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Technological Parameters of Belt Grinding Process of Hard Steel

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A mechanical workpiece in the field of the automobile industry (crankshaft, camshaft, valves, gear, synchronizer gearbox ... etc) is good quality, if it fulfills the function for which, it is destined. To ensure the required function of these workpieces, they are necessary for the purpose of machining a high precision superfinishing process. There are several methods of superfinishing in this area, for example: honing, polishing, belt grinding ... etc. The belt grinding is a mechanical manufacturing process by removing of material involving a tool called abrasive belt. It is complementary to the hard turning and recent compared to other process principle and objective. To date the cutting mechanism and its exact effect on the surface integrity remains unclear.

This study allows optimizing the technological parameters, such as time of belt grinding, size of the abrasive grains, the rotation speed and lubrication, and seeing the influence of these parameters on the surface state of the hard steel.

Keywords: belt grinding, super-finishing, hard turning, surface integrity, abrasive film.

1. Introduction

Manufacturing operations of the mechanical parts are linked to each other, from design to finishing and the quality of the piece depends greatly on these different operations. Hence, it is important to perform it under favorable conditions. Each step of obtaining must provide the following satisfactory performance starting with the design, shaping and finishing.

This increased need for improvement grows to define new ways of precision in finishing processes, more modern techniques have emerged (the grinding to crossed lines, the honing, the belt finishing, ...) for the superfinishing of these parts ever more accurate because of the increasing technological demands.

The belt finishing method is a recent superfinishing technique in its use [1], it is another way to substitute traditional grinding to reduce manufacturing costs. Therefore the abrasive belt is a finishing process by abrasion which is carried out by rubbing with a cloth using a moving part of both an oscillating and rotating movement [2, 3].

The belts are comprised of a support (fabric, paper or synthetic film) on which is deposited a layer of graded abrasive grains. This finishing process is remarkably simple and can reduce manufacturing costs by decreasing production time and improve the overall quality of the product [4]. Unfortunately and because of the basic physical mechanisms of this finishing process, its practical development seems to be difficult [2]. Thus, in the industry, the range of belt grinding process is still empirical, with each new production specification, preliminary tests are indeed necessary to achieve optimal operational configuration of the process [5].

The belt finishing is a complementary process in the hard turning; indeed, many studies showed that despite the hard turning performance in the dimensional accuracy and surface state, significant problems can arise and exist on the surface integrity [6, 7]. In particular it was shown that the wear of turning tools results in a decrease of the residual tensile stresses [8], and the metallurgical changes (white coats), which deteriorate the fatigue and decrease the wear resistance of the mechanical parts. In addition, this drift is accompanied by a deterioration of the surface topography due to the appearance of rejections of material on the sides of the grooves. These pieces of very hard materials which are very fragile and easily detachable are considered as major source of damage [7].

2. Experimental procedure

2.1. *Belt finishing device*

The belt grinding device is designed and produced in our laboratory; it is mounted on a conventional lathe instead of the tool holder (see Fig. 1) [9]. The lathe allows the positioning and rotation of the cylindrical workpiece. The belt grinding system is modular and allows the workepiece finish either by machining pinch or roller arm.

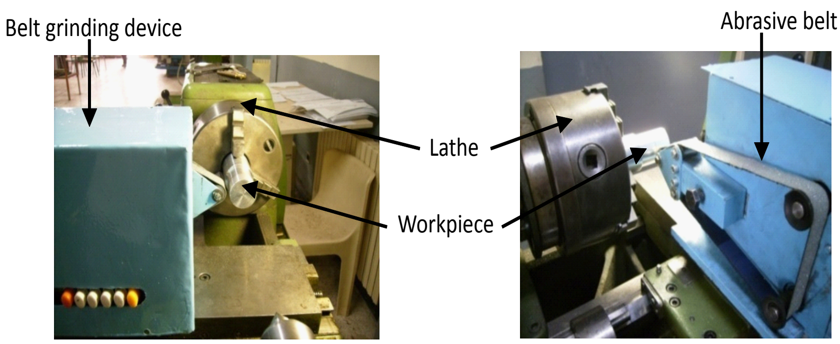


Figure 1 Belt grinding device mounted on a conventional lathe

2.2. *Materials used*

The material used is a 16MC4 casehardened steel hardness 30 HRc, induction hardening and tempered. Tempering is done in oil at a temperature of 860° C, followed by income to 200° C. Its surface hardness after income is 52 HRc.

