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Mechanical Properties of Chromium Coating Resistance: Experimental Study and Modelisation

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Abstract: Research relates to the characterization of hard chromium deposit on a steel slightly allied (42CrMo4), by electrolytic way. This characterization was carried out by Vickers indentation, where we calculated the number of hardness according to the applied load, which is generally defined like the penetration resistance of an indenter, also, an evaluation of the Young modulus under the various loads of indentation was made. A simplified approach of the calculation of tenacity for the various shapes of cracks (standard M and P) is presented, showing a progressive transition from a mode of cracking to another, according to the applied load.

Key words: Surface treatment, chromium plating, cracks, pores, indentation

INTRODUCTION

Facing requirements of the market, the durability of the parts and mechanical systems interest much the industrials. The criteria of wear resistance, friction and corrosion tend today to be superimposed on the basic functions. This tendency exists in several industries where a great component must reconcile mechanical and tribological functions like friction-wear with a corrosion resistance increasingly higher. This need for improving the properties of surface of materials led to the development of the technique of the hard chromium coating deposited on a substrate with the more modest mechanical properties (Guffies, 1986). By chromium coating certain parts, working with friction, we improve inter alia, their operation, realizing from point of view of the friction the excellent conditions considering the low friction coefficient of chromium. The layer thickness of hard chromium varies according to the application, but in general it ranges between 20 and 500 μm, where as the thickness of decorative chromium coating does not exceed the 1 μm (Gawne *et al.*, 1984). New processes of depositions were born, allowing the implementation of coating with high performances, helped in that by the appearance of ranges of preparation of surfaces, increasingly rigorous.

The electrolytic coating today, is largely used in industry, relative with the undeniable economic interest which they present.

This study relates to a study of characterization of a hard chromium deposit, deposited on a slightly allied steel 42CrMo4, by electrolytic way, used for the construction of the jacks of the industrial machines. This characterization was carried out by Vickers indentation, where we calculated the number of hardness according to the applied load, which is generally defined like the penetration resistance of an indenter, as well as the effect of load and calculation of tenacity of the deposit.

Heat treatments: They performed before and after deposit. In these treatments, we include a degasification which is carried out quickly after chromium plating (Gawne *et al.*, 1984). The heat treatment carried out is a hardening by induction heat at 400°C, with the parameters as given in Table 1.

Characteristics of the substrate: The based allow was a slightly allied steel 42CrMo4. Its mechanical characteristics and its chemical composition are given respectively in the Table 2a and 2b.

Table 1: Parameters of hardening induction heat

Tension	500 V
Intensity	110 A
Power	50 KW
J.Sin φ	0
Rotation of the part	200 Tr min^{-1}
Advance of inductor	5 mm sec^{-1} time of:
T1	preheating
T2	hardening
T3	cooling

Table 2a: Mechanical characteristics of the substrate

Hardness	270-330 HB = 26-27 HRC
Yield stress	R_P (MPa/mm²) = 650
Tensile strength	R_m (MPa/mm²) = 900-1100
Lengthening	A% (mm) min = 12
Impact strength	min = 41 (j/cm²)

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Table 2b: Chemical composition of the substrate

Element	Content
C	0.38-0.45
Si	0.15-0.40
Mn	0.50-0.80
P	Max: 0.035
S	Max: 0.035
Cr	0.90-1.20
Mo	0.15-0.30

MATERIALS AND METHODS

Surface state of the substrate: With an aim of reducing the tensions at the surface of the substrate, a heat treatment was carried out with a correction and a mechanical polishing. The micrographies given on Fig. 1 and 2, respectively show, the surface quality of an untreated part and that of the part having undergoes a hardening by induction heat. The first has a marked roughness and cracks being able to lead to a fissured and porous chromium deposit and the second, has a less marked roughness.

Tests of micro hardness: For the characterization of the coating, Vickers hardness testing was carried out on samples having various thickness deposits. Indentation load varied in the range of 0,1N-25N.

