

Surface quality effect on tribological behavior

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Abstract

The surface quality for a given product is induced by the different factors involved in the process of cutting, and represented by the value of roughness. It is therefore necessary to define the influence of the surface state (the result of the turn cut) on the friction and wear behavior (dry) of the steel-steel pair under atmospheric conditions. To do this, tribological tests were carried out using a pin-cylinder tribometer (tracks, different roughness were machined and tested in contact with different metal pins), mounted on a lathe using of a device (realized) equipped with an acquisition software. Treatment and observations of the results were recorded using a profilometer, optical microscope, SEM and EDX. The results have increased the influence of the roughness, on the coefficient of friction (μ) which thus varies positively on the wear rate (W), which increases progressively by varying the surface state. We find a surface of the pin of hardness inferior (to the disk), plowed, cracked and plastically deformed, thus more loss of material by adhesion, oxidation of the formed particles compacted on the disk, from which a transfer of material and formation of the layer of metal oxide.

Keywords: Quality; Tribology; Behavior; Friction; Wear; Cutting;

1. Introduction

In industrial process of mechanical fabrication, the objective is to obtain a better product quality defined by roughness. Surface state is one of the most demanding mechanical properties in metal cutting, since it represents the final control phase [1]. Its effect is very important on the tribological behavior of each pair brought into contact during the operating life of a mechanical system. Our study consists in analyzing the influence of this quality of surface on the dry contact, of two metal parts [2], in permanent contact in order to evaluate the variation of the coefficient of friction and the rate of wear.

Some works presented by researchers, such as the Archard approach [3], which defined the wear rate of a couple of materials, depends on many factors intrinsic to the material and related to contact conditions such as applied load, the sliding speed and the presence or absence of lubricant. Kerridge and Lancaster [4] have shown the possibility of transferring the material from the hard disk to the pin, which could increase the hardness of the contact surface of the pin, and consequently reduce the wear rate. Thus J. Ayel [5] presented two actions, the shearing and formation of micro-chips or by plastic deformation which cause the displacement of material..etc.

The aim of this paper, is to present contribution is to specify the tribological behavior of the steel-steel pair: 42CrMo4-20MnCr5, as a function of the roughness (R_a), result of the cylinder cut on a turn, by varying the cutting parameters, then mounted using a tribometer, in permanent contact with a pin (sphere-cylinder contact). The coefficient of dry friction (μ) and the wear rate (W) mass loss of the pin are determined by means of an acquisition device. The results observed are presented at the end of this work.

2. Experimental Study

Nine (9) tracks were made on a disk of nuance 42CrMo4, of dimensions ($\Phi = 40$ mm, $L = 134$ mm). The operation carried out is the finishing turning of 0.5 mm of step on a parallel turn of power $P = 9$ KW. The second piece is a pin of nuance 20MnCr5, of dimensions ($\Phi = 10$ mm, $L = 20$ mm), see figure1. The principle is to realize in the cylinder surface different roughnesses divided into several tracks, in permanent dry contact with a pin, to study the tribological behavior in friction and wear.

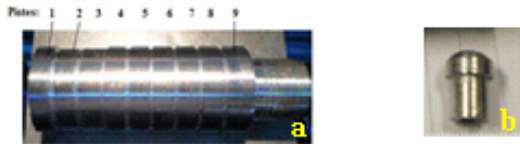


Figure 1. Machined pieces:
(a) Cylinder 42CrMo4, (b) Pin 20MnCr5

2.1. Materials

In this study, two materials were chosen, first the 42CrMo4 (for the disk) which is a preliminary process of metal used for loaded transmission parts, camshaft, gears and crowns, second the 20MnCr5 (for the pin) which is a more or less hard and resistant treatment metal, often used for rocker arm, chain sprockets and spindle. The chemical composition and the mechanical properties are presented in Tab. 1 and Tab. 2.