Tab. 1 gives the chemical composition of the steel 16MC4.

Table 1 Chemical composition of case-hardened steel 16MC4

% mass	% C	% Cr	% S	% Si	% Mn	% Mo
Value measured	0,16	0,03	0,015	0,23	0,72	0,01

The samples are machined by stock removal with a ceramic tool having good edge retention, high toughness and high wear resistance. His designation to the ISO norm is: SNGN 12 08 08. However, the designation of the tool holder used is: CSSNR3225 P12. The cutting conditions in hard turning are: cutting speed, V_c = 63 m/min, feed rate, f = 0.1 mm/rev,; depth of cut, a_p = 0.3 mm. Fig. 2 shows the design of workpieces used.

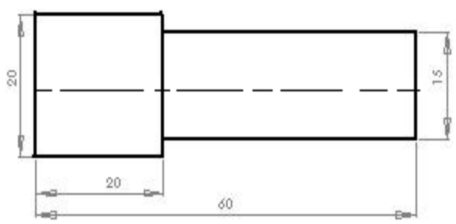


Figure 2 Design of samples casehardened steel 16MC4

Measurements of roughness were made on a profilometer 2D TAYLOR HOBSON (PRECISION MEASUREMENT SYSTEM FORM TALYSURF 120) of 0.8 nm precision, using a Gaussian filter and a cut-off = 0.8 mm. The roughness profiles are measured over an evaluation length L_n = 4,8 mm, according to ISO 4288 and ISO 13565 norms. 2D and 3D images are obtained by profilometer Altisurf 500, the surface was sampled in 0,5 x 0,5 mm^2. Each surface has been characterized by five measurements.

The roughness parameters measured during all tests by belt grinding superfinishing are: R_a: Arithmetic mean roughness, R_z: Maximum height of roughness profile, R_{PK}: Reduced peak height, R_K: Core roughness depth, R_{VK}: Reduced valley depth.

In this experimental study, abrasive belts used in belt grinding tests are constituted by a flexible cloth, resin and a single layer of grains of aluminum oxide with different grain size: 60 μm, 40 μm, 30 μm, 20 μm, 15 μm and 9 μm. The conditions of belt grinding fastened during all tests are:

1. Speed of the abrasive belt: 44rev/min.
2. Moving the abrasive belt: 2 mm.
3. Lubrication system: Minimum Quantity Lubrication (MQL).

3. Results and interpretations

3.1. *Effect of the belt grinding time, on the loss in thickness and the surface texture*

In this step, we take the size of 20μm abrasive grains and the rotation speed of the sample 900 rev/min.

3.1.1. *Thickness loss*

This loss is measured with the vertical horizontal microscope of 0.1μm precision. Fig. 3 shows the evolution of the loss in thickness depending on the belt grinding time with and without lubrication.

The rate of removal of the layer left by hard turning process is given by the equation:

$$V_{rem} = \frac{\Delta e}{t_{belt}} \tag{1}$$

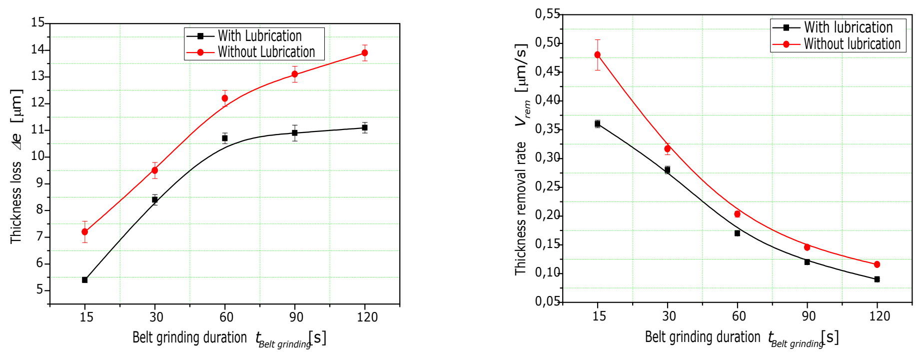


Figure 3 Loss in thickness and thickness removal rate depending on the belt grinding time with and without lubrication

