Abrasive wear tests were carried-out by using the scratch tester under the dry conditions. Three normal loads of 10, 50 and 100 N and the constant sliding speed of 4 mm/s were used. Scratch test was chosen as a relatively easy and quick test method. Wear mechanism analysis showed significant influence of the hardfaced coatings structure, which, along with hardness, has determined coatings abrasive wear resistance.

1. INTRODUCTION

More than 50 % of all wear-related failures of industrial equipment are caused by abrasive wear [1]. The estimated costs of abrasive wear are between 1 and 4 % of the gross national product of an industrialized nation [2]. For these reasons, the abrasive wear resistance is a subject of great importance in many industries, such as agriculture, mining, mineral processing etc.

Hardfacing could be defined as "coating deposition process in which a wear resistant, usually harder, material is deposited on the surface of a component by some of the welding techniques". In most cases, hardfacing is used for controlling abrasive and erosive wear, like in mining, crushing and grinding, and agriculture industries (buckets, bucket teeth, mill hammers, ball mills, digging tools, conveyer screws, etc. [3,4]). Hardfacing is also used to control combinations of wear and corrosion, as encountered by mud seals, plows, knives in the food processing industry, pumps handling corrosive liquids, or slurries [5]. The hardfacing is considered as economical way to improve the performance of components submitted to severe wear conditions, with wide range of applicable filler materials [6,7].

The iron-based filler materials have drawn much attention due to their low cost and good resistance to abrasion in the hardfaced condition. However, their use is limited in applications where high impact loading is present, i.e. high-stress or gouging abrasion [8]. For this reason, efforts are being made towards the improvement of their impact and other properties [9]. The progress is achieved mostly by modifying the hardfaced coating's structure. Taking into account their low price and improved properties, the resistance to abrasive wear of the iron-based hardfaced coatings is normally tested against the resistance of proven, but more expensive materials, such as WC-based hardfaced coatings.

Abrasive wear has been defined as "wear by displacement of material from surfaces in relative motion caused by the presence of hard particles either between the surfaces or embedded in one of them, or by the presence of hard protuberances on one or both of the surfaces" [10]. The second part of this definition corresponds to pure two-body abrasion, where tested material slides against harder and rougher counter face material, while the first part corresponds to the three- and two-body abrasion, respectively. Another interesting example of two-body abrasion is the abrasive erosion, which is the special case of erosive wear. Abrasive erosion has been defined as "erosive wear in which the loss of material from a solid surface is due to relative motion of solid particles which are entrained in a fluid, moving nearly parallel to a solid surface" [10]. Scratch test offers a possibility for comparison of different materials relatively easy and in short period of time, with good reproducibility [11]. In single-pass scratch test a stylus (which tip is made of hard material) slide over the test sample producing a single scratch, which seems to be appropriate simulation of the two-body abrasion.

In this study, the abrasive wear resistance of the three different hardfaced coatings (two iron-based and one WC-based) was investigated and compared.

2. EXPERIMENTAL DETAILS

2.1 Materials

The filler materials (coating materials) were manufactured by Castolin Eutectic Co. Ltd, Vienna. Their nominal chemical composition is shown in Table 1. The iron-based filler materials (basic covered electrodes) were deposited by using the shielded metal arc welding (SMAW) process. The WC-based filler material was deposited by oxy-fuel gas welding (OFW) process. The substrate material was the hot-rolled S355J2G3 steel.

Table 1. Coatings composition, process and hardness.

Coating	Nominal chemical composition	Hardfacing process	Hardness HV 5
4541	Fe-Cr-C-Si	SMAW	739
5006	Fe-Cr-C-Si	SMAW	781
7888 T	WC-Ni-Cr-Si-B	OFW	677

All coatings were deposited by hardfacing in a single pass (one layer). The substrate preparation and hardfacing procedures (deposition parameters) are described elsewhere [9,12]. The measurements of near-surface hardness are performed on the cross-section of hardfaced samples by Vickers indenter (HV 5), and presented in (Table 1).

