JJMIE

Volume 15, Number 5, December. 2021
ISSN 1995-6665
Pages 441 – 449

Jordan Journal of Mechanical and Industrial Engineering

Impact of Abrasive Grit Size and MQL Supply on the Surface Roughness in Belt Grinding of a Case Hardened Steel

Amine Hamdi*, Sidi Mohammed Merghache

Laboratory of mechanical engineering, materials and structures, Faculty of Sciences and Technology, University of El Wancharissi-Tissemsilt, 38000, Algeria

Received April 29 2021 *Accepted October 6 2021*

Abstract

In automotive industries, the belt grinding (BG) is a mechanical manufacturing process by removing material using a tool called an abrasive belt. This technique enables high surface quality and reproducibility of high-precision mechanical parts to be achieved. The main objective of this paper is to provide a detailed account of the effect of superfinishing on the surface texture of 16MC5 casehardened steel by the belt grinding process under the alumina abrasive grains (Al_2O_3) with average sizes (60, 40, 30, 20 and 9 μm), respectively. The surface quality was characterized by one surface roughness parameter (Ra) and three parameters of the Abbott-Firestone curve (Rpk, Rk and Rvk) in order to determine the relationship between the grains size reduction and the surface texture. As all mechanical machining processes with undefined tool geometry (e.g. grinding, polishing, lapping,...etc.), experimental results obtained during measurements suggest a clear relationship between the reduction in abrasive grains size and the surface texture. The minimum quantity lubrication (MQL) also decreases the surface roughness; the lubrication addition helps to achieve better surface quality than the dry belt grinding.

© 2021 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved

Keywords: Abrasive grains, Belt grinding, Superfinishing, Surface texture;

1. Introduction

The belt grinding process is a machining technology ranked among the superfinishing processes by chip removal. In the automotive industry, it is very important for the superfinishing of automotive engine components subjected to variable (cyclical) requests in time, such as: crankshafts, camshafts, valves ... etc. The texture of its surface is obtained by mechanical action of a cutting tool consisting of a large number of high hardness abrasive grits, randomly between them and the small applied on elastic polyester backing and maintained by a resin. In the socio-economic world, the innovation of this method is to place the machining device on a conventional lathe. Therefore, the significant investments in the machine or even in the level of the infrastructure are not necessary. Over the last decade, abrasive belt grinding has attracted much attention from industry and academia due to the rapid development of abrasive belts [1, 2]. Mezghani et al. [3–5] has also found that this superfinishing process is extensively used in the automotive industry to finish the journals crankshaft. In this research, the authors indicate that the essential goal of belt grinding is to improve surface texture and to increase wear resistance and fatigue life. However, the cutting tool (abrasive belt in this case) is a critical variable that affects the surface quality.

Previous research [6, 7] has shown that the arithmetical mean height parameter of profile *Ra* passes by 0,27 μm to 0,09 μm and the core roughness depth *Rk* passes by 0,9 μm to 0,38 μm if one operates on a bearing steel 100Cr6 (AISI 52100) of 62 HRC hardness for hard turning and belt finishing. The same researcher, but studying the surface roughness of the same hard steel before and after belt finishing in another paper [8], found that the initial arithmetic average of the roughness profile *Ra* = 0,25 μm had been improved to 0,1 μm after belt grinding, reflecting a 60% decrease. In addition, the belt grinding process removes the average width of the roughness profile elements created by hard turning. This constitutes a major benefit in terms of limiting the working surface running-in time. After two belt grinding operations with 30 μm and 9 μm grains, the mean peak spacing parameter *Rsm* decreases significantly, the value of this parameter obtained with the CBN cutting tool by the hard turning is 62,5 μm and becomes 20,5 μm after the belt grinding with the abrasive grit size reduction (30 μm + 9 μm). Furthermore, after both finished abrasive processes, the root mean square (RMS) slopes $R\Delta q$ decreases and oscillates slightly about 4° [9]. Therefore, the abrasive belt machining is considered a flexible and very precise superfinishing method [8–11].

The effect of two-passes belt grinding using abrasive belts with 30 μm and 9 μm grains on the standard 3D surface roughness parameters of hardened steel 41Cr4 with a hardness 57 ± 1 HRC was established by Grzesik et al. [12]. They showed that this machining technique greatly improves the 3D surface roughness parameters for nine seconds of belt grinding with the supply of oil mist provided by a *MQL* system, the surface arithmetic average roughness *Sa* parameter decreases successively from 0,4 μm to 0,04 μm and the maximum surface height *Sz* obtained is 1,33 μm. Minimum quantity lubrication (*MQL*) is currently a

* Corresponding author e-mail: hamdi_amine@ymail.com.

