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The behavior of the wear of steels before and after nitriding treatment

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ABSTRACT

In our study and from the experimental results obtained after the nitriding treatments, it was possible to validate the mechanical behaviors (Hardness Vickers), which increases to the treated surface and decreases to the core of the steel. We have been able to put the tribological concepts of the mechanism of the wear and to validate the hypotheses which allow degradation like the losses of mass during the wear of the surfaces. We have validated the comparison with the same steel before nitriding.

1. Introduction

The tribology concerns the study of surfaces in contact and in relative motion; it thus includes the lubrication, the friction, and the wear of the machine elements. The economic boom given in 1994 confirms that the order of 26 billion euros per year in France, or 1% of GDP if all the knowledge acquired in tribology were applied to the industry (Belot and Rigaut, 1994). The good knowledge of the used material is essential for the realization of a satisfactory structure that gives, the production of the sacred pieces and the profiles with respected standards, and more and more apt to answer the dimensional intentions. The experimental determination of these mechanical characteristics of nitrided steel (the nitrided depth should not exceed 300 µm in order not to promote superficial cracking) (Fewell and Priest, 2008).

However, when low-temperature nitriding is used, close to 400ºC, the hardening mechanism changes from nitride precipitation to lattice distortion of the FCC austenitic phase, leading to the formation of expanded austenite, with hardness close to 1400 HV and no loss of corrosion resistance (Fewell et al., 2000; Borgioli et al., 2005; Mingolo et al., 2006). The hardening mechanism is related to high compressive residual stresses arisen from lattice distortion.

2. Material and procedure

The material of our study is low alloy steel 42CD4which a good oil hardenability, good overload resistance in the treated state. This steel is very used in mechanics, for parts of medium and strong sections: Shafts, axles racks, crankshafts, connecting rods, gears. This steel is sometimes used for parts hardened superficially. Its composition is recorded in Table 1.

Table 1: Chemical composition

C	Si	Mn	Cr	Ni	P	C
0.42	0.25	0.79	0.93	0.13	0.015	0.42

The surface areas of the mechanically stressed parts have an important role because their properties condition friction, wear, and fatigue resistance. It is, therefore, often sought to produce superficial layers of high hardness resting on a ductile core. Nitriding is a thermochemical treatment intended to improve the mechanical properties (resistance to fatigue, hardness, and resistance to wear) or chemical properties (corrosion resistance) of the materials (Musil et al., 2000).

Archard's equation (Chekour et al., 2003) implies that if Ku is constant for a given slip system, then the volume of material lost will be proportional to the slip distance. Eq. 1 is relevant for plastic contacts; it cannot be applied to cases where the contacts are elastic. In tribology, hardness H is usually defined as the average contact pressure leading to the plastic flow of the material. In the case of Vickers hardness, sheis expressed by dividing the indentation force by the actual area of contact (Stott, 2002).

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$$Ku = \frac{V}{F.D} \quad (1)$$

Ku is a coefficient of Wear, V is Volume, F is Normal load, and D is Sliding distance.

3. Results and discussion

From the results shown in the curves of Fig. 1 and Fig. 2, the nitriding treatment resulted in a considerable increase in surface hardness. There is a medium superficial hardness (after nitriding) of the order of 341.7 MPa. This growth in values is mainly due to treatments (nitriding), followed by heat treatments. On the other hand, the untreated surfaces have smaller micro-hardnesses, with an average of 180 MPa. This homogeneous decrease from the surface to the core of the metal is explained by the basic hardness of the steel in question. A comparison of wear coefficient before and after nitriding and the wear before and after nitriding function of time were shown in Fig. 3 and Fig. 4, respectively.

