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RESEARCH

# Wear Behaviour of Hard Cr Coatings for Cold Forming Tools Under Dry Sliding Conditions

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A B S T R A C T

*Cr hard coatings are largely used in industry in metal cutting and cold forming processes; This work on quantitative way represents improvement, in terms of wear resistance, which is obtained by depositing Cr hard coating on foundation material. Wear testing is done on tribometer with block –on –disc contact geometry at sliding contact of Cr hard coated sample with steel disc. Testing was performed in conditions without lubrication at variable value of contact parameters (normal load, sliding speed). Cr hard coatings in all contact conditions show smaller values of wear rate.*



## 1. INTRODUCTION

Chrome is metal with huge industrial use and it is used as both protective and decorative coating. When it comes to decorative role, chrome is applied on smooth surfaces (usually nickel) to create a thin and bright layer; the thickness of this layer is about 0.25–0.50 μm. Chromium plating systems are very versatile, allowing to use a variety of substrates (like steel, zinc, copper, aluminum and plastic), and they provide bright and long-lasting appearance to the chromated components, so that they have great use in auto-industry [1, 2].

Industrial technologies are advancing and certain mechanical components require the combination of dimension invariability, good technical characteristics, moderate wearing and good corrosion resistance. The solution is in applying thin hard coating, in order to protect the base material with appropriate mechanical characteristics and adequate wear resistance [3-7]. Hard chromium has a greater thickness than bright chromium and has a large variability, going up to 100 μm. Thanks to the good corrosion and wear resistances, with an excellent compromise in high hardness and fracture toughness, hard chromium is a material adopted in many industrial fields [8–11].

One of the main purposes for which this coating is chosen, is the production of very hard surfaces, resistant to pressure, impacts and wear; many types of tools can be made as gauges, mechanical components, rolls of many kinds [12].

Hard chromium plating is very widespread technique of improving the resistance of components to wear and corrosion, and it is used in many situations where resistance to abrasive wearing is of vital importance. Hard chromium can be electrodeposited to a considerable thickness with relatively simple equipment. Nevertheless, a great drawback of the electroplating process is the presence of hexavalent chromium ($Cr^{6+}$) in the electrolyte, which is environmentally harmful. In order to solve this problem, electrolytes containing $Cr^{6+}$ are now substituted by $Cr^{3+}$ [13].

The aim of this study was to quantify the influence of hard chromium coatings to extend the service life of tools in metal forming applications. The tests were conducted in dry sliding conditions and at different values of contact load and sliding speed. Results of testing samples at different values of contact load and sliding speed are presented in the form of graphs and histograms in order to highlight the benefits of hard Cr coating compared to uncoated material.

## 2. EXPERIMENTAL

The steel X165CrMoV12 is taken as the substrate on which the coating is being deposited and it is often used for tool making in processing of metal forming. When defining tribological tests, it was taken into consideration that contact conditions, as much as possible, correspond to real exploitation condition. Also, based on a few sample tests, the contact parameters are being defined so that there is no penetration of coating, because the primary goal of testing is the tribological potential of hard Cr coatings. Work on quantitative way represents effects of depositing these coatings on lifetime of tools in metal forming applications in conditions without lubrications.

### 2.1 Material

Contact pairs are made of alloy tool steel with great toughness and hardness, label X165CrMoV12. This steel is wear resistant and scheduled to work on cold. Hardening in oil and loosening were done before mechanical grind processing. Mechanical characteristics are given in Table 1, and chemical composition in Table 2.

In order to test them, the samples were coated with hard Cr coating. It should be pointed out that the substrate was heat-treated alloy tool steel X165CrMoV12.

Hard chroming procedure is perfomed in ZCZ – Zastava Tools. Chromic coating thickness before final processing by grinding and polishing was about 0.2 mm, and after final processing was 30μm. Surface defects on these groups of samples, before performed tests, are not noticed.