promising alternative to traditional application of fluid coolant [13]. Wang et al. [14] presented a study on the influence of applied force and finishing duration on residual stresses produced during dry belt grinding of bearing parts (AISI52100). When measuring these stresses, the authors observed high compressive residual stresses in the external layer of about 5-10 µm. However, the belt grinding time has no significant effect on the stress distribution and the growing applied force may increase surface circumferential residual stresses marginally, but has an unavoidable impact in the oscillation direction. Simultaneously, Wang et al. [15] investigated the changes produced by dry belt grinding operations on the surface texture of the part and the wear of the abrasive tool. The belt ground material in this work is bearing steel (100Cr6: AISI 52100) with a hardness equal to 62 HRC. The authors indicate that the abrasive grains wear of the cutting tool can be evaluated by three surface roughness parameters (3D: *Sz*, *Sdq* and *Spc*).

In the year 2013, Jourani et al. [16] produced a three-dimensional numerical model (3D) in abrasive belt machining. The abrasive grains made up of the belt-grinding tool are represented by cones of two abrasive papers S20 and S30. The effect of the local geometry of abrasive grains on two machining output variables (friction coefficient (μ) and wear rate (f_{ab})) is studied using this multi-asperity model. During the process, the belt ground surface is represented by a perfectly flat surface and penetrators with different attack angles (abrasive grains) do not deform. The results show a proportional relationship between the output parameters (μ and f_{ab}) and the penetration depth (δ_i). In addition, the same correlation found between the calculated quantities (μ and f_{ab}) and the abrasive grains size (S20 and S30). By the same method and for the same superfinishing process, Jourani [17] developed a three-dimensional model (3D) to study the temperature distribution at the interface abrasive paper/belt ground part. The output variable (T) determined under the effect of the curvature radius (R_i) and the attack angle (α_i) of each abrasive grain. The latter is represented by a cone with a hemispherical tip (R_i). The numerical results indicate a proportional relationship between the output parameter distribution (T) and the both input parameters (R_i and α_i). Recently, Hamdi et al. [18] studied the impact of seven polymer contact rollers (PS-R, POM C-R, PA 6-R, PPC-R, PPH-R, HDPE-R and LDPE-R) on the belt ground surface texture. The latter was characterized by eight roughness parameters (*Ra*, *Rz*, *Rp*, *Rv*, *Rsk*, *Rku*, *Rsm* and *Rdq*) and five parameters of the Abbott-Firestone curve (*Rpk*, *Rk*, *Rvk*, *Mr1* and *Mr2*). The material machined in this experimental study is 16MC5 hardness steel 52 HRC and the abrasive belts used are abrasive grain size 30 µm and 20 µm. After a comparison between the results of seven rollers, the authors indicate that the polyamide roller PA 6 of hardness 60 Shore D gives a better surface texture than that obtained by other rollers of the same hardness or of different hardness. However, optimal medium pressure between the abrasive tool and the belt ground workpiece allows chip removal without fracturing the abrasive grains.

A recent study examined the abrasive belt superfinishing, whereby there are several finishing operations, which are used, in the final stage of manufacture of the high-quality mechanical parts making up the automotive engine in order to reduce the friction between the surfaces, for example, they cited: antifriction coating technology, texturing technology, or more generally, reducing surface roughness [19]. Very recently, the belt grinding has become a very efficient method of superfinishing crankshaft journals and pins to minimize surface peaks, improve geometric efficiency and increase wear resistance and fatigue [19, 20]. Typically, this is achieved by processing three or more belt grinding steps while successfully reducing the size of the grits [19, 20]. There are actually three common superfinishing techniques for abrasive grains, but there are different kinematic techniques: grinding, belt grinding, and belt finishing. The grinding is a very well known operation. The belt is endless in the belt grinding, and the worn grains return still in contact. Moreover, on the belt, no oscillation is applied. On the contrary, fresh grains are continuously inserted into contact in the above application, while worn grains are removed at the same time [21]. Based on a numerical method, Wang et al. [22] proposed a study of geometry interaction between abrasive grains of the belt and workpiece during belt grinding. The results found indicate that the roughness parameter *Ra* is significantly influenced by the belt length and the abrasive wear height, while the cutting depth has an insignificant effect on the same parameter (*Ra*).

However, the studies on the belt grinding under the effect of the abrasives grits size are still lacking. The goal of this paper is therefore to successively investigate the impact of this technique on the belt ground surface texture (five-pass belt grinding). In particular, the surface roughness parameters and the bearing area curve (BAC) parameters were determined.