Table1: Chemical Composition

Tribological couple	Specification	Chemical Composition				
		% C	% Mn	% Si	% Cr	% Mo
Pin	Experimental Values 20MnCr5	0.12	1.07	0.24	1.0	0.014
Cylinder	Experimental Values 42CrMo4	0.41	0.86	0.22	1.11	0.22

Table2: Mechanical Characteristics

Standard	Elastic Limit $\geq [N/mm^2]$	Resistance to traction $[N/mm^2]$	Elongation %	Breakdown Striction %	Resilience [J]	Hardness [HV] 20Kg of Load
20MnCr5	240	450-600	24	45	27	240-270
42CrMo4	650	900-1100	12	50	35	340-355

2.2. Roughness measurement

In order to analyze the profile and to identify the real value of the roughness, a profilometer (Alti Surf 500) equipped with (3D) image processing software and (2D) profile was used (Fig.2). Two measurements of the average arithmetic roughness (Ra) were carried out, the first issue of the roughing operation in final stage of each track as a function of the different cutting parameters (FIG. 5), the second after the tribological test (Fig.6).



Figure 2. Profilometer Type Altisurf 500

2.3. Tribological Test

2.3.1 Test specimens

The same disk of 42CrMo4 nuance, used in the previous part, of cylindrical shape of dimensions ($\phi = 40$ mm, $L = 134$ mm), have nine (9) tracks, different roughnesses obtained by varying the cutting parameters (speed, advance and radius spout). The second piece is the pin of 20MnCr5 nuance, nine (9) pins were machined, correspond to the number of tracks tested, dimensions ($\phi = 10$ mm, $L = 20$ mm).

2.3.2 Tribometer

The study of the tribological behavior in friction, was carried out on a pin-cylinder tribometer (manufactured at the laboratory level), equipped with a device of acquisition figure 3. The dry tests took place in an atmospheric environment, which allowed to obtain values of the coefficient of friction (μ_{sec} close to 0.7).

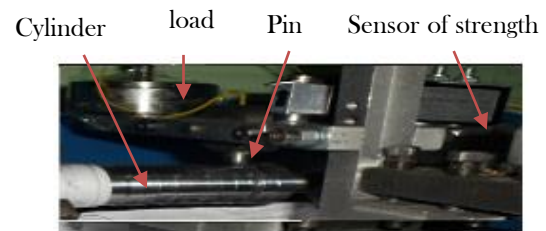


Figure 3. Contact pin-cylinder: Dry Contact



Figure 4. (a) Cylinder Tracks,
(b) Track of pin After Tribology

3. Results

✓ Figure 4, shows the real state of the parts (disk and pin) after tribological test in dry contact, we find worn disk tracks, disappearance of peak roughness, their shapes are wider and deeper, stratified surfaces and Extensive smooth plates, almost polished, have debris on the surface (Fig. 4 a), which corresponds to the material removed from the worn pin (Fig.4 b).

✓ We find, according to the results obtained by the profilometer, before and after tribological tests, that these tracks after tribology, are less rough (examples: $0.92\mu\text{m}$, $0.69\mu\text{m}$), the value of the roughness (Ra) decreases by (examples: $1.44\mu\text{m}$ to $0.92\mu\text{m}$), during dry contact. This explains the disappearance of the peaks of the rotating part roughness (cylinder) and the increase of the wear rate of the pin in contact (Fig.5 (a, b)) and (Fig. 6(a,b)).

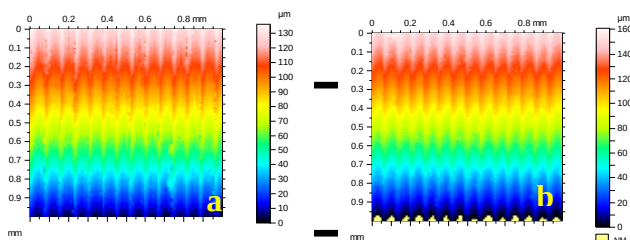


Figure 5. Example of roughness, Ra disk case, after machining (a) $V_c = 800\text{ rpm}$, $R_a = 1.44\mu\text{m}$ et (b) $V_c = 1600\text{ rpm}$, $R_a = 1.50\mu\text{m}$

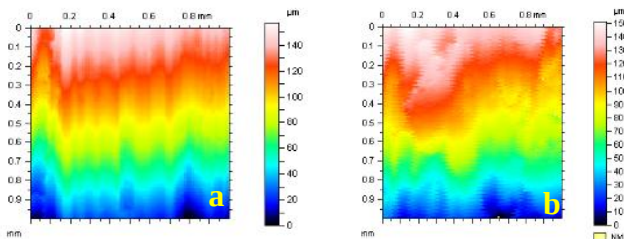


Figure 6. Example of roughness Ra, of the disk, after tribological test, dry contact $V_c = 740\text{ rpm}$, (a) lane12, $R_a = 0.92\mu\text{m}$, (b) lane3, $R_a = 0.69\mu\text{m}$.