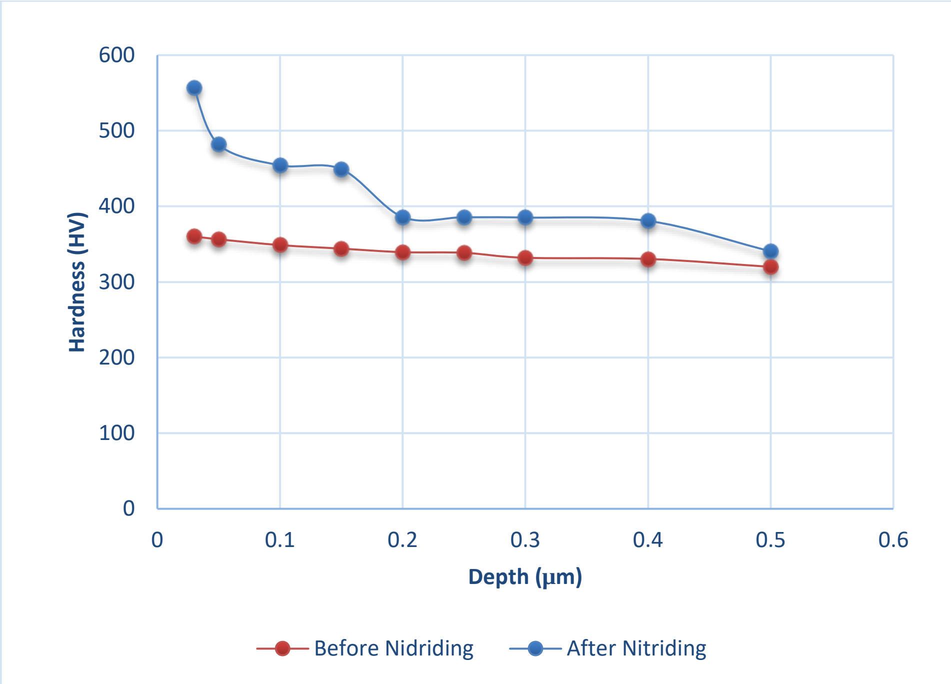

Fig. 1: Hardness as a function of the depth of steel

Wear is a complex set of phenomena, leading to debris emission with loss of mass, ribs, shape, and accompanied by physical and chemical surface transformations. It does not generally vary in a progressive manner depending on parameters such as speed, temperature, or time. The wear is generally combated because of its negative effects, but it also has favorable aspects. Persson et al. (2004) showed that also the initial residual tension stresses of a certain intensity in the steel would retard the initiation of cracks by thermal fatigue. On the other hand, compressive constraints of all intensities favor the formation of cracks. Most of the time, the global wear of a mechanism is due to several processes that act simultaneously, more rarely to a well-defined and identifiable process. In the first moments of friction, it is the superficial screens that undergo all the mechanisms inherent to friction (thermal, mechanical, or chemical effects). Then, these mechanisms take turns or interpenetrate according to the multiple conditions present would show that also the initial residual tension stresses of a certain intensity in the steel would retard the initiation of cracks by thermal fatigue. On the other hand, compressive constraints of all intensities favor the formation of cracks.

In general, a part suffers throughout its life three stages of wear:

1. Lapping: Fast wear with a decreasing wear rate.
2. Normal operation: Service life (low and constant wear).
3. Aging and death: Increasing wear rate.