2. Experimental procedures

2.1. Material, workpiece and tool

The belt grinding operations related to the roughness and bearing area curve parameters were realized on 16MC5 (%C 0,14/0,18) casehardened steel test pieces that are 52 HRC in hardness. The material induction hardening and quenched, quenching is done in oil at a temperature of 860 °C, followed by income to 200 °C. The belt-grinding device on which the superfinishing operations were performed is shown in Figure 1 [18, 23]. The abrasive belts used in the belt grinding tests in this experimental study consist of a flexible backing, resin and a single layer of Al_2O_3 abrasive grains of varying sizes: 60 µm, 40 µm, 30 µm, 20 µm and 9 µm (see Figure 2).

The white ceramics inserts used are square-shaped, removable and fixed by an SNGN 120808 flange that is mounted on a tool holder of CSSNR3225 P12 designation. Cutting parameters used were: cutting speed : Vc = 100 m/min, feed rate : f = 0,1 mm/rev and depth of cut : ap = 0,3 mm.

For each measurement of the belt ground surface texture, a 2D TAYLOR HOBSON profilometer with a 2 µm diamond stylus radius is used. According to the ISO 4288 and ISO 13565 standards, the roughness profiles were carried over an evaluation length equal to Ln = 4,8 mm, a cut-off length was set at 0.8 mm and using a Gaussian filter. An AltiSurf®500 optical metrology unit is also used to improve the visualization of the roughness of the machined surfaces. It allows for a thorough examination of the 3D topography of the belt ground surface texture [23].

The belt grinding conditions which are set during all the tests are shown in Table 1.

3. Experimental results and discussion

3.1. Surface Roughness

In the Figure 3 the variation in the surface quality (Ra) is shown as a function of the reduction in the size of abrasive grits without and with lubrication.

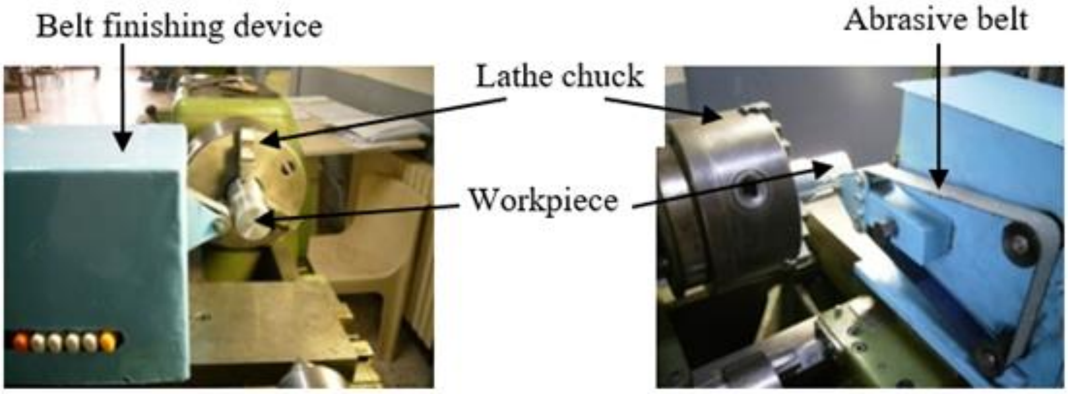


Figure 1. Belt grinding device mounted on a conventional lathe.

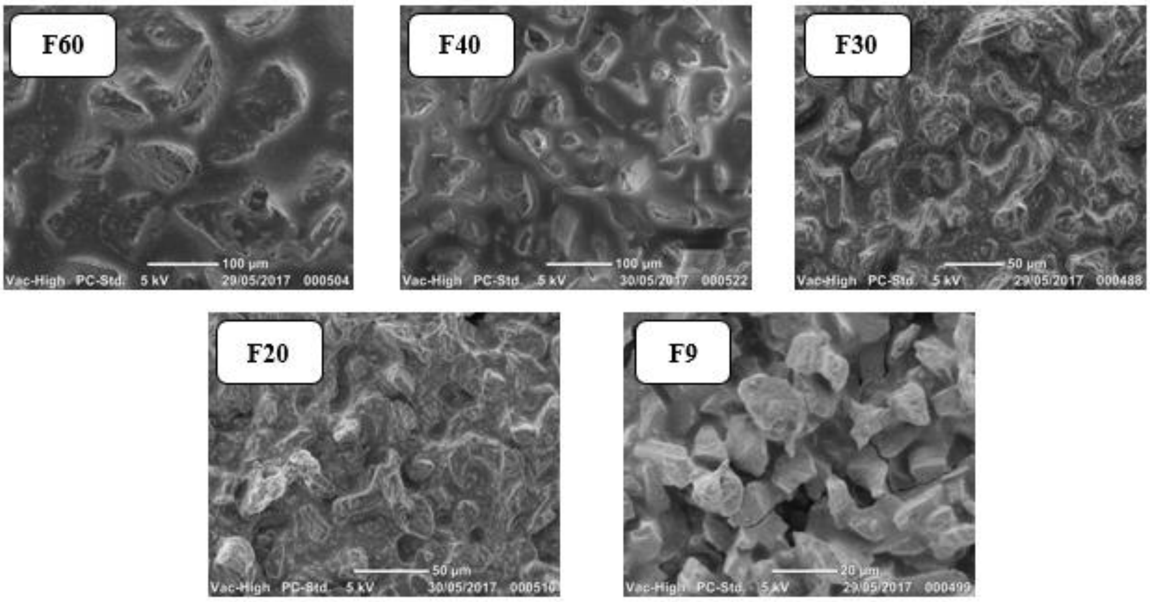


Figure 2. SEM images of new abrasive belts.

