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WEAR PERFORMANCE OF DUPLEX TREATED LOW ALLOYED STEEL AGAINST WOOD (BEECH) AS STATIC PARTNER

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ABSTRACT

The sliding tribological behaviour of Cr-(WC-Co) coating against wood (beech) as counterpart was investigated using a duplex treatment of low carbon steel (DIN 18CrMo4). The duplex treatment consists of LPC (low pressure carburising) + R.F magnetron co-sputtering of Cr and WC-Co. Pin on disk configurations in dry condition wear tests were performed. The wear scars of the coatings were evaluated using optical profilometry, scanning electron microscopy (SEM/EDS) and the wear mechanisms were consequently discussed. The aim of this work is to study wear mechanisms on the wood pin/disc couple. It was concluded that best behaviour was observed in the case of higher Cr content coating.

Keywords: duplex treatment, Cr-(WC-Co) coating, wood, wear.

AIMS AND BACKGROUND

Woodworking tools should be hard and need to have low friction coefficient. However, wood cutting tools should not be too hard, because surface of wood must be smooth. In the last decade, some works^{1,2} were conducted to replace HSS (high speed steel), carbides (WC-Co) and other ceramics by coatings like CrN or TiN. Chromium nitride family, used for wood cutting tools, shows a superior performance than family of titanium nitride coatings. Tribological tests were carried out for several specimens prepared from different types of woods, i.e. oak,

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beech, spruce and pine³⁻⁵. Abrasive wear properties of a large variety of coniferous wood and hardwood are reported in Ref. 6. Beech wood (*Fagussylvatica*) has good strength properties, a high abrasion resistance and a density $d=0.73 \text{ g/cm}^3$. It can be cut, planed, drilled and milled easily. Beech is the most abundant broad-leaf tree species in central Europe and the quality of beech round wood is suitable for high quality rotary cut veneer⁵ in manufacture of furniture, floor, various carpentry of the interior. The aims of this study are: (i) to optimise the carburising of the steel substrate and deposition conditions of Cr-(WC-Co) coatings; (ii) to investigate the wear resistance of duplex treated samples against wood (beech) in view to their application on wood cutting tools.

EXPERIMENTAL

Sample elaboration. The substrate used in this work was a commercial low alloy steel DIN 18CrMo4. Before thermo-chemical treatment, the samples were polished with P800 paper, ultrasonically cleaned, and finally introduced into a vacuum furnace 'BMI Furnace'. The carburising gas was ethylene (C_2H_4) and the temperature was 900°C . The total durations of the boost/diffusion stages were 120 min (carburising C1) and 105 min (carburising C2). After the carburising process, samples are in-situ quenched in a high pressure N_2 environment (500 kPa), subsequently annealed at 200°C for 120 min, and finally cooled in a 100 kPa N_2 atmosphere. The Vickers hardness values of C1-treated surface layer is $H_{v.100} = 768 \pm 5$ and the C2-treated samples yield $H_{v.100} = 654 \pm 5$. Additionally, carbon analysis of the surface layer yields 0.667 wt.% and 0.615 wt.% for C1 and C2 treatments, respectively. Both of treated C1 and C2 samples present the same hardness's value at the core of the substrate ($H_{v.100} \sim 300$) and approximately the same depth of carburised layers (550–600 μm). A standard and typical microstructure was developed after carburising process. At the top layers, the microstructure consists of martensite phase and cementite (Fe_3C) with evidently a few quantities of γ retained austenite. After that, Cr(WC-Co) coatings onto carburised surface samples were elaborated as can be seen in Fig. 1.

Deposition of Cr-(WC-Co) coatings was done by RF magnetron sputtering in a modified commercial system (Nordiko

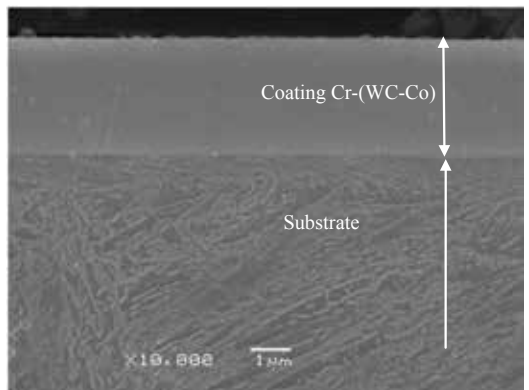


Fig. 1. SEM micrograph: cross-section view of duplex treated samples. The Cr-(WC-Co) layers developed a dense structure