**Table 1.** Mechanical characteristics of alloy tool steel X165CrMoV12

| Hardness after soft annealing HB max | Tensile strenght after soft annealing MPa max | Hardness after hardening in oil and loosening HRC | Measured hardness on the used tool HRC |
|---|---|---|---|
| 250 | 830 | 57-65 | 58-63 |

**Table 2.** Chemical composition of alloy tool steel X165CrMoV12

| Chemical element | % |
|---|---|
| C | ~ 1.65 |
| Si | ~ 0.30 |
| Mn | ~ 0.30 |
| $P_{max}$ | ~ 0.035 |
| $S_{max}$ | ~ 0.035 |
| Cr | ~ 12.0 |
| $Ni_{max}$ | ~ 0.25 |
| Mo | ~ 0.60 |
| V | ~ 0.10 |
| W | ~ 0.50 |

### 2.2 Tribological test

Tribological tests are performed on na block-on-disc sliding wear testing machine with the contact pair geometry in accordance with ASTM G 77-83. A schematic configuration of the test machine is shown in Fig. 1. The test block was loaded against the rotating steel disc. This provides a nominal line contact Hertzian geometry for the contact pair.

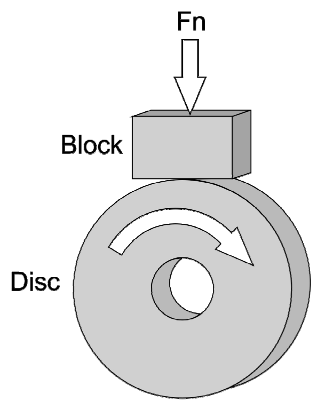



**Fig.1.** The scheme of contact pair geometry.

The test blocks (6.35 x 15.75 x 10.16 mm) were prepared from tool steel X165CrMoV12, while one part of the samples is coated with hard Cr coating. The values of surface roughness were measured on the prepared samples before and after depositing of coating. Measuring of surface roughness was done on Talysurf 6 device and appearance of material layout in surface layer on referent length $l$=1.2 mm. Measured value of surface roughness for samples of tool steel and samples on which hard Cr coating is being deposited is $Ra$=0.01 μm and $Ra$=0.01 μm respectively. Surface profilometer of these surfaces are shown in Fig. 2 and Fig. 3.

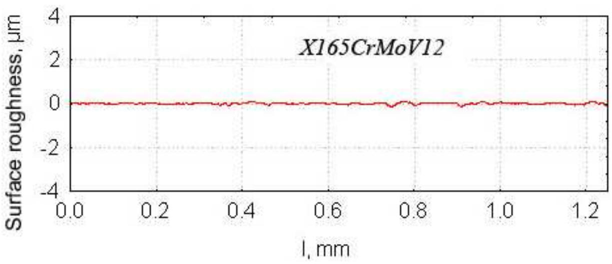



**Fig. 2.** Surface profile X165CrMoV12.

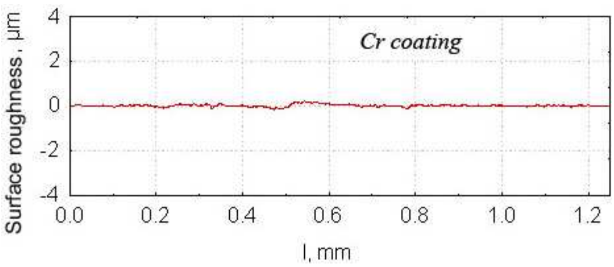



**Fig. 3.** Surface profile X165CrMoV12 + Cr.

More detailed description of the tribometer is available elsewhere [14]. The wear behavior of the block was monitored in terms of the wear scar width - h (Fig. 4). Using the wear scar width and geometry of the contact pair the wear volume (in accordance with ASTM G77-05) and wear rate (expressed in $mm^3$) were calculated. The repeatability of the results for replicate tests was found as satisfactory (variation of wear scar width was under 5%).

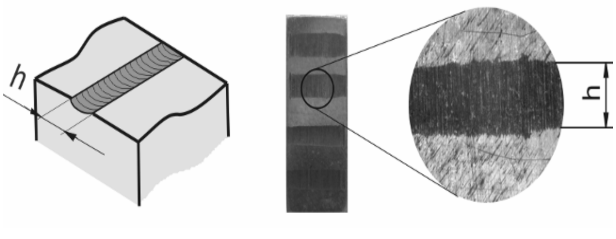



**Fig. 4.** Wear scar.

## 3. RESULTS AND DISCUSSION

Tribological tests of two groups of prepared samples are performed. The first group is base material, steel, of marking X165CrMoV12, while the second group are samples with hard Cr coating applied on base material. Prepared samples are tested in conditions without lubrication, with varying values of sliding speed and normal load. Sliding speed in contact was taking three values 0.25, 0.5 and 1 $ms^{-1}$. The normal load value also had three values 10, 20 and 30 N during the tests. During each test these values have remained constant. The normal load values are selected to avoid coating perforation during the testing, which was achieved.