Table 1. Belt grinding conditions set during all tests

Working conditions	Value
Rotation speed of the workpiece	900 rev/min
Applied force between belt and workpiece (Fn)	100 N
Belt feed (Va)	44 rev/min
Belt grinding duration ($t_{belt\ grinding}$)	9 s
Oscillation amplitude (a_{osc})	0 mm
Oscillation frequency (n_{osc})	0 mm
Lubrication system (microlubrication: Minimum Quantity Lubrication (MQL))	Oil Tasfalout 22^M diluted to 1/10. The mineral oil flow rate is 60 ml/h and injected at very high velocity (80 m/s). A single nozzle is oriented between the workpiece and the abrasive belt (cutting zone).

 © 2021 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 15, Number 5 (ISSN 1995-6665)

From this Figure 3, surface state represented by the arithmetic average of roughness profile *Ra*improves progressively when the abrasive grits size decreases. This explains why the roughness of the hard steel surface tends to decrease under the effect of grits size. Both profile roughness parameters of the hard turning are: *Ra* = 0,781 µm and after belt grinding without lubrication up to the abrasive grits size 9 µm, they decrease: *Ra* = 0,049 µm, which represents a reduction of about 94 %. Concerning the second case with lubrication, they are much better: *Ra* = 0,020 µm, which represents a reduction of about 97 %, for the same grits size (9 µm). The *Ra* parameter is less than 1 µm in both cases of belt grinding, which meets the surface quality criterion of high precision machining [24].

The equations adopted in this analysis are linear in shape since they have the uppermost coefficients of determination (denoted R^2). So, the linear regression equation of the arithmetic average of roughness profile (Ra) with lubrication is given by formula (1) and without lubrication is expressed by formula (2). The value of the coefficient of determination (R^2) is 98,1%, 98,6%, respectively.

$$Ra_{\text{With lubrication}} = 0{,}009\text{Gs} - 0{,}087 \quad (R^2 = 0{,}981) \tag{1}$$

$$Ra_{\text{Without lubrication}} = 0{,}011\text{Gs} - 0{,}07 \quad (R^2 = 0{,}986) \tag{2}$$

Thus, it can be noted in Figure 4, that the peaks of the belt grinding of abrasive grains size reduction with or without lubrication are distinctly low compared to the peaks of hard turning. Indeed, this finding can be explained by the fact that the contact surface between the grits and the finished surface is larger during the belt grinding by large grits, so the grits eliminate more macro-geometric defects and prepare the surface in the next step, mean or fine grits. However, finer grits in contact with the surface constitute a smaller contact surface and thus remove more micro-geometrical defects. The roughness decreases proportionately with the reduction in the size of abrasive grits, suggesting a correlation between surface quality and grain size. This phenomenon of the belt grinding process is similar to the work of Belkhir et al. [25] which relates to optical glass polishing. This observation is confirmed further by Figure 5, compared with the second case without lubrication, the peaks obtained by belt grinding decreasing the size of abrasive grains (up to 9 µm) with lubrication are higher. Therefore, this approach helps the process to clip the peaks of the roughness leash, which greatly improves the final surface of the hard steel.

Comparing our results with others obtained by a finishing process of the same principle and commonly used in the automotive industry (grinding), we take for example, the results of a recent research by Grzesik et al. [26]. These researchers rectified a 41Cr4 (AISI 5140 equivalent) steel of hardness 57 ± 1 HRC by a conventional cylindrical grinder using mono-crystalline aloxite Al_2O_3 wheel with 5 passes plus spark-out. The obtained roughness parameter *Ra* was about 0,3 µm and the other *Rz* was 2,4 µm. Therefore, this last parameter is superior to 1 µm (high-precision machining surface quality criterion with *Rz* < 1 µm), although is close to the precision machining interval with *Rz* = 2,5-4 µm [12, 24–27].