Indentation load was applied in a continuous manner. The progressive application of the load measurement in real time, of the displacement of the point of the indentor as a function of the load. Figure 3 shows the load-displacement curves obtained for applied loads, varying between 0,1N and 25N. The calculation of hardness results from the report of the reached maximum loading with the maximum depth corresponding to this load.

The relative depth evolution of the print (residual depth h_p of the print on the maximum depth h_m) is given on Fig. 4. We observe a more significant plasticization for the high loads. For the great loads, the report h_p/h_m tends to be stabilized.

To study influence of deposit thickness on the hardness of coating, several samples were prepared under the following conditions:

$$CrO_3 = 272 \text{ g L}^{-1},\ SiF_6 = 1{,}1 \text{ g L}^{-1},$$
$$SO_4H_2 = 8{,}5 \text{ mL L}^{-1},\ T = 58°C,\ I = 300A.$$

The immersion time is selected so as to obtain a layer thickness concerned:

Sample A: e = 38 μm
Sample C: e = 50 μm
Sample E: e = 31 μm
Sample I: e = 12 μm
Sample J: e = 14 μm

Fig. 1: Front view of a part not quenched and mechanically not polished

Fig. 2: Front view of a part quenched and mechanically polished

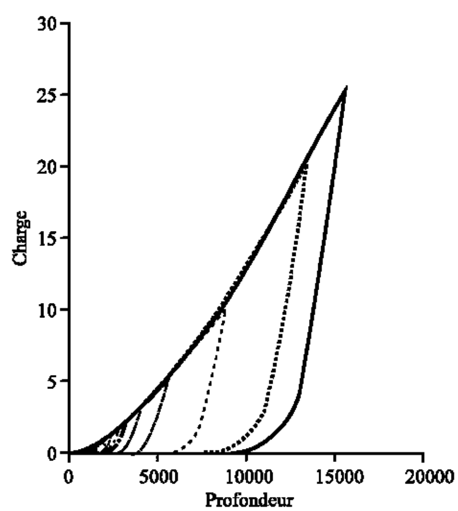

Fig. 3. Load-displacement curve

The hardness of the coating was measured in order to characterise the deposit. The dependence of hardness function of the load occurs in the case of a thick coating. When coatings have a low thickness, the value of measured hardness is the result of the contributions of coating and substrate.