From Fig. 3, we realize that the look of the two belt grinding curves with and without lubrication is identical namely a transitional area where the removal of material is very important and stability from t$_{beltgrinding}$ = 60 s. Indeed, the belt grinding corrects the defects left by hard turning and the process shows two regimes. The first between t$_{beltgrinding}$ = 0 and t$_{beltgrinding}$ = 60 s, the cutting phenomenon is predominant, which increases the removal rate of the thickness. The second regime t$_{beltgrinding}$ > 60 s, the friction phenomenon is predominant and the thickness removal rate decreases. This can be explained by the crushed abrasive grains and micro-chip lodged between the grains, this reduces the cutting ability of the abrasive belt and no longer allow to accelerate the cutting action.

3.1.2. *Roughness*

The following figure shows the variation of these two parameters roughness depending on the belt grinding time with and without lubrication.

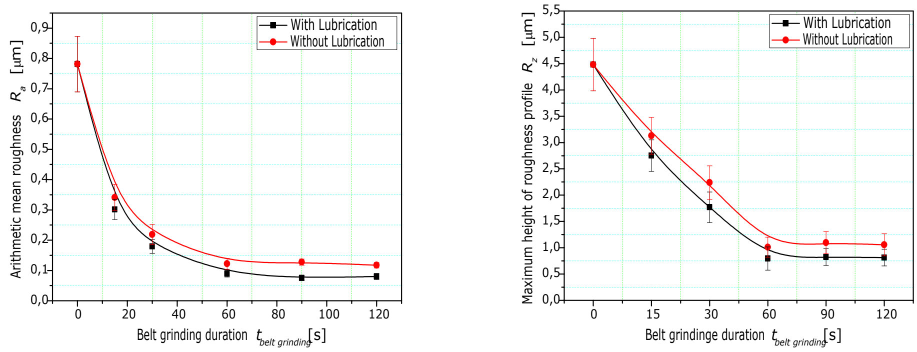


Figure 4 Variation of arithmetic mean roughness R_a and maximum height of roughness profile R_z depending on the belt grinding time with and without lubrication

Fig. 4 show that the state surface of hard steel 16MC4 improves considerably with the belt grinding time with or without lubrication. Indeed, the two curves R_a and R_z roughness (arithmetic mean roughness and the maximum altitude of profile) is a decreasing function up to belt grinding of time $t_{beltgrinding}$= 60 seconds, then they seem to be stabilizing. The belt grinding is a finishing process that attacks the peaks profiles without improving the hollow caused by hard turning.

Fig. 5 and 6 confirm the results of the roughness of hard steel surface 16MC4 obtained by the two profilometers TAYLOR HOBSON and Altisurf 500. Indeed, the arithmetic mean roughness of belt grinding with lubrication pass R_a = 0,7815 $\pm$0,0916μm to R_a = 0,0823 $\pm$0,011 μm after 60 seconds. However, in the second case (belt grinding dry), the roughness parameter pass R_a = 0,1074 $\pm$0,009 μm after the same time. So, we can say that under the conditions used, the optimum time of belt grinding by our device is $t_{beltgrinding}$ = 60s. Otherwise, we note that the roughness obtained by belt grinding with lubrication is always better compared to the belt grinding without lubrication, but the change is weak and this throughout the belt-grinding phase as a function of time.