✓ The value of the roughness goes from (1.44 to $0.92\mu\text{m}$) after tribology, so a decrease of (0.5), on the other hand for a rougher quality it decreases by (0.81) whether (1.5 to $0.69\mu\text{m}$), hence the increase of the wear rate from this limit value of fine surface condition (more than $1.5\mu\text{m}$ is a poor quality, rough surface and less polished).

✓ With a load ($P = 12\text{N}$) and a speed ($V_c = 740\text{ rpm}$), the coefficient of friction (μ) varies with time (Fig.7 (a, b)). The figures show that the coefficient of friction remains practically constant throughout the duration of the test and its value varies according to the initial roughness of the disk used ($\mu_{\text{dry}} = 0.3$ to 0.9).

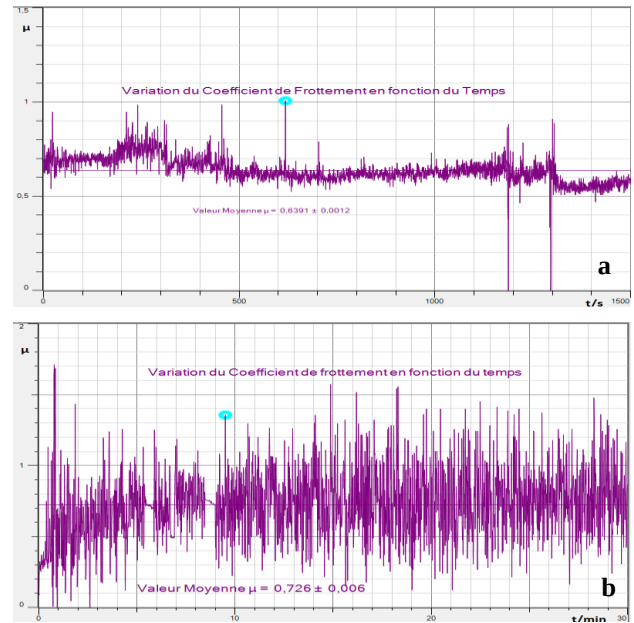


Figure 7. Example of the variation of the coefficient of friction as a function of time, $P = 15\text{N}$, $V_c = 740\text{ rpm}$: Contact sec, (a) $R_a = 1.44\mu\text{m}$, $\mu = 0.6$ et (b) $R_a = 1.5\mu\text{m}$, $\mu = 0.7$

✓ During the operation of the test, three distinct phases are observed (Fig.7):

First phase: it is a break-in phase, the first contact of the asperities of the surfaces, which lasts about (2) minutes and during which the coefficient of friction varies from (0.2 to 0.6) (Fig. 7), according to the roughness of the chosen track. Second Phase: it is a disturbed phase (transient) that lasts about (1 to 2) minutes where the asperities of the antagonists become entangled thus increasing the contact and the adhesion ($\mu = 0.6$ to $0.9\mu\text{m}$) (Fig. 7). The harder disk peaks ($42\text{CrMo}4$) than the counterface sink into the surface of the metal of the pin, plowing and tearing material (Fig. 11) [5].

Plastic deformation results in a rise in the average temperature at the interface between 40°C and 99°C (Fig. 8 a)[6]. The latter was taken using a thermocouple placed 2 mm from the contact. This temperature rise affects the mechanical properties of the surfaces such as yield strength and shear stress of the softer material ($20\text{MnCr}5$ nuance), thereby decreasing friction and increasing the wear rate (Fig.10 a).