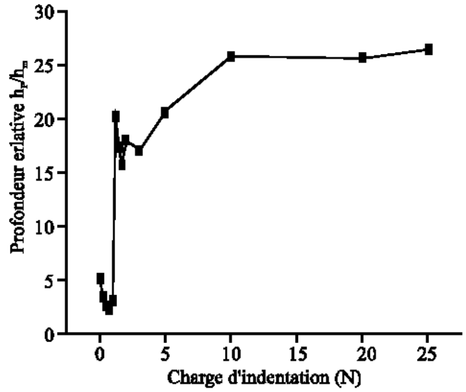

Fig. 4: Evolution of the report h_p/h_m as a function of indentation load

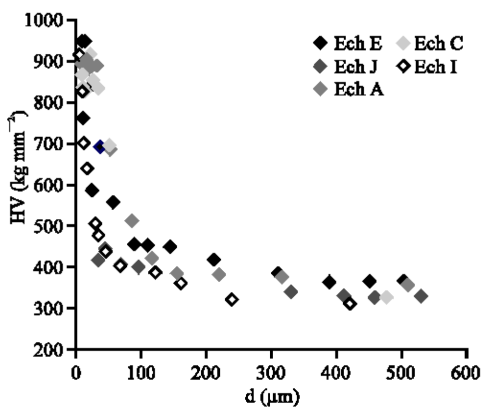

Fig. 5: Thickness influence of the deposit on hardness

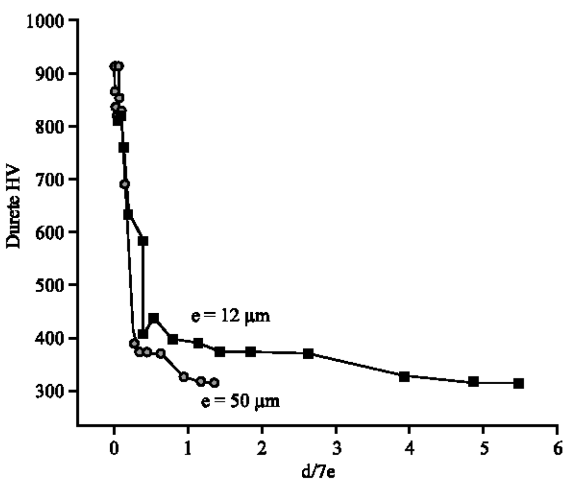

Fig. 6: HV hardness as a function of report d/7^e. Where: d-diagonal of the print; e-Layer thickness

Figure 5 and 6, respectively show the variation of HV hardness as a function of the diagonal of the print and report between this diagonal and seven times the thickness of the chromium layer.

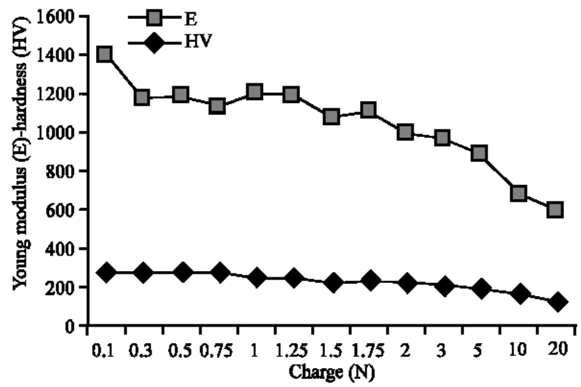

Fig. 7: Variation of the Young modulus (E) and hardness according to indentation load

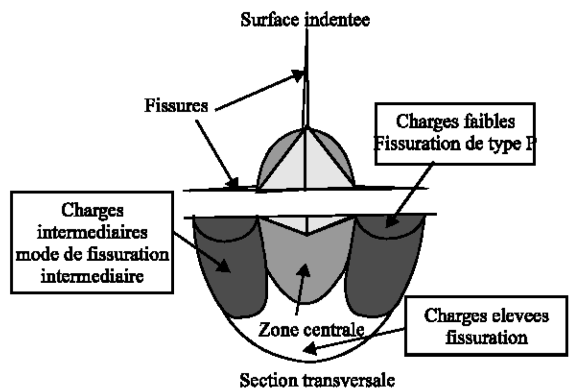

Fig. 8: Diagrammatic sight of indented surface and the cross section of a system of cracking per Vickers indentation

On Fig. 5, we can notice that the chromium layer hardness quickly decreases quickly and becomes almost constant into the substrate. The substrate has undergoes a part of plastic deformation generated by the indentation. Consequently, the value of the calculated hardness starting from the measured print is the result of the contributions of both the substrate and coating. Figure 6 show also that more significant is the thickness of the layer greater the contribution of coating.

Figure 7, shows the evolution of hardness and Young modulus according to the load of indentation.

Calculation of tenacity up to fracture: For the calculation of tenacity, it is necessary to know the fissure shape because the mathematical expressions used which depend on the mode of cracking. Indeed, when the cracks touch constantly borrows it, the cracks are of type Median (standard M) and when they seem to deviate from borrows residual, they are of type Palmqvist (standard P).

Figure 8 very well schematically explains the transition between the two systems from cracking per Vickers indentation.

As Fig. 8 shows it, the size of the central zone is related to the dimension of the diagonal of borrows. Thus, for the weak loads, the crack would be of P type whereas, for the raised loads, the cracks would be of M type. The load being sufficient so that the crack can cross the central zone. We can think that the phenomenon of cracking can thus develop gradually between the two modes, this assumption would contradict then the assertions of Lin *et al.* (2003), supposing a brutal transition between the two modes from cracking.