Table 1. Chemical composition and mechanical properties of coatings

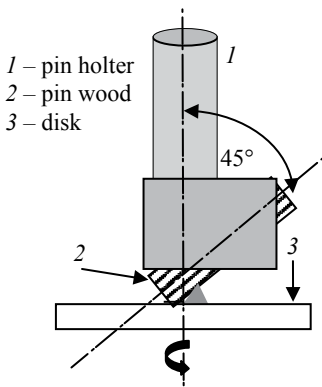
Coatings code	Chemical composition (at. %) O ₂ ~ 0.7				Thickness (μm)	Hardness (GPa)	The Young modulus (GPa)
	C	Cr	Co	W			
F101	22.3	41.6	8.3	27.1	2.3	26.4	324.1
F102	23.3	35.4	8.8	31.8	2.2	26.7	331.3

3500). Substrate to target distance was 8 cm and the base pressure was 6×10^{-5} Pa. The targets were Cr (Neyco, 99.95%) and WC-6 wt.% Co (Ampere, 99.5%). The substrates were initially chemically cleaned, followed by a 12 kV DC glow discharge pulsed plasma (25 ms on/50 ms off) for 5 min at an argon pressure of 2 Pa. The chemical composition and mechanical properties of coatings are presented in Table 1. As can be seen, 2 different compositions were obtained by F101 (Cr:W = 1.53:1) and F102 (Cr:W = 1.21:1), respectively.

Samples characterisations. Wear properties of the coatings were evaluated under dry sliding condition at room temperature using a pin-on-disk tribometer (CSM HT1000) and Tribotest 4.1.1 software. The two main standards referring to the pin-on-disk tribometer are DIN 50324 and ASTM G 99 – 95a (Ref. 7). The pin-on-disk tests were performed with the test configuration schematically illustrated in Fig. 2. The pin wood with a diameter of 6 mm is positioned at 45° on the holder and loaded against a rotating disc. Only cemented (C1 and C2) and cemented +coated (F101 and F102) samples were studied.

In order to approach real contact conditions, e.g. the wood process as peeling of beech, test parameters were chosen appropriately as listed in Table 2. A particular preparation is needed when tests are conducted with wood counterpart: the pin was cut perpendicular to fibres (length 20 mm; \varnothing of 6 mm) from a specific specimen of beech tree provided by a regional sawmill. It was then polished to remove any chips and immersed into hot water (70–75°C) for 24 h.

After the tribo-tests, the profiles of the wear tracks were measured by 3D optical profilometry (VEECO, Wyko NT-1100) and the wear rate was calculated using conventional equations. The wear tracks, wear debris and edges of wood pin were analysed by

**Fig. 2.** Pin-on-disk tests**Table 2.** Parameters of experimental wear tests

Parameters	
Humidity	40%
Sliding speed	2 cm/s
Normal load	5 N
Track radius	4 mm
Sliding distance	200 m
Temperature	20°C

SEM/EDS, using a Jeol JSM-5900LV microscope.

RESULTS AND DISCUSSION

Coefficient of friction evolution. As can be seen in Fig. 3a, when sliding against the wood pin, the coefficient of friction (COF) of the C1 specimen at the start increases rapidly after that it decreases slightly. Then it reached a maximum value of 0.65 (500 cycles), followed by a sudden decrease to 0.25 (6000 cycles). This phenomenon is also observed when the applied load equals to 1 N. At the end of test, the friction coefficient increases to its maximum value of ~ 0.8 – 0.85 . However, the coefficient of friction of the C2 sample rises slowly and gets stabilised at the end of test about 1–1.2 (Fig. 3b). Both curves show a run-in period followed by a friction coefficient increase. The C1 sample presents a lower COF (0.85) than the C2 sample (1.15) after 8000 cycles of sliding against wood pin.

When duplex treated samples were tested, the coefficient of friction showed a run-in period, and afterwards an increase in slope of curves, as can be seen in Fig. 3. The F102 coating had a high run-in friction and showed a short period of