Kenda et al. [27] studied the effect of the abrasive flow machining (AFM) process parameters on the surface integrity of the hardness 59 HRC heat treated tool steel AlS1 D2 in recent polishing process. By electrical discharge machining operation (EDM), the initial state of the parts was obtained. They measured the roughness before and after the abrasive flow machining in two directions (along and transverse). According to this study, the lower roughness (*Ra*, *Rz* and *Rt*) are obtained for the direction of longitudinal measurement to the workpiece and the maximum pressure (6.0 MPa). The reduction ratio of the arithmetic average of roughness profile is about 86 per cent. In this comparison, the reduction ratio of Ra of belt grinding with lubrication is about 97 per cent.

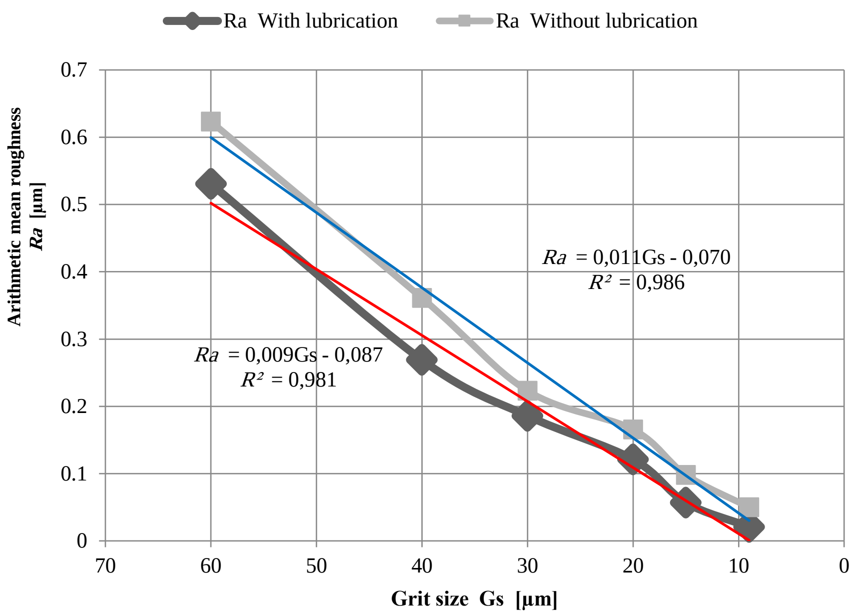
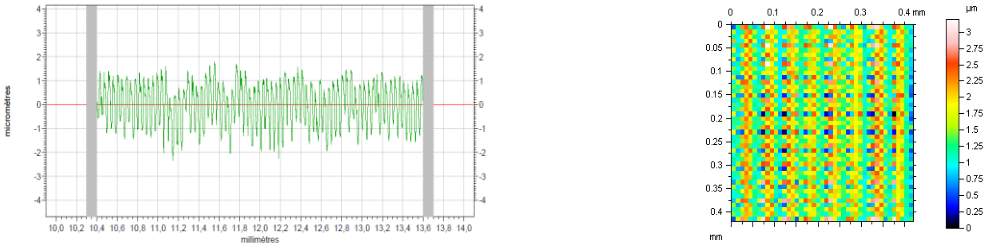
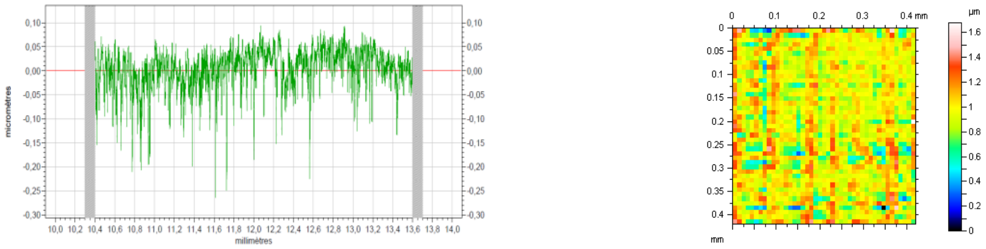


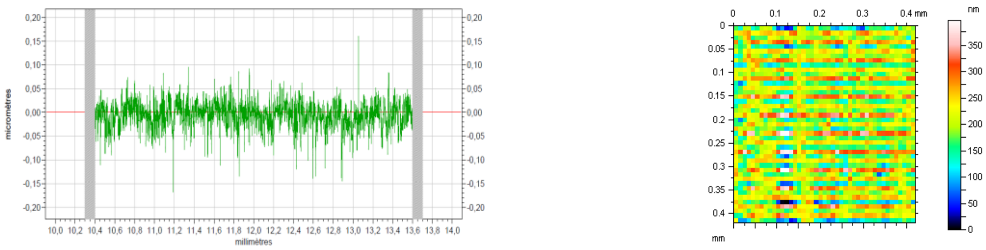
Figure 3. Ra generated by the belt grinding process without and with lubrication under abrasive grit size reduction.