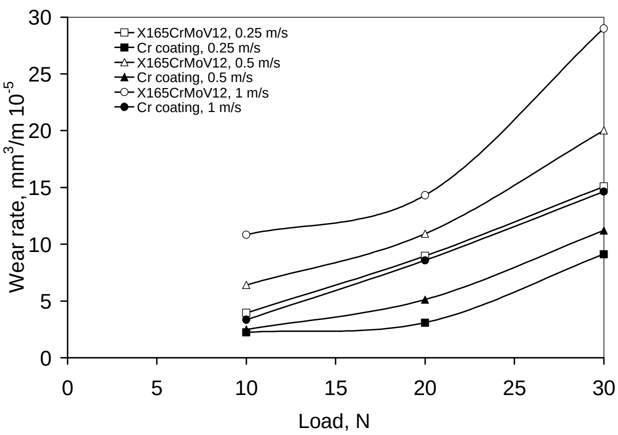



**Fig. 5.** Wear rate dependence of tested samples on the normal load value (10, 20 and 30 N).

The Fig. 5 represents wear rate dependence of the normal load value, at constant speed sliding values. The diagrams shows, that in all contact conditions, the wear rate value of hard Cr coating is lesser in comparison to wear rate value of the sample without coating. Also, it is noticed that with increase of normal load value in the contact zone there is increase of wear rate value, which is accordant to theoretical patterns.

Figure 6 displays wear rate dependence of tested samples on changing sliding speed value in contact zone, at constant normal load value. Presented diagram shows increase of wear rate with increase of sliding speed, the only exception represents the wear curve referring to wear value obtained at the smallest normal load value of 10 N. Based on this, we can say that at normal load values of 10 N, the change of sliding speed does not influence the wear rate. This could be due to the way the contact is achieved. Because of small contact loads, can be said that the contact is achieved only on the peaks of asperities, about which the wear rate values witness and they are in this occasion very small.

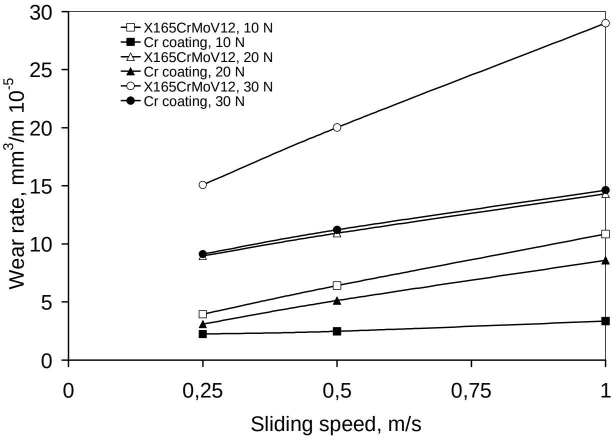



**Fig. 6.** Wear rate dependence of tested samples on sliding speed (0.25, 0.5 and 1 $ms^{-1}$).

The work of L.H. Chiu has showed the stability and satisfactory wear resistance of hard Cr coating (7 μm thick), in the long run, at contact pressures up to 11 MPa [15]. In our case, the contact pressures in initial moments, when the contact is achieved along the line, were, depending on the load, within the range of 30 to 60 MPa. With the wear development the contact pressure decreases, and then the contact is achieved on the surface.