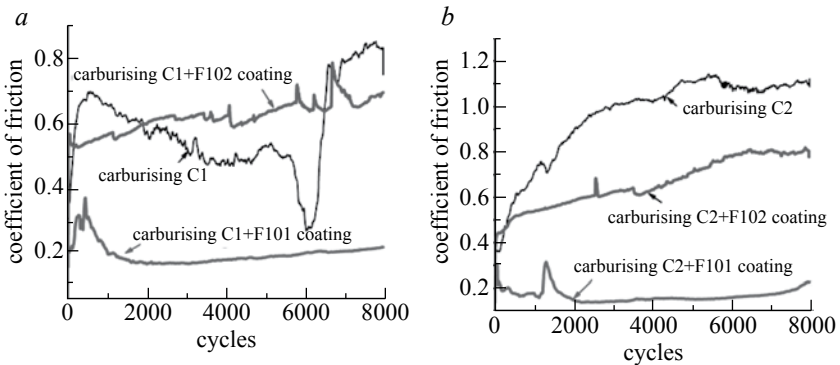


Fig. 3. Friction behaviour of the duplex treated samples ($C_{1,2}+F101$ and $C_{1,2}+F102$) compared with uncoated samples (C1; C2) in interaction with pin wood as counterpart

stabilised COF of around 0.6–0.65 for (C1+F102) and (C2+F102). On the contrary, the F101 coating shows a nearly constant evolution of COF. For both (C1+F101) and (C2+F101) samples, after a run-in period, a value about 0.2 was reached.

Wear analysis. After a tribotest, SEM analysis of the uncoated samples surface revealed a large wear track (1.5–1.8 mm), and substantial amount of wear particles on its edges. These remarks are valuable for all samples treated C1 and C2. An example of wear track of disk seen on C1 samples is shown in Fig. 4a: inside the circular wear track, wear debris were formed. SEM micrographs show also finest and parallel grooves as result of ploughing by oxide particles (third body wear).

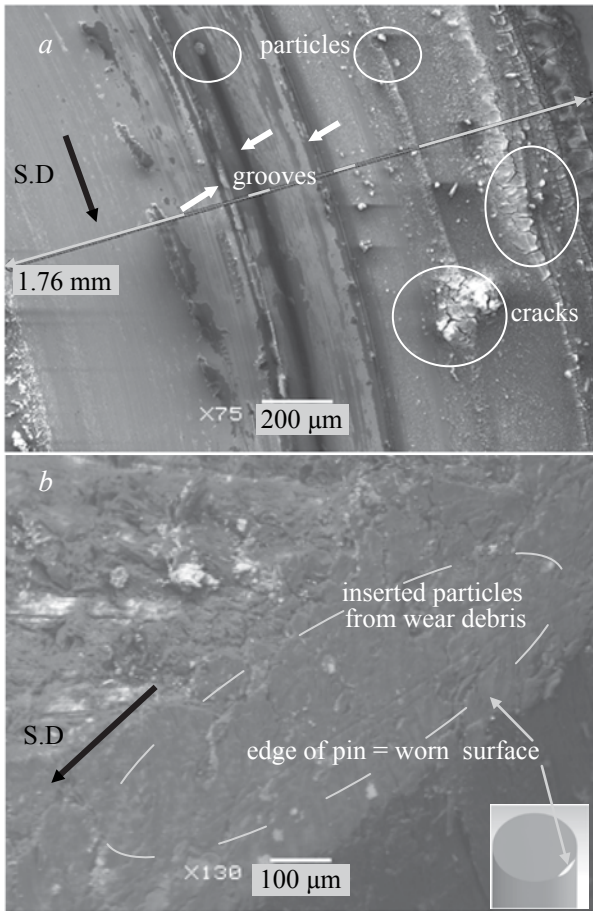


Fig. 4. Example of SEM micrographs of: wear track on disk carburized C1 (a) and the corresponding counterpart worn surface of pin wood after pin-on-disk test (b). The insert image was obtained by CATIAV5 software

Moreover, the wear scar of the counter face, i.e. the edge of the pin wood became smooth as reported in Fig. 4b. Some particles (oxides) are incrustated inside the fiber of wood and a few ‘chips’ are formed at its circumference. Thus initially, at the asperity contact tips, formation of oxides film and, after reaching a critical thickness, breaking of this oxide film (cracks in Fig. 4a) occur as debris formation. Consequently the first step of wear mechanism for the cemented samples sliding against a wood pin is an oxidative wear and the second step is a mild abrasive wear mechanism.