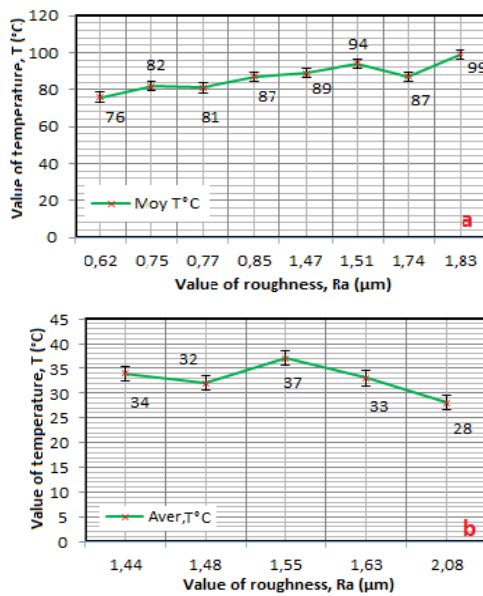


Figure 8. Mean Temperature T (°C), depending on the roughness R_a (μm) (a) Second phase dry contact, (b) Third phase dry contact.

Third Phase: this last represents the stationary regime, during this long phase, the equilibrium state is established by the stability of the operating conditions at the interface. In this zone the coefficient of friction decreases from (0.4 to 0.7) (Fig.7), depending on the chosen track, while the temperature decreases to (28°C) (Fig.8 b).

Figure 9 shows the evolution of the coefficient of friction (μ) as a function of the roughness (R_a), indeed (μ) increases from (0.3 to 0.9) when (R_a) increases. We have reached a known result, the roughness of the cylinder has an influence on the coefficient of friction [7].

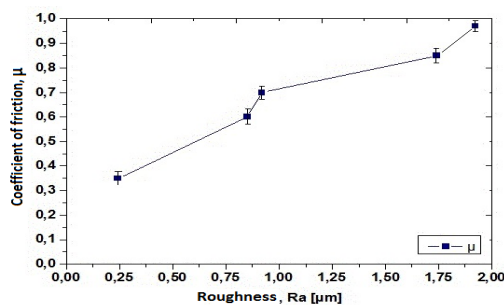


Figure 9. Variation of wear rate W , according to roughness R_a , dry contact

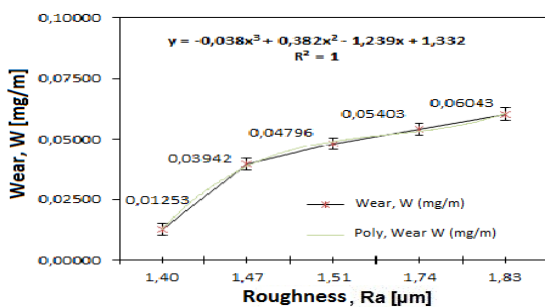


Figure 10. Variation of coefficient friction μ ,

✓ Figure 10, shows the evolution of the wear rate (W) according to the roughness (R_a), in dry contact, indeed, (W) increases from (0.0125 to 0.06 g/cm³) when (R_a) increases from (1.40 to 1.83 μm). The values of the roughness reflect the better quality of the surface of the disk before the test, of higher hardness (340 HV), these peaks will act positively and progressively by varying their value, plow the surface of the pin of hardness lower (240 HV), and increase the wear rate (W), so more material loss by adhesion and oxidation of the compacted formed particles from the friction pin can be plastically deformed to form the metal oxide layer, this result has been asserted by Lepesant et al, Mouadji [8,9].

✓ In addition, we have noted the presence of cracks, along the contact surface of the pin, have been created (Fig. 11 b) given the severe operating conditions, and the cyclic stresses exerted on the surface. These cracks give rise to fatigue wear which generates medium sized active debris at the interface [8] (Fig.11 (c, d)). This debris accumulates and sinks into the peg by tearing off the metal (abrasive wear) (Fig. 11 a). Oxides action (brown color on the disk track) was observed (Fig. 11 a) due to temperature increase during plastic deformation.

✓ The worn track of the disk corresponds to the pin of low hardness (Fig. 12 a) has a rough surface with deterioration elements consisting mainly of local adhesive scars (Fig. 12 a) and particles (Fig. 12 b), the EDX spectrum associated with the particle reveals the presence of chromium and manganese, which proves that these particles come from the material of the pin (material transfer from the pin to the disk). It is proposed that this debris is the result of the micro-scaling and fragmentation of the low hardness pin material induced by the cumulative shear as suggested by Lepesant et al [9]. The EDX analysis confirmed that these particles are mainly composed of oxidized disk material of the type (FeO), because it was detected that very little chromium element.