The samples for structure characterization are obtained by cutting the hardfaced materials perpendicular to coatings surface. The obtained cross-sections are ground with SiC abrasive papers down to P1200 and polished with alumina suspensions down to 1 μm. The polished surfaces are analyzed by using the scanning electron microscope (SEM) equipped with energy dispersive system (EDS). The SEM-EDS analysis was performed at University of Belgrade, Faculty of Mining and Geology by using the JEOL JSM–6610LV SEM connected with the INCA350 energy dispersion X-ray analysis unit. The electron acceleration voltage of 20 kV and the tungsten filament were used. Before SEM-EDS analysis was performed, polished surfaces were 20 nm gold coated in a vacuum chamber by use of a sputter coater device.

The Fig. 1a shows the near-surface structure of the 4541 iron-based hardfaced coating. The primary austenite phase occupies more than a half of volume (50.7 vol. %) and the rest is the lamellar eutectic mixture of austenite and Cr-carbides [9].

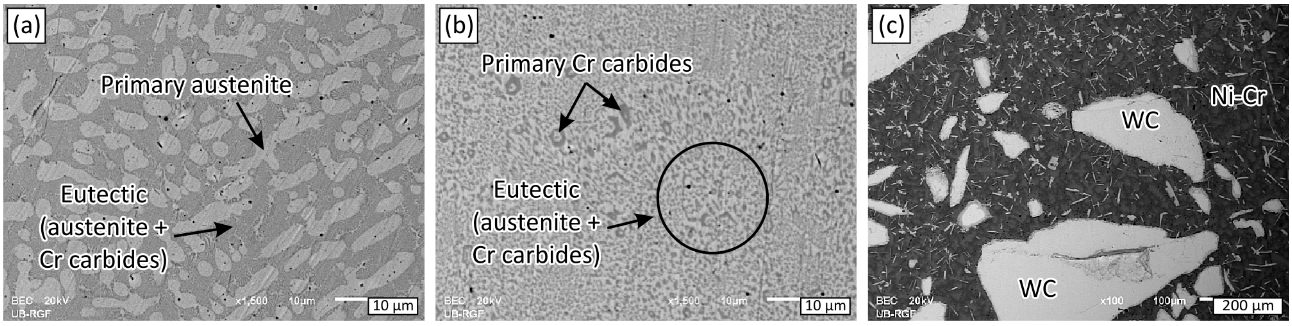

Fig. 1. The structures (SEM) of: (a) 4541, (b) 5006 and (c) 7888 T hardfaced coating; back-scattered electron images.

The 5006 material during solidification achieves near-eutectic structure (Fig. 1b). A small spherical primary Cr-carbides are observed (9.1 vol. %) in the eutectic matrix. Based on electron microprobe analysis (EMPA), both coatings 4541 and 5006 contain $(Cr,Fe)_7C_3$ primary and eutectic carbides. The Figure 1c shows a larger WC grains (60 vol. %), which are embedded in the Ni-Cr based matrix.

2.2 Scratch abrasion testing

Abrasive wear tests are carried out on the scratch tester under the dry conditions, in ambient air at room temperature (≈ 25 °C). A schematic diagram of scratch testing is presented in Figure 2. Stylus (indenter) was pressed with selected normal load (10, 50 and 100 N) against surface of the test sample and moved with constant speed (4 mm/s), producing the scratch of certain width and length (10 mm) on the test sample. Indenter had Rockwell shape and the cone was diamond with radius of 0.2 mm.

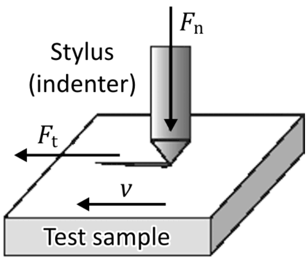

Fig. 2. Schematic diagram of scratch testing.

On surface of each material under investigation at least three scratches are made with a gap between scratches of at least 1 mm. Before and after testing, both the indenter and the test samples are degreased and cleaned with benzene. The wear scar widths on the surface of the test samples are measured from SEM images at the end of testing. The wear scar widths and the known indenter geometry are used to calculate the volume loss. After testing, the morphology of the test samples worn surfaces is examined with SEM.

3. RESULTS AND DISCUSSION

The results of the wear tests are presented in Figures 3, 4 and 5. Taking into account significant differences in structure homogeneity of the hardfaced coatings (Fig. 1), the repeatability of the results, in terms of standard deviations, is satisfactory (within 16 %). Wear rate of the tested materials (volume loss divided by scratch length) increases with normal loading, as expected. The highest wear exhibits coating 7888 T. Nevertheless, wear rates for all coatings are high, even for abrasive wear. The reason for this is primarily due to the experimental conditions.