All of the duplex treated samples sliding against pin wood showed the largest wear scar but not very deep (Fig. 5a,b). The coatings are then efficient and well protected by the cemented steel. Few of particles inside circular wear track were observed for both coatings F101 and F102 (Fig. 5b). Based on SEM micrographs, no difference was evident between F101 and F102 coating wear tracks was shown and can explain the coefficient of friction evolution in Fig. 3. EDS analysis of the

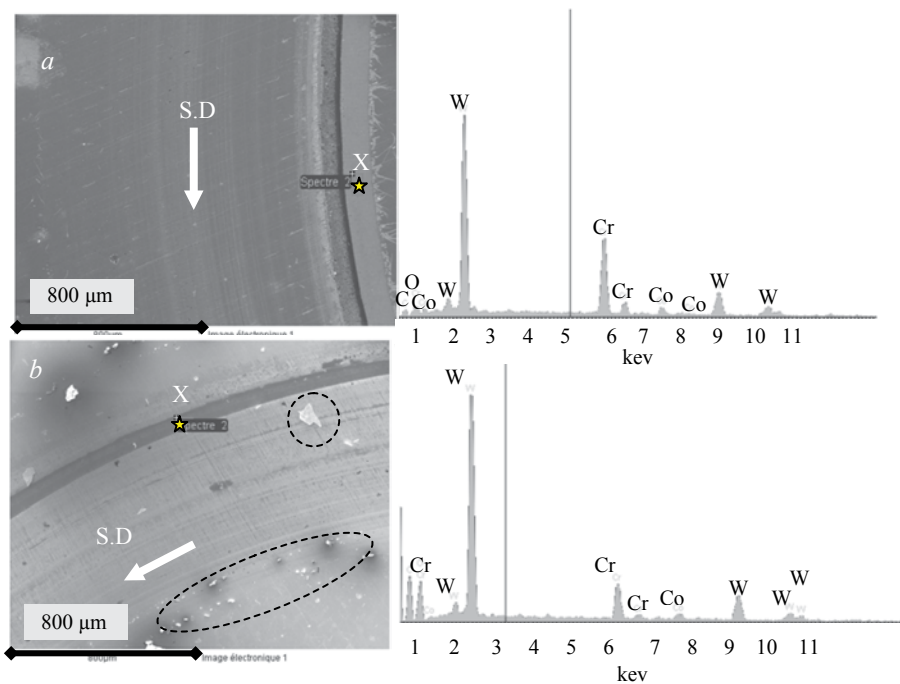


Fig. 5. Duplex treated samples: example of SEM micrographs of wear tracks and corresponding EDS spectra at point 'x': C1+F101 (a) and C1+F102 (b)

worn surface and the debris inside wear scar (Fig 5 *a,b*) reveals only the presence of elements of coating (Cr, W, Co): no iron (Fe) signal or oxygen (O) were found, consequently the wear track is free of oxides. In comparison to the carburised samples and according to the above mentioned results, it can be concluded that the wear mechanism undergone by discs was only a slight abrasion wear.

Figure 6 shows the wear scar on wood pin after 200 m sliding distance against duplex treated samples. Considerable difference exists between surface morphology of pin edge after sliding against F101 (Fig. 6a) and F102 (Fig. 6b) coatings. The wear scar of the pin in the case of the F101 coating shows few quantities of particles, dispersed on a smooth wood surface. These particles contain metallic and organic elements of wood as revealed by EDS analysis spectra. Again, no iron peak (Fe) or oxygen (O) were detected; that proves that coating is not entirely destroyed yet. Therefore, the detachment of the coating was presented in the form of wear debris. Some scratches (furrows) parallel to sliding direction are also present and are caused by particles (no oxides) between the contact surfaces. The small amount and size of the observed particles are not sufficient to cause an abrasive wear mechanism. Besides, the COF evolution curve of the F101 coating (Fig. 3), regardless the substrate, indicated that was a mild wear compared to the