Criterion of cracking: The most used relations were proposed by Evans *et al.* (1976) and Shetty *et al.* (1985) for the modes of cracking of the type M and P. These relations are presented by the following respective Eq.:

$$K_{ICM} = 0.0824\frac{P}{c^{3/2}} \quad \text{For the M type} \tag{1}$$

With: c = a + L

$$K_{ICP} = 0.0319\frac{P}{al^{1/2}} \quad \text{For the P type} \tag{2}$$

Where: P the load applied;
c and L lengths of the cracks;
a the half-diagonal.

To distinguish the two modes from cracking, we can study the evolution of the report (c/a) according to the applied load (P). Indeed, the lengths (c) and (L) are connected to the half-diagonal (a) by a simple relation utilizing the load:

$$\frac{c}{a} = \left(1 + \frac{1}{a}\right) = f(a) \tag{3}$$

From the relations (1) and (2), it is possible to write the reports (c/a) and (L/a) of the relation (3) according to the applied load (P) and the half-diagonal (a) in the following way:

$$\frac{c}{a} = \left(\frac{0.0824}{K_{ICM}}\right)^{2/3}\frac{P^{2/3}}{a} = C_{M1}\frac{P^{2/3}}{a} \tag{4}$$

$$\frac{1}{a} = \left(\frac{0.0319}{K_{ICP}}\right)^{2}\frac{P^{2}}{a^{3}} = C_{P1}\frac{P^{2}}{a^{3}} \tag{5}$$

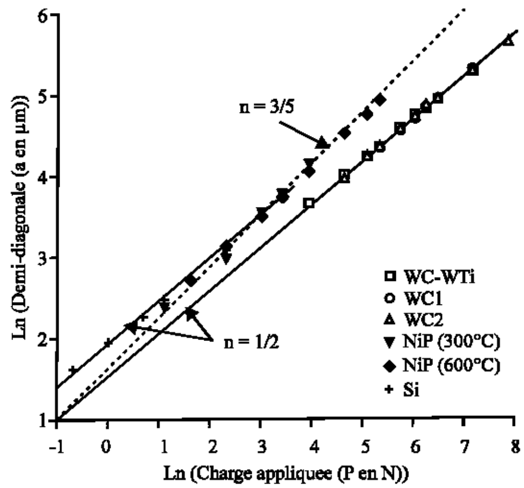

Fig. 9: Relation between A and P

Where: C_{M1} and C_{P1} are constants depending on materials.

To express these relations according to the load alone, it is necessary to know the variation of the half-diagonal (a) of borrows Vickers according to the applied load. For that, the simplest relation between the half-diagonal and the applied load are as follows:

$$a = a_m P^n \tag{6}$$

Where: m and n are coefficients and index similar to those of the law of Meyer.

In this way, we can write the relations:

$$\frac{c}{a} = C_{M2}P^{g} \quad \text{For the M type} \tag{7}$$

$$\frac{1}{a} = C_{P2}P^{f} \quad \text{For the P type} \tag{8}$$

Where: $C_{M2} = \frac{C_{M1}}{a_m}$, $C_{P2} = \frac{C_{P1}}{a_m^3}$, g = 2/3-n and

F = 2-3n (= 3.g) is constants.

Under these conditions, the double logarithmic representation of the report/ratio (c/a) according to the load (P), must lead to a line of slope equal to F or g according to the type of cracking. This is a new tool, which will enable us to distinguish the two modes from cracking.

As we can note it on Fig. 9, for bulk materials and coatings of nickel-phosphorus, the slope (n) of hardness is of ½, which makes it possible to calculate F = ½ and g = 1/6.

CONCLUSIONS

To characterize the deposit, the indentation tests were realized. They showed that since the withdrawal of the indentor, there remain in the coating a residual print surrounded by a plastically deformed zone. This plastic deformation varied with both applied load and thickness of coating.

As we can say as the determination of tenacity by indentation uses a very simple technique but the analysis of the results of cracking must be carried out with precaution. It is as shown, as it is not necessary to determine as a preliminary the fissure shape to calculate tenacity. The only measurement of the crack lengths on the surface of indented material is sufficient.

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