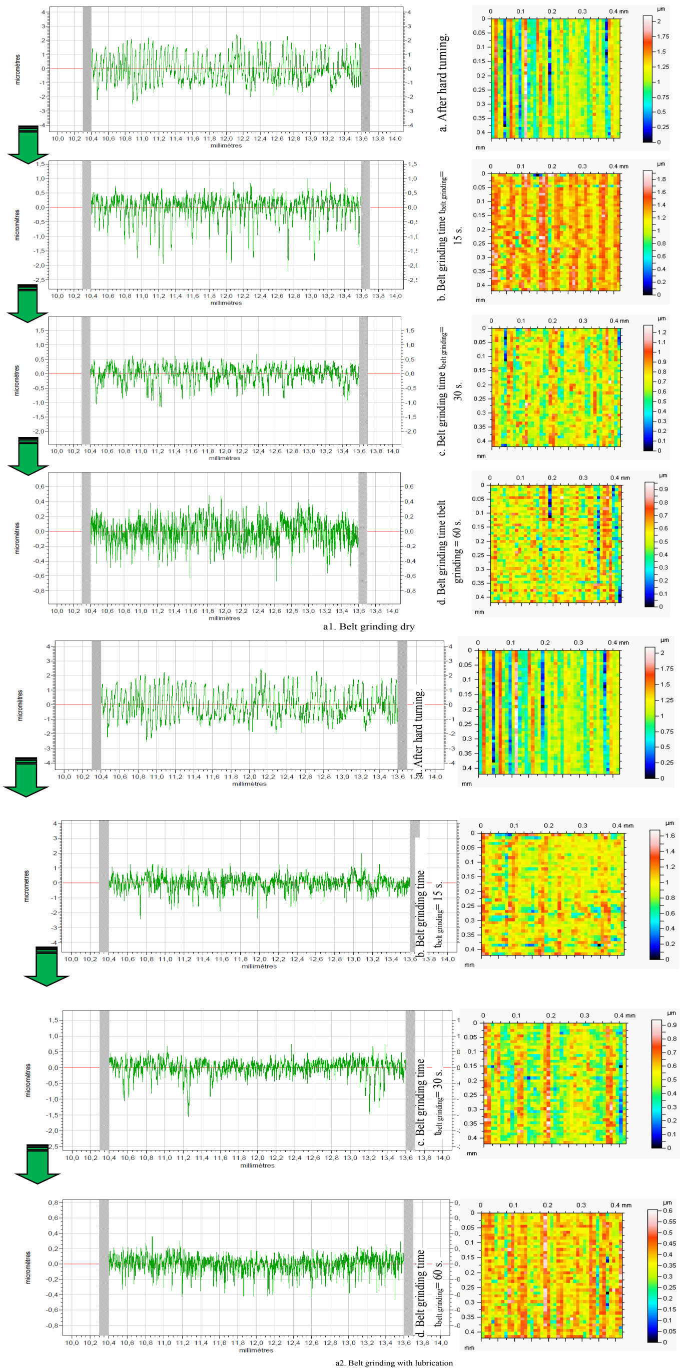


Figure 5 Profile surface finish: a. – after hard turning, a1. – after belt grinding dry, a2. – after belt grinding with lubrication

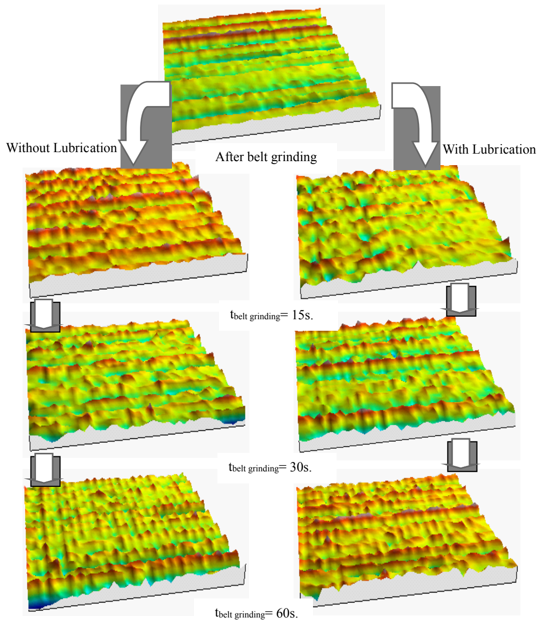


Figure 6 Surface topography according belt grinding time with and without lubrication