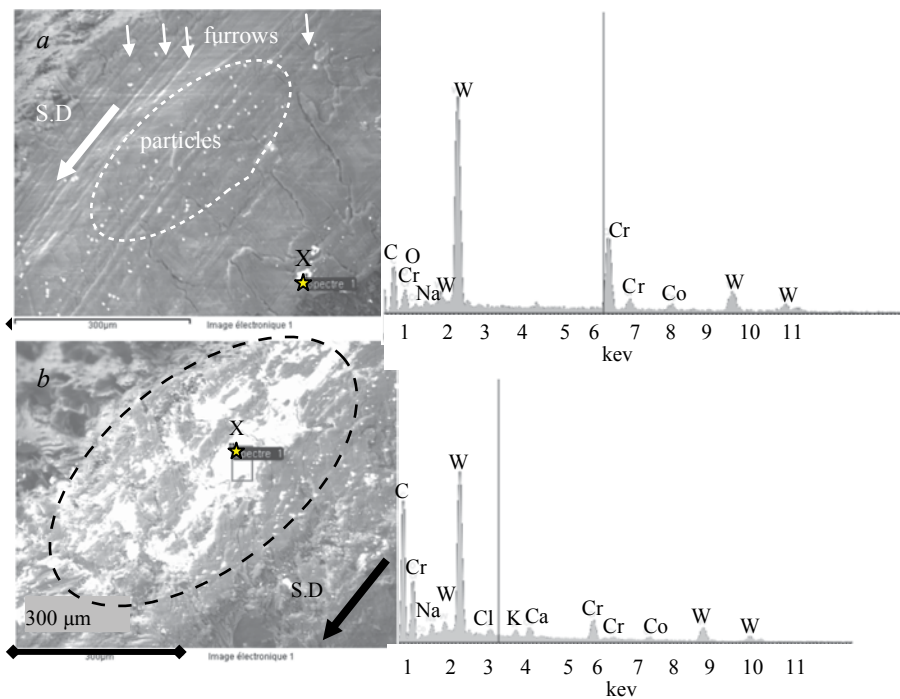


Fig. 6. Example of SEM micrographs of worn surfaces of wood pins against C1+F101 (a) and against (C1+F102) (b). EDS analysis spectra carried out the particles indicate by X

F102 one. As a consequence, no evidence of abrasive wear was found. We suppose that movement of particles during sliding can be due to rotation or rolling as reported in literature⁸⁻¹⁰. The coatings are worn gradually, slowly and with continuous wear with micro-chipping of small coating fragments in connection to surface defects. The SEM micrographs of the pin worn surface sliding against F102 is shown in Fig. 6b. This part of the wear scar shows a significant amount of adhered counter material which indicates a stronger adhesion between contact surfaces. This is in agreement with the corresponding friction curve in Fig. 4, which shows significantly higher and more fluctuating values as compared with the friction curve displayed by F101 coating. The wear mechanism in this case is adhesive.

Quantitative analysis. From the wear track profile obtained by 3D profilometry, the volume loss and wear rate of disc were calculated, for all the samples. The wear scar of the counterpart (pin wood), is an ellipse. Then major and minor semi-axes were measured by profilometry and to calculate the volume loss CATIAV5 software was used (see the inserted image in Fig. 4b). The results are presented in Fig. 7.

The highest wear rate was obtained for wood pin and the lowest for the duplex treated samples. An intermediate wear rate is observed for the cemented samples. This is probably due to the softer hardness of the wood pin in comparison to the cemented and duplex treated steel samples. Besides, the cemented samples showed a similar wear rate value as the duplex C1/F101 and C2/F101 or C1/F102 and C2/F102 treated samples. Nevertheless, the duplex treated samples (wear rates K of about 1 to $2 \times 10^{-6} \text{ mm}^3/\text{N m}$) were much more wear resistant than the only cemented ones (wear rates K of about $7 \times 10^{-6} \text{ mm}^3/\text{N m}$).

It can also be seen that the F101 coating has a lower wear rate than the F102 one probably due to its low COF (0.2). This confirms SEM analysis and the COF evolution curves.

CONCLUSIONS

According to the above-mentioned results the following conclusion can be made:

- An oxidative followed by an abrasive wear mechanism is observed when cemented samples were in contact with a wood pin.

- After sliding against the duplex treated samples, the severity of sliding friction depends strictly on the adhesive interactions of the wear debris. In the case of the F101 (Cr:W=1.53:1) coating, a few and small metallic particles were detached and trapped between the contact surfaces, acting as a protective layer and thus reducing the friction coefficient while an adhesive wear characterised by larger and metallic debris was observed for the F102 (Cr:W=1.12:1) coating;

- If the application of the steel is wood machining, the C1/F101 or C2/F101 duplex treatments are recommended to protect the steel cutting tools against wear and to have the lowest COF;

- The effect of a duplex treatment is obvious here to improve the wear resistance of the steel in comparison to carburising and in view to apply it in wood machining.

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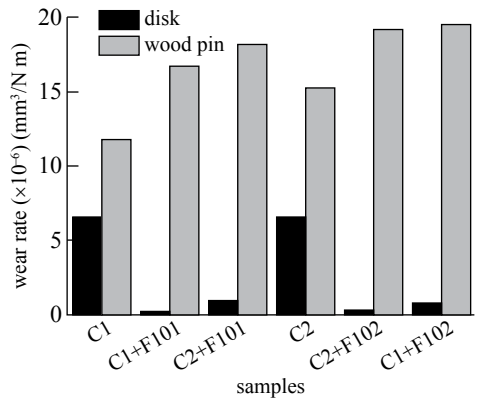


Fig. 7. Estimated wear rates of the tribological couple wood pin/disc

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