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Effect of grinding on the sub-surface and surface of electrodeposited chromium and steel substrate

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ABSTRACT

Grinding is a machining process widely used in industry for machine parts manufacturing. In the case of electrodeposited chromium on steel, grinding does affect not only the chromium coating, but also the steel substrate. The microstructural changes of both coating and substrate were quantified under several grinding conditions. Depending upon whether the grinding process was gentle or abusive, residual stresses, crystallographic texture and microstructure evolve over large or small depths within the coating. Metallurgical and microstructural changes have been observed within the substrate. Measurement of the grinding temperature combined with finite element simulations, the modelling of the temperature rise through the material shows a good agreement with the microstructural observations.

1. Introduction

Hard chromium coatings, obtained by the well-established electrodeposition technique, are widely used to enhance attractive surface properties such as the wear and corrosion resistances and hardness at the surface of engineering components [1].

Depending on the application, the coating thickness usually varies in the range 20–500 μm.

Due to the deposition process, these coatings are extensively microcracked and present a complex microstructure. As observed by several authors [2,3], electrodeposited chromium coatings exhibit a strong crystallographic {111} fibre texture. This fibre texture results from a selective growth of well oriented small crystallites (so-called nanocrystalline chromium structure [4]) having their preferential [111] growth direction parallel to the normal of the substrate surface [5]. As a result of the selection growth process, the sharpness of the fibre texture increases in the coating with its thickness. The strength of this behaviour depends on the nature of the substrate: more significant for stainless than for ferritic steel [2].

Depending on the electrolytic bath temperature, chromium is deposited by continuous growth or germination columnar growth: above 50 °C a columnar growth is expected [5].

Residual stresses are intrinsic microstructural characteristics of electrodeposited chromium coatings. Pina et al. [2] have shown that the residual stresses can reach values as high as 800 MPa at the coating surface but that their strength decrease inside the coating. The tensile stresses and the inherent cracks are mainly due to a shrinkage of the coating during deposition either by phase transformation or by hydrogen and oxygen degassings [5]. Note that the amount of residual stresses close to the interface depends on the coating thickness and on the mechanical strength of the substrate.

Grinding is a machining process widely used in industry because it provides high quality of the surface components and high precision with an excellent surface finishing [6]. In the case of the hard chromium coating, which is intrinsically difficult to machine, grinding is one of the only way to obtain good surface finishing surface.

The conventional grinding process has been the focus of several works dealing with a variety of materials such as ferrous and non-ferrous alloys, superalloys as well as ceramics [6–9]. These previous works have essentially focused on the chip formation [10], the modelling of the stresses and temperature fields [11], the evaluation of the temperature at the tool/material interface and within the material [12,13] and on the microgeometry and topography of the machined surface in conjunction with the variation of some grinding wheel characteristics [14]. These investigations were essential to better understand the grinding process and to improve its effectiveness. However, little information has been reported in the literature concerning the characterization of the deformed electrodeposited chromium coating after grinding. Thus, the consequences of grinding process on the coating integrity are still rather poorly understood. Eliaz et al. [15] have reported pre-cracking of the steel substrate induced by an improper choice of the grinding parameters of chromium coated parts which exposed the steel to local overheating during grinding. Other work has dealt with the influence of grinding parameters on fatigue resistance of chromium coatings concluding that the grinding finishing process could be a deteriorating factor in terms of fatigue resistance [16].

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Table 1
Composition of the 40NiSiCrMo7 steel substrate.

C	Ni	Si	Cr	Mo	Fe (balance)
0.40%	1.80%	1.60%	0.85%	0.40%	94.95%

During the grinding process, the original workpiece is dissociated into the machined surface and the chips. It is generally assumed that the deformation energy delivered during metal machining transforms mainly into heat along the arc of contact material / grinding wheel interface [17]. More precisely, the heat energy is generated by severe plastic deformation and by friction [6,18]. In addition, if an increase in heat transferred leads in an elevated temperature of the coating, early damage of the surface (generally called "burned surface") may be generated. The end-properties of the machined material are obviously affected by these damages which require an increase of the production costs to be avoided.

Introducing the concept of critical maximum temperature, Malkin and Guo showed that the specific grinding energy governs these processes [6]. In the case of coated substrates, it is very likely that both the coating and the substrate are affected by heat conduction through the coating. The affected depth mainly depends on the mechanical and physical properties of the coating and substrate materials as well as on the machining parameters [19,20].