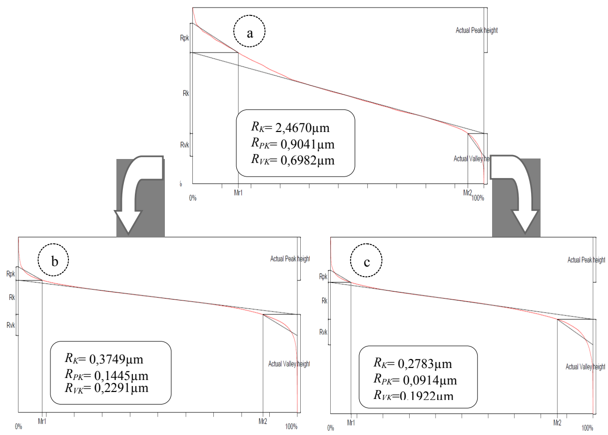


Figure 7 Evolution of the profile bearing ratio: a) Before belt grinding, b) After belt grinding dry, c) After belt grinding with lubrication, (Conditions: $t_{beltgrinding}$ = 60 s, Ø = 20 μm, N = 900 rev/min)

3.1.3. *Surface bearing area ratio*

The bearing length ratio is the ratio of the sum of the bearing lengths of the profile at a given depth C and the evaluation length.

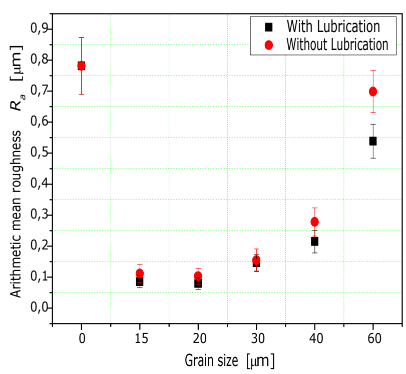
The material ratio curve (Abbott-Firestone curve) describes the variation in bearing length ratio as a function of increasing depth of the roughness profile. This curve allows us to understand the qualifying wear that will occur into operation, the effect of grinding or honing.

Fig. 7 shows the difference between the curves of the bearing ratio obtained before and after belt grinding to hard steel 16MC4.

From this curve Abbott-Firestone, we note that the belt grinding process to improve the shape of the curve obtained by hard turning in both cases with and without lubrication. The operation of belt grinding change the slope of the curve: where a decrease in the average height of protruding peaks, located above the clipped profile (R_{PK} of belt grinding dry pass 0,9041 μm to 0,1445 μm and 0,9041μm to 0,0914 μm of belt grinding with lubrication), This reduction limits the motor running time. The median part represents the section that performs the function of the surface (depth set on the roughness profile clipped R_K), the lower slope (fig. 7-c) is obtained by lubricated belt grinding, this more low slope, more a motor runs long. The last part is the average depth of the valley, located below the profile clipped R_{VK} that will never be used to retain a lubricant (oil reserves), is observed in both cases a small improvement, which limits the possibility of motor seizure. This enables a pre-honing of the functional surface before its commissioning.

3.2. ***Effect of abrasive grains size on the roughness***

In this part, rotation speed is fixed to the part 900 rev/min and the time of belt grinding 60 seconds and changing the size of the abrasive grains. Fig. 8 illustrates the variation of the arithmetic mean roughness R_a and the maximum amplitude of profile R_z depending on the size of abrasive grains for the hard steel.



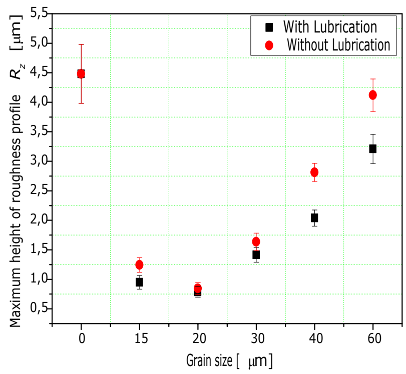


Figure 8 Variation of the surface roughness R_a and R_z with respect to the abrasive grains size

Fig. 8 and 9 shows that the surface roughness of behavior of both cases (with and without lubrication) is almost the same and it gives optimum roughness values to a grain size equal to 20 μm. This can be explained by the adjustment of particle morphology and size distribution of the abrasive belt with the initial state of the surface steel obtained by hard turning. Otherwise, poor roughness is achieved by the abrasive belt size 60 μm, this can be explained by the fact that during the large belt grinding, the contact surface between the abrasive grains and the finished surface is larger and therefore the grains remove more material which generates significant deficiencies as lower grain diameter.