(a) After hard turning (HT)

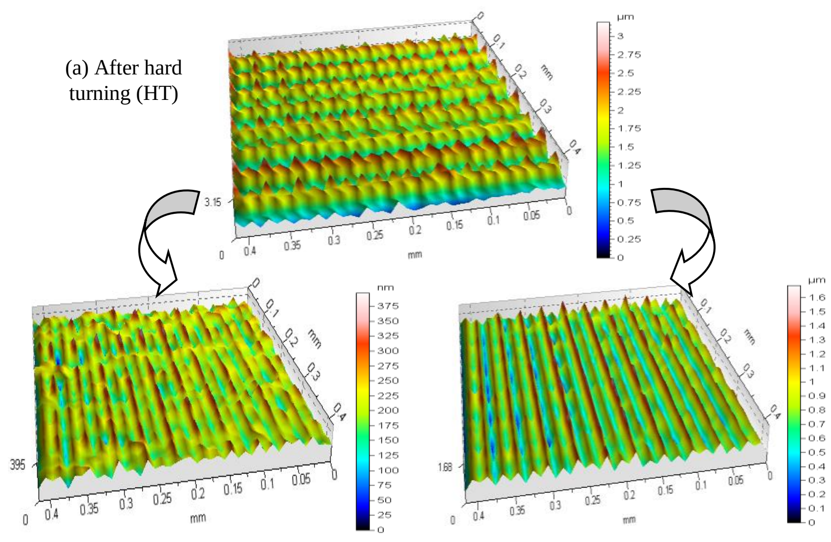


(b) Grains size: 60 µm + 40 µm + 30 µm + 20 µm + 9 µm



(c) Grains size: 60 µm + 40 µm + 30 µm + 20 µm + 9 µm

Figure 4. Surface profiles generated by: (a) after hard turning, (b) successful belt grinding without lubrication, (c) successful belt grinding with lubrication.



(c) With lubrication

(b) Without lubrication

Figure 5. Surface topography 3D generated by successive belt grinding (up to 9 µm) without and with lubrication.

This process does not make it possible to eliminate the extra thickness such as the extra thickness from grinding. The belt finishing does not introduce heating only over a small number of asperity peaks and the contact temperatures distribution increases with the abrasive grains size [28], contrary to the grinding, which induces a modification of the microstructure of the surface layer of part. Moreover, contrary to ground surfaces, the characteristics of superfine surfaces are completely constant, as well on the part itself as in all the parts of a series.

This comparison clearly shows that belt ground surfaces are best compared to ground surfaces or obtained with abrasive flow machining. In addition, the technique of superfinishing by abrasive belt induces compressive residual stresses in a very thin sublayer of around 5-10 μm according to the previous study by Rech et al. [21]. By this great improvement in surface roughness and compressive residual stresses, the belt grinding process greatly improves the surface integrity, which positively influences fatigue strength and improves service life of the mechanical parts.

Finally, after this section, we can notice that the high-precision finishing process by belt grinding attacks the hollow profile crests of hard turning which resists little wear and gives a full profile that is more resistant to wear. The surface integrity can not only be completely changed during the application of lubricated belt grinding process, but also improved compared to dry finish turning (hard turning) as reported by Courbon et al. [29]. In a study of dry hard turning of AISI D3 steel of hardness 62 HRC, Bhemuni and Rao Chalamalasetti[30] used central composite design (CCD) to perform experimental testing and response surface methodology (RSM) to model Ra roughness. The best roughness found is 0.561 µm by the following cutting parameters: Vc = 165 m/min, f = 0,05 mm/rev et ap = 0,3 mm. In their conclusion, the author indicates that the roughness found is close to that obtained in grinding. Sureshchandra Maheshwari and Ratnakar Gawande [31] studied the improvement of surface quality of AA 6351 by the stiff burnishing process. The previous methods (CCD + RSM) are used to do the experimental part and the second digital part. The best roughness found is: Ra = 0,057 µm. So, after this comparison, the belt grinding remains the most effective technique in order to obtain a better surface quality.

3.2. Bearing ratio parameters

Nowadays, characterization of the belt ground surface texture affected by the ISO 13565 standard takes an important place by the automotive industry; this method based on analysis of the material/bearing ratio curve (or Abbott-Firestone curve) parameters of roughness profiles. According to Hamdi et al. [32], the surface functionality can be described by the parameters of the bearing ratio curve (Rpk, Rk and Rvk), plus other roughness parameters (like for example: Ra, Rt, Rsm, ... etc.). The following Figures 6–7 shows the variation of various parameters from bearing area of belt grinding depending to grits size reduction.