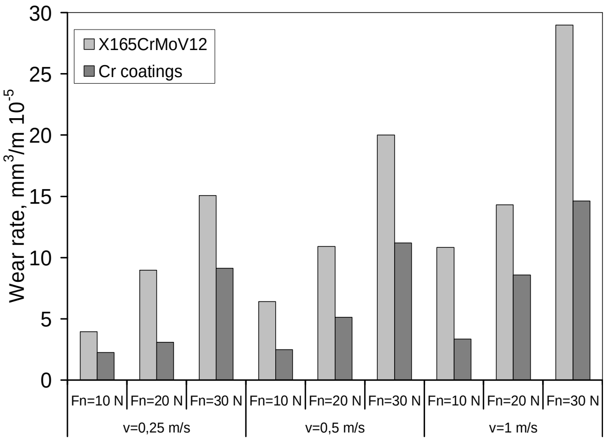
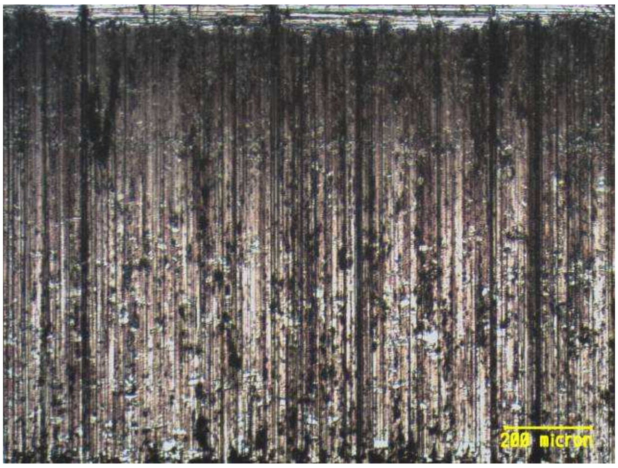
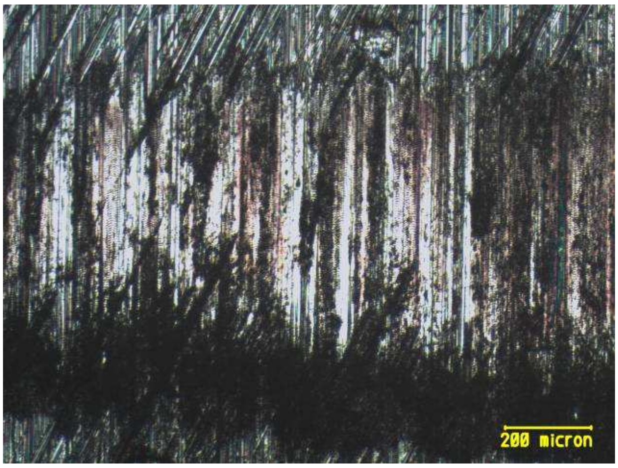



**Fig. 7.** Histogram display of wear rate value for tested samples.

Histogram display (shown on Fig. 7) enables to perceive, from quantitative aspect, the advantages of material with hard Cr coating in comparison to the material without coating. It can be seen that, when considering wear rate, the material with coating has significantly lesser wear values in comparison to the material without coating. The difference in wear rate value is in the range of 40-60 %. The most uniform difference in percentages in wear rate value of these two groups of samples is 0.5 m/s at sliding speed.




(a)




(b)

**Fig. 8.** Wear tracks after sliding distance of 200 m, normal load value of 30 N and sliding speed of 1 $ms^{-1}$ (a) without coating; (b) hard Cr coating.

Primarily we should say that adhesive wear occurs when the contact pressure between sliding surfaces is high enough to cause local plastic deformation and welding between the contacting asperities. Abrasive wear, however, occurs between two hard sliding surfaces when hard debris particles are indented and make grooves in the sliding surface of the material. Both kinds of wear can be lessened by either a decrease on the contact pressure or an increase in the mechanical strength of the material itself. Fig. 8 presents wear tracks of tested samples in the conditions without lubrication and after sliding road of 200 m. Displayed tracks in Fig. 8 are created in condition of the highest sliding speeds and maximum normal load in this test. Based on the appearance of wear tracks, we can conclude that the dominant wear mechanism is abrasive wear.

At the very beginning of making contact we can talk about adhesive wear, which is the consequence of contact block-on-disc, or high contact pressures which appears when contact is achieved only on the peaks of asperities. With further development of the wear, contact passes from linear into contact on the surface, when the domination of abrasive wearing begins.

## 4. CONCLUSIONS

Tested samples coated by hard chrome coating showed higher wear resistance in comparison to the samples without coating, samples of tool steel. Comparative display of measured wear rate value of both materials shows that wear rate of hard Cr coating samples is for 40-60 % lesser. Based on this we can conclude that by depositing of hard Cr coatings on steel base, the lifetime of tool in metal forming application could be considerably prolonged.

Also, hard Cr coatings have shown durability and wear resistance at contact pressure of 60 MP, which is the consequence of the line contact and normal load value of 30 N.

Based on the Figures of wear tracks of tested samples we can conclude that the dominant wear mechanism is abrasive wear.

## Acknowledgment

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