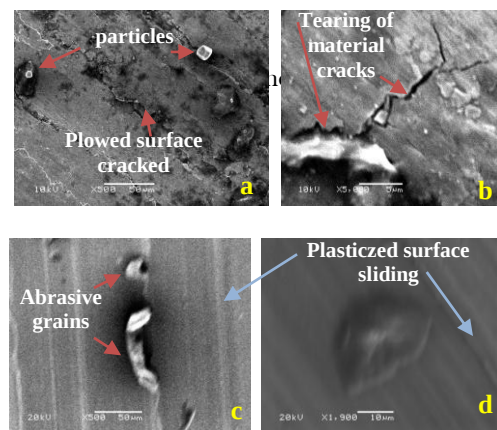


Figure 11. (a, b) Images of pin in SEM, (c, d) tracks of the disk in EDX (X500, X1900, X5000): Dry contact (a, b) R_a =1.44 μm, (c, d) R_a =0.92 μm

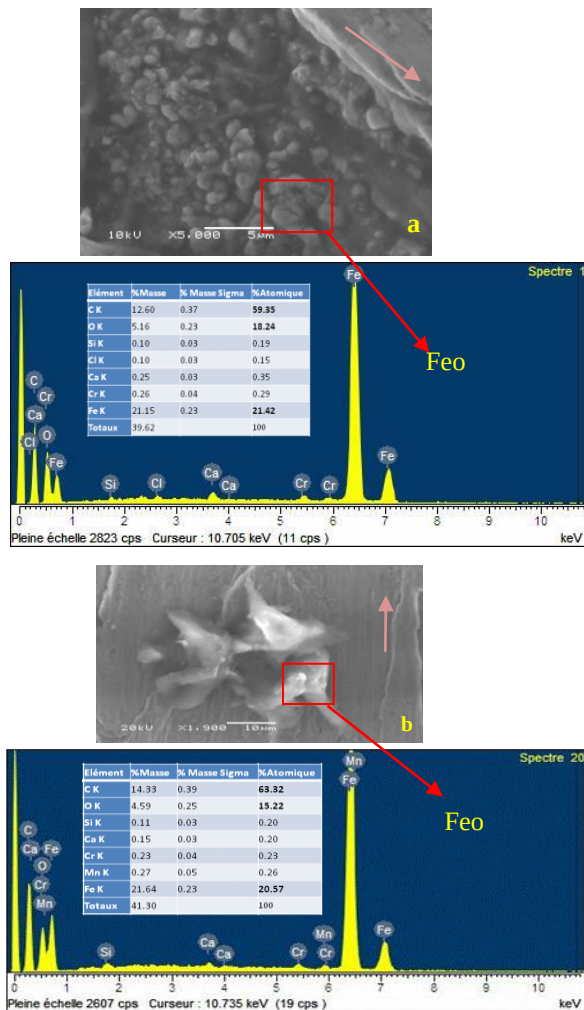


Figure 12. EDX image of track spectra of the disk after tribological test at 20kv Disk site (a, b) Dry contact

4. Conclusion

The present study aimed to observe and put in practice certain phenomena, namely:

-A decrease in the maximum value of the roughness (R_a), and disappearance of the peaks due to the high shear stresses at the level of the asperities after tribological test.

-A variation of the coefficient of friction (μ) as a function of the time and presence of three phases during the dry contact (steel-steel), which depend on the surface state of the cylinder track.

-We have reached a known result, the roughness of the cylinder affects the wear rate (W) (loss of material of the pin of lower hardness).

-Micro-cracks (along worn surfaces) and wear debris in the form of particles or abrasive grains on the surface of the disk, which explains the ease of material removal after dry testing.

-Presence of oxides due to the increase in temperature, during the phase of plastic deformation.

-In perspective, we suggest to use lubricant to stabilize the temperature, to evacuate the abrasive grains, to facilitate the sliding of the surfaces in contact.

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