Combining electron back scattering diffraction (EBSD) mapping for microstructural investigation and X-Ray Diffraction (XRD) analysis to determine both residual stresses and crystallographic texture, this study gives a detailed analysis of the chromium coating sub-surface and substrate. Accurate temperature measurements were ensured by using a double-pole grindable thermocouple. Numerical modelling (using MSC Marc software®) was used to determine the absorbed heat flux by fitting the numerical solution to the temperature profile measured during the cooling phase, behind the contact. The specific case of heterogeneous material was analysed by Lefebvre et al. [20] for WC–Co coating.

The primary aim of this study is to provide a better description of the coating integrity and a better knowledge of the metallurgical transformation arising in the substrate after a grinding operation leading to the formation of the so-called burned surfaces. Another objective of this work is to couple these experiments with a temperature modelling within both the coating and the substrate in view to identify eventual grinding damages developed in the substrate.

2. Experimental procedure

2.1. Studied material and grinding tests

Chromium was electrodeposited on 40NiSiCrMo7 steel plates. Chromium electrodeposition was done by direct current with an intensity of 30 to 50 $A \cdot dm^{-2}$ in a electrolytic bath maintained at the temperature of about 55 °C ± 5 °C. The chemical composition of the steel plate is given in Table 1. Before electroplating, the substrates were mechanically and chemically cleaned, and then shot-peened. Shot peening before coating induces high compressive residual stress in the surface layer of the substrate and prevents the propagation of cracks into the substrate material.

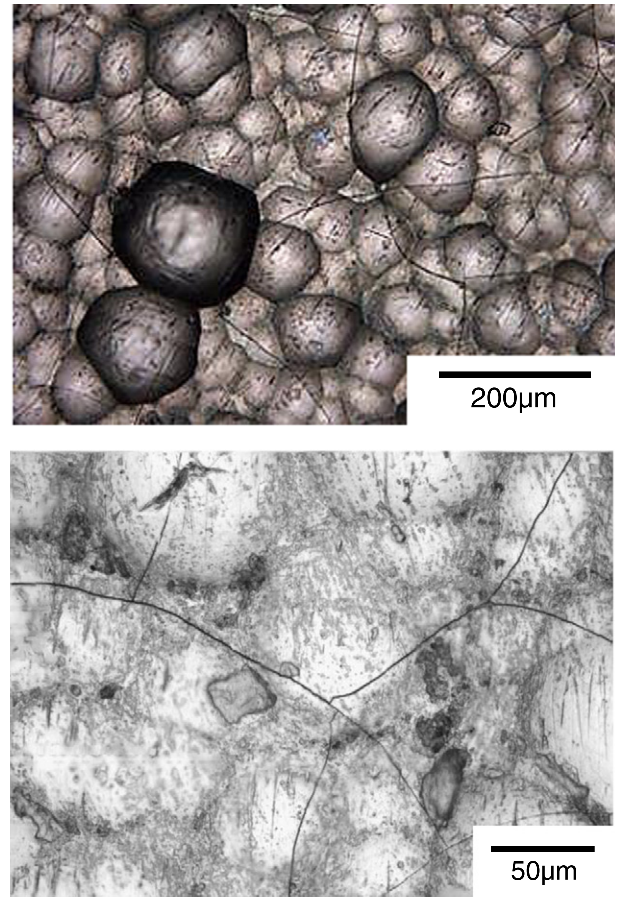

Fig. 1. Optical observation of the coating surface.

Chromium has a BCC crystallographic structure. The 40NiSiCrMo7 substrate is a low-alloyed medium carbon steel containing some austenite in a bainitic/tempered martensitic matrix (Si addition favours retained austenite over cementite). X-ray phase analysis revealed that the steel substrate contains less than 6% of austenite.

2.2. Samples characterization

The obtained coatings were characterized by using Wide X-Ray Diffraction experiment (WXRD) before grinding and after the final grinding step. Stresses measurements were carried out on a goniometer

Table 2
Studied samples and grinding conditions (index w for wet and d for dry).

Samples	Lubricant	Burning	Peripheric speed of the wheel V_s ($m \cdot s^{-1}$)	Feed Rate V_w ($m \cdot min^{-1}$)	Grinding depth a_p (μm)
Sample Gw (gentle wet)	Yes	No	28	8.8	5
Sample Gd (gentle dry)	No	No	28	8.8	5
Sample Ad (abusive dry)	No	Yes	28	2	50
Sample Aw (abusive wet)	Yes	No	28	2	50
Sample Td (dry)	No	Yes	28	2	20
Sample Tw (wet)	Yes	No	28	2	20