These parameters are determined from the bearing ratio curve by integrating the distribution of height over the whole surface. They are shown of particular interest to characterize the surface texture [19]. According to Figure 6, we note that the three curves (Rpk, Rk and Rvk) represent almost the same trend; there is proportionality between the three parameters and the abrasive grits size reduction. The final reduced peak height Rpk of belt grinding with lubrication to the grits size up to 9 μm is about 96 per cent less than the initial Rpk and without lubrication is about 94 per cent, which transmit a percentage of 4 per cent of the asperities to remove during the first hours of honing operation (Rpk represents the material portion in the vicinity of peaks being removed during sliding interactions. So, the running-in period can be shortened as much as possible [33]). The final kernal roughness depth (or core roughness depth) parameter Rk is about 96 per cent less than the initial and 95 per cent for dry belt grinding, it represents the material quantity available for wear to the engine life. In regards to, the third parameter (reduced valley depth) Rvk, it is less than the initial state of a percentage of about 93 per cent and 88 per cent of dry belt grinding, leaving 7 per cent of those who will never be worn to retain the lubricant required for proper functioning. Khellouki et al. [6] studied via a design of experiments, the effects and the interactions of the belt finishing parameters on the surface state of AISI 52100 bearing steel. It's have shown that the belt finishing improves considerably the surface bearing curve parameters (Rk pass by 0,9 μm to 0,38 μm, Rpk pass by 0,35 μm to 0,12 μm and Rvk pass by 0,12 μm to 0,15 μm).

The formula of the reduced peaks height *Rpk* with lubrication is given by formula (3) and without lubrication is given by formula (4). The value of the coefficient of determination (R^2) of these formulas is equal to 98,5%, 98,5%, respectively.

$$Rpk_{\text{With lubrication}} = 0{,}009Gs - 0{,}055 \quad (R^2 = 0{,}985) \tag{3}$$

$$Rpk_{\text{Without lubrication}} = 0{,}011Gs - 0{,}04 \quad (R^2 = 0{,}985) \tag{4}$$

The linear regression equation of core roughness depth *Rk* with lubrication is given by formula (5) and without lubrication is given by formula (6). The coefficient of determination (R^2) is 97,8%, 99,1%, respectively.

$$Rk_{\text{With lubrication}} = 0{,}032Gs - 0{,}272 \quad (R^2 = 0{,}978) \tag{5}$$

$$Rk_{\text{Without lubrication}} = 0{,}035\ Gs - 0{,}22 \quad (R^2 = 0{,}991) \tag{6}$$

The linear equation of reduced valley depth *Rvk* with lubrication is given by formula (7) and without lubrication is given by formula (8). The coefficient of determination (R^2) of these formulas is equal to 97,2%, 97,8%, respectively.

$$R_{vk\ \text{With lubrication}} = 0{,}01Gs - 0{,}004 \quad (R^2 = 0{,}972) \tag{7}$$

$$R_{vk\ \text{Without lubrication}} = 0{,}011Gs - 0{,}024 \quad (R^2 = 0{,}978) \tag{8}$$

Table 2 gives a comparison between three parameters of the material ratio curve (*Rpk*, *Rk* and *Rvk*) in terms of percentages left by the belt grinding process with the minimum quantity lubrication (*MQL*).

Table 2. Percentage of three parameters (*Rpk*, *Rk* and *Rvk*) generated by the belt grinding process with *MQL*

Parameters	Percentage [%]	Remarks
Rpk	4	Low: Good to reduce running-in time and wear
Rk	4	Low: Good to reduce oil consumption
Rvk	7	Great: Good for feeding, circulation and storage of oil