The test conditions were specific, i.e. the speeds were very low (4 mm/s) and the contact stresses very high. At the end of test, the normal stresses were between 2 and 5 GPa, which depends on the material, i.e. scratch width and applied normal load. With these conditions, a high-stress or even gouging abrasion can be expected. With high-stress abrasion, the worn surface may exhibit varying degrees of scratching with plastic flow of sufficiently ductile phases or fracture of brittle phases. In gouging abrasion, the stresses are higher than those in high-stress abrasion, and they are accompanied by large particles removal from the surface, leaving deep groves and/or pits [8].

The relation between the wear rate and the hardness of tested hardfaced coatings is shown in Figure 6. The first feature is that the abrasive wear rate decreases as the hardness increases, i.e. the hardest material (coating 5006) showed the highest abrasive wear resistance.

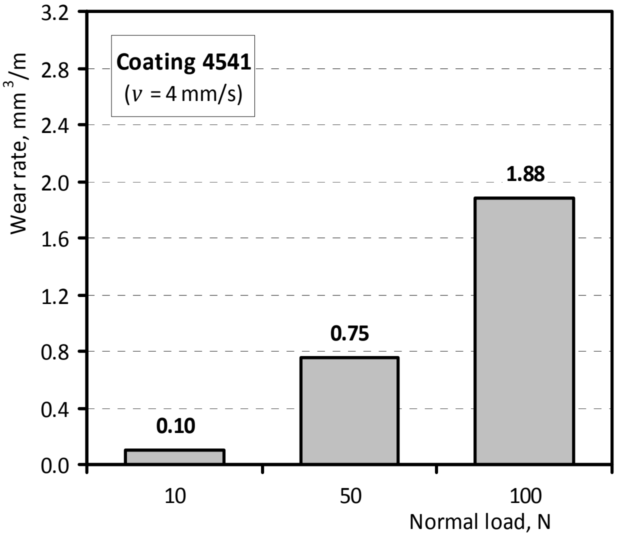

Fig. 3. Wear rates of coating 4541 for different normal loads.

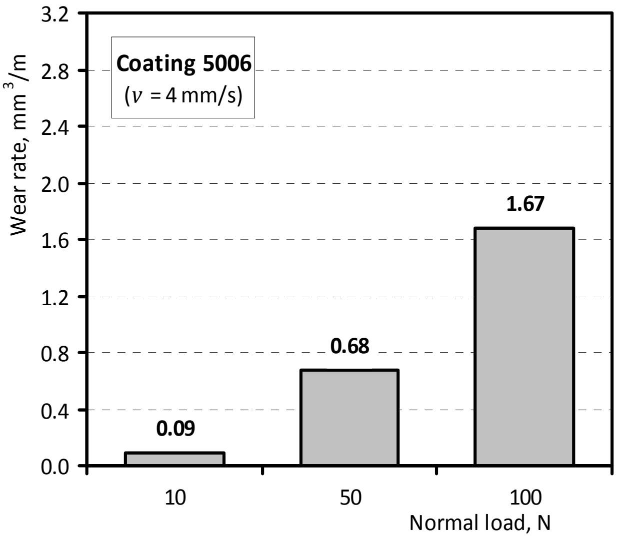

Fig. 4. Wear rates of coating 5006 for different normal loads.

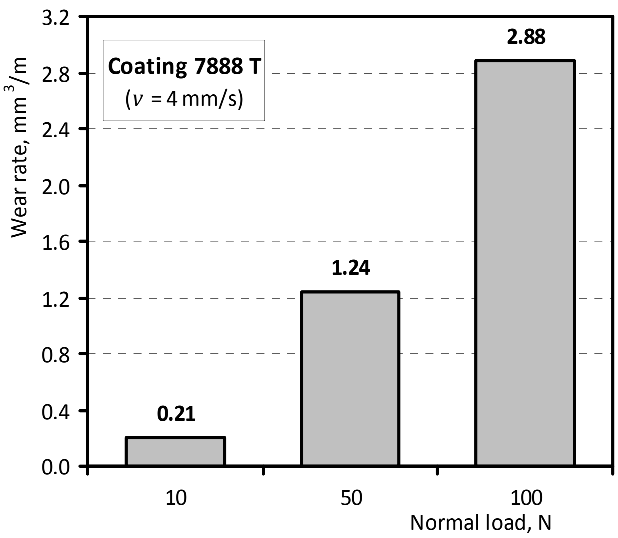

Fig. 5. Wear rates of coating 7888 T for different normal loads.