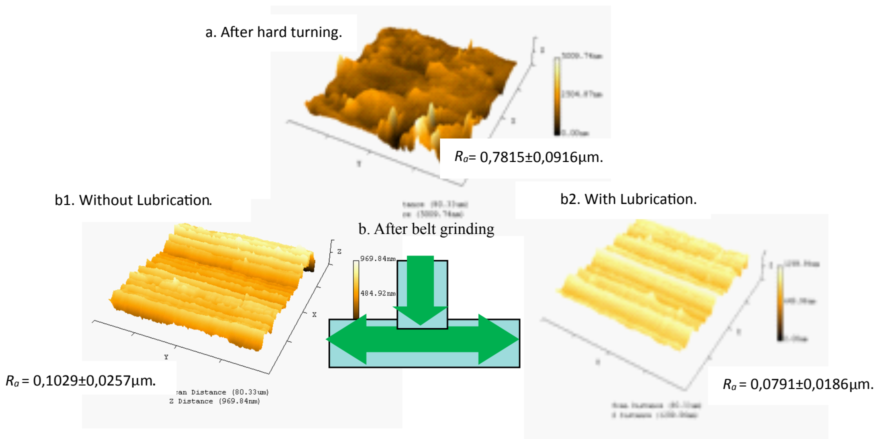


Figure 9 Microscopic image by AFM before and after belt finishing by size 20μm

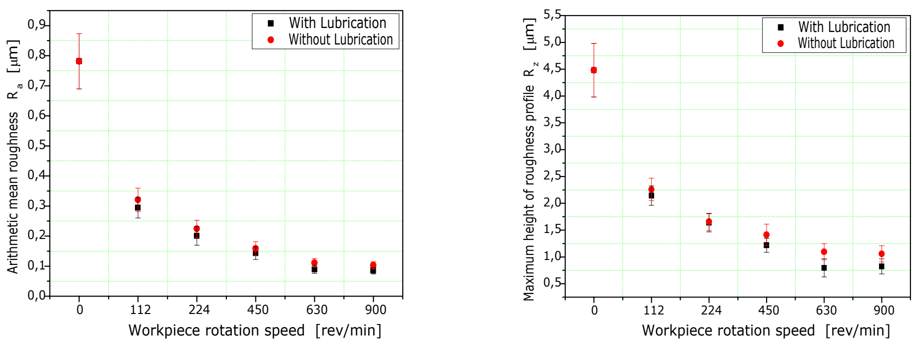


Figure 10 Belt grinding device mounted on a conventional lathe

3.3. *Effect of the workpiece rotation speed on the roughness*

In this part, we fix the belt grinding time $t_{beltfinishing} = 60$ s, the abrasive grains size 20 μm and change the workpiece rotation speed.

Fig. 10 shows the variation in the arithmetic mean roughness R_a and the maximum height of roughness profile R_z in relation to the workpiece rotation speed for both cases of belt grinding with and without lubrication.

Fig. 10. Variation of the surface roughness R_a and R_z as a function of the workpiece rotation speed with and without lubrication.

Fig. 10 that the surface state of the two cases belt grinding without and with lubrication hard steel improves when the rotational speed increases. Indeed, the curves of arithmetic mean roughness R_a and the maximum amplitude of roughness profile R_z decrease to the rotational speed of the part equal to $\sim$ 600 rev/min and then appears to be stabilizing somewhat; So we can say that 900 rev/min is the optimum rotation speed for steel pieces finished by belt grinding.

4. Conclusion

According to this study, the belt grinding proves to be an efficient and economical finishing process. Thus, it provides an excellent surface finish of hardened steel. Obtaining the final surface finish is achieved by clipping machining peaks without reaching the bottom of the valley, which allows eliminate defects of aspects and forms in order to retain the initial settings. The surface roughness parameter R_a of 0,08μm were observed, which allowed to determine the technological parameters of machining optimum and it only depends on the size of the abrasive grains and their particle sizes on the one hand and of the effectiveness of treatment of the other steel. Finally, the belt grinding is a promising finishing process and that there are ways to improve and increase its effectiveness.

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