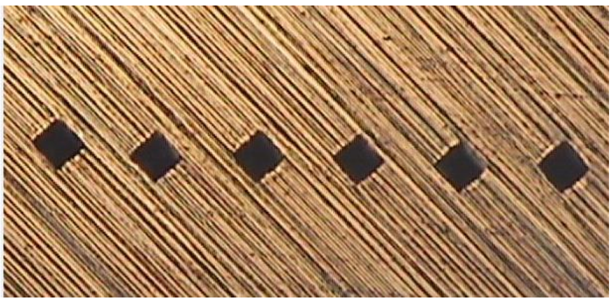

Fig. 2: The Vickers indentation imprints before nitriding

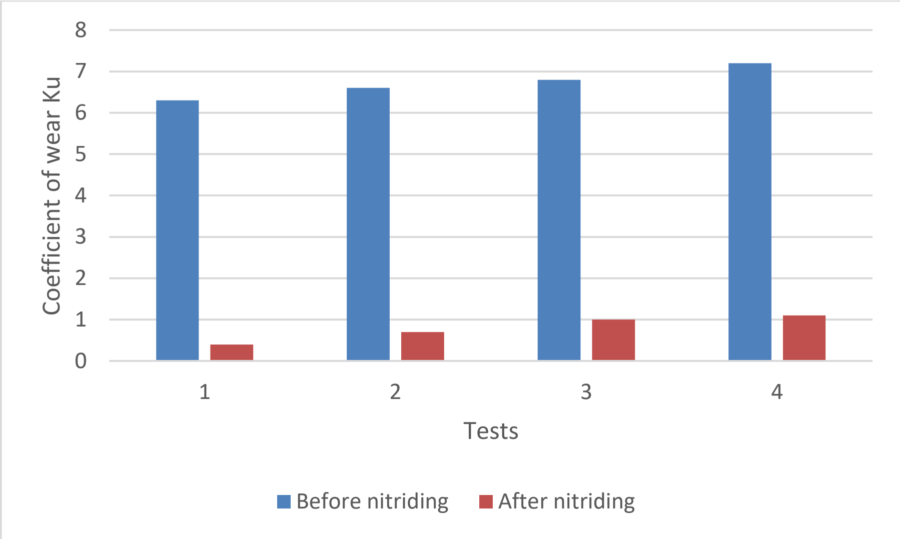

Fig. 3: Comparison of wear coefficient before and after nitriding

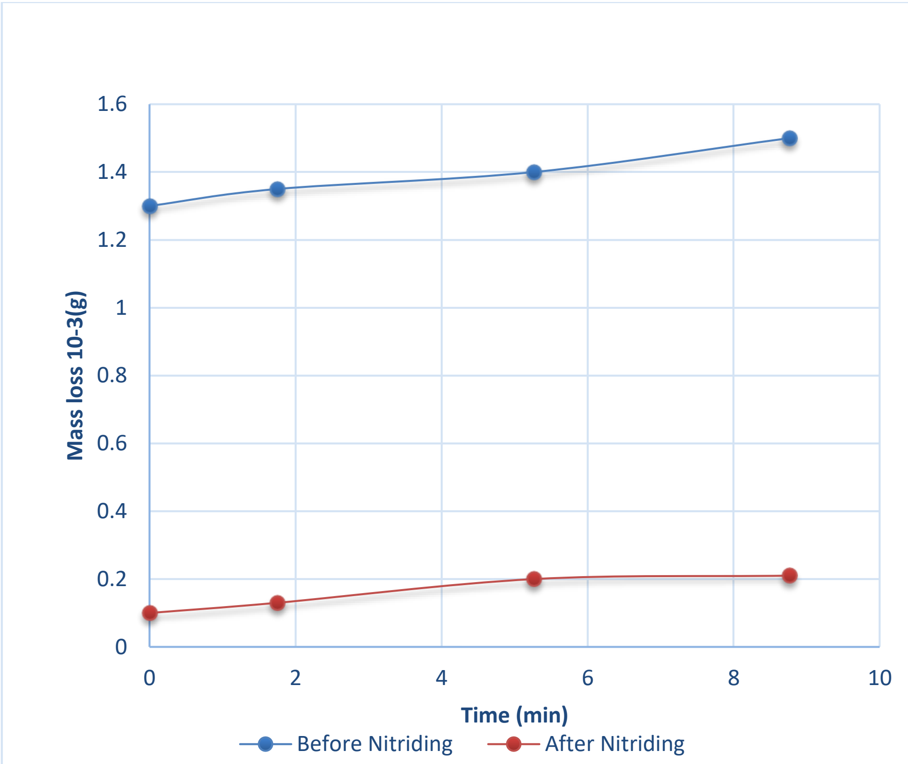

Fig. 4: The wear before and after nitriding as a function of time

It can be seen that the sample before nitriding exhibits a significant loss in mass as a function of the wearing course, compared with the sample after nitriding (Fig. 4). From the presented profiles, the nitriding treatment (after nitriding) caused a considerable increase in surface hardness. This consolidation properties improved wear resistance with low mass losses, which resulted in minimal wear coefficients (Fig. 4).

It can be seen that the raw sample that is to say without any treatment has a significant loss in mass as a function of the wearing course if one compares with the heat-treated sample where resistance of the material expressed by the loss in low mass after the first 100 meters of course. This is due in our opinion on the phenomenon of hardening, which leads to a consolidation of the material. The ridges corresponding to the wear of the heat-treated material after 500 m, of course, are fine evidence of low wrenching of the material (Fig. 3).

The curves have a close appearance; that is to say, for a nitriding treatment, behavior, and almost identical in the case of prolonged treatments (4h and 6h), the corresponding curves (4h and 6h) are below the curve corresponding to 2h.

4. Conclusion

From a strictly mechanical point of view, the nitriding treatment of steel results in a considerable increase in hardness and the establishment of a field of residual compressive stresses in the nitrided layer. The combination of these effects has the consequence, in addition to improving the wear resistance, a very significant increase in mechanical properties.

List of symbols

F	*Normal load*
D	*Sliding distance*
K_U	*coefficient of Wear*
V	*Volume*

Acknowledgment

I dedicate this modest work to all our fellow researchers in the world.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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