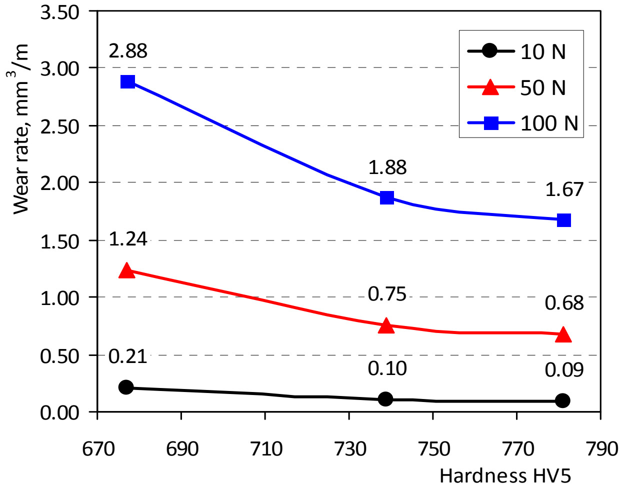

Fig. 6. Wear rate vs. hardness of tested materials for different normal loads.

For all applied loads, the relation between hardness and wear rate is non-linear. It is more curved for higher loads (Fig. 6). This is connected with the coatings structure and exhibited wear mechanism. Coatings 4541 and 5006 exhibit mainly ploughing abrasive wear (Fig. 7a), while coating 7888 T dominant type of abrasive wear is fracture (cracking) abrasive wear (Fig. 7b).

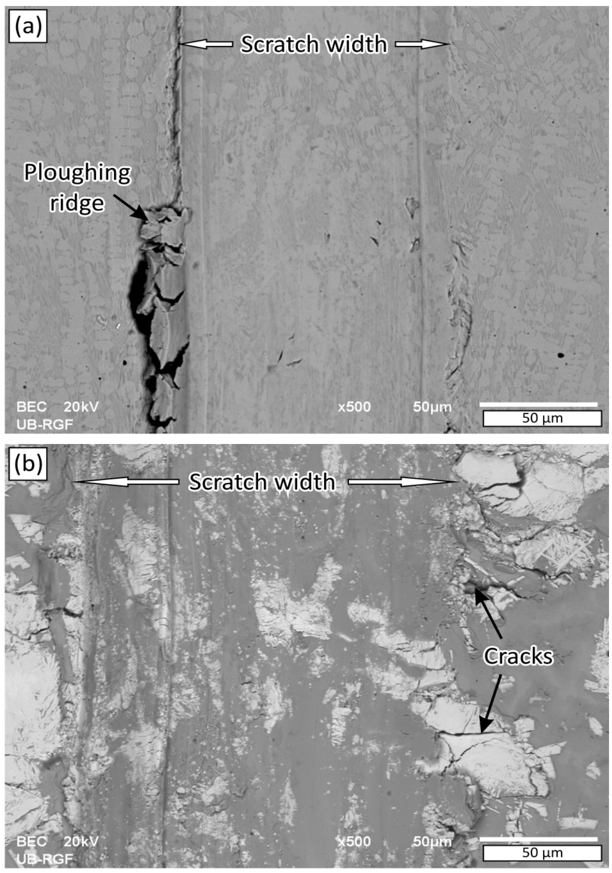

Fig. 7. The wear scar appearance (SEM) of: (a) 4541 and (b) 7888 T hardfaced coating; 50 N normal load; back-scattered electron images.

4. CONCLUSION

Scratch test offers relatively easy and quick comparison of different materials on abrasive wear.

Structure of tested coatings showed influence on the dominant type of abrasive wear, which together with coatings hardness determined coatings abrasive wear resistance.

Coatings with lower hardness showed lower abrasive wear resistance, but the dependence (hardness vs. wear rate) was non-linear.

In the case of iron-based coatings, dominant type of abrasive wear was ploughing and in the case of WC-based coatings, it was fracture (cracking) abrasive wear.

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