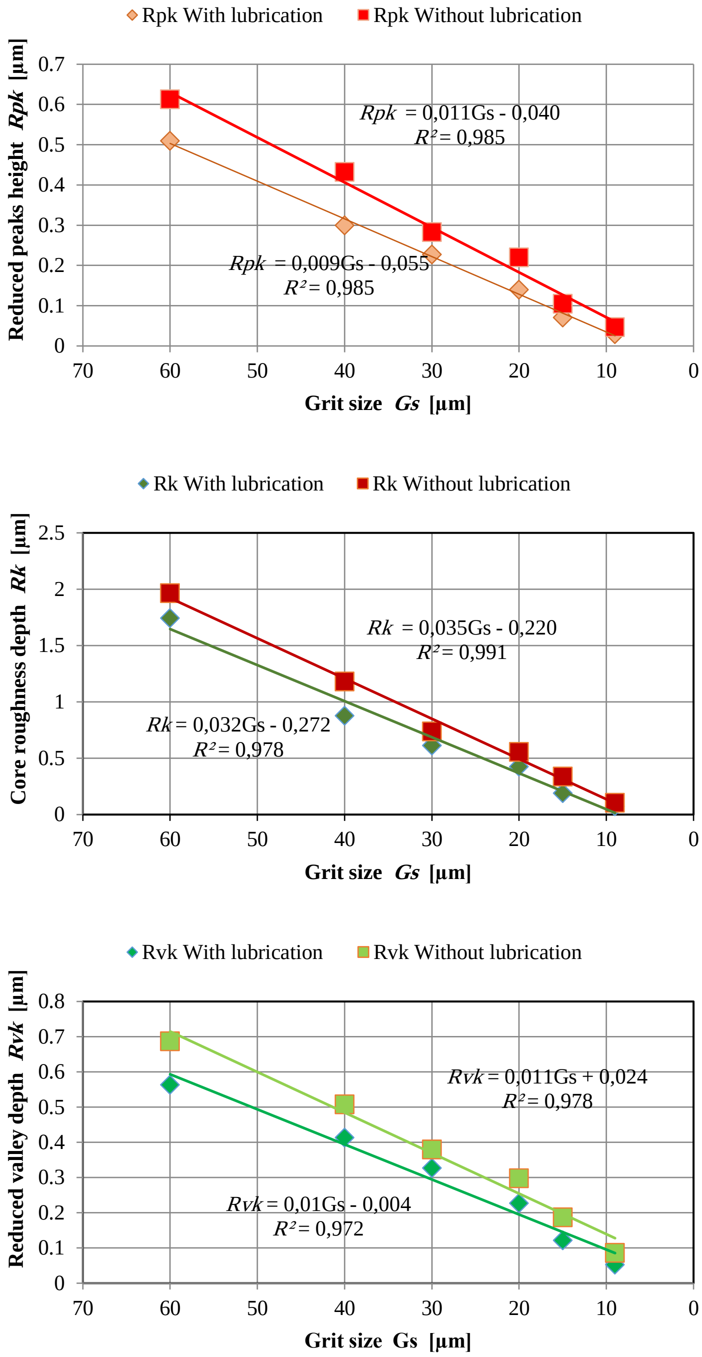
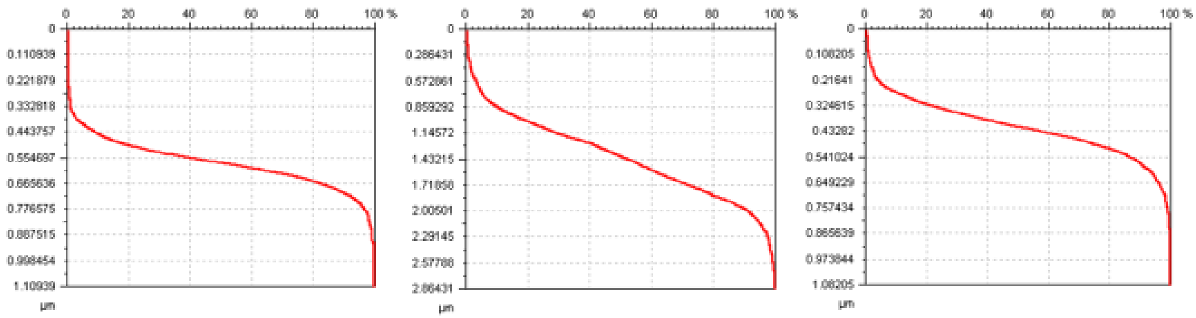


Figure 6. Settings the bearing area curve (*Rpk*, *Rk* and *Rvk*) of belt grinding according to grits size reduction.



(b) After BG without lubrication. (a) After hard turning. (c) After BG with lubrication.

Figure 7. Material ratio curve (BAC) of successful belt grinding (BG) with and without lubrication: up to 9 µm.

© 2021 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved - Volume 15, Number 5 (ISSN 1995-6665)

About the equivalent straight line of the bearing ratio curve (Figure 7) is very significant because it is related to the wear rate of the surface, see that the equivalent slope of the two cases of successful belt grinding is lower than for hard turning (the curve obtained by hard turning falls rapidly: Figure 7.a) and successful belt grinding with minimum quantity lubrication is lower relative to the dry belt grinding (see that the curve is relatively a horizontal line in its intermediate part; Figure7.c), confirming that the belt ground surface obtained with lubrication having an almost perfect shape tray, so the engine runs long. In comparison with the work of Khellouki et al. [8], on bearing steel 100Cr6 (AISI 52100) tempered at 62 HRC as a function of the increase in applied force, they found that the slope of the bearing area curve reduced and the peaks are decreased. Thus, the belt finishing surface approaches the configuration which characterizes a 'plateau' surface. This kind of surface is required for its good bearing properties. Jourani et al. [34] presented a three-dimensional numerical model (3D) of belt grinding and showed that both processes (hard turning (HT) or belt grinding (BG)) improve the surface texture and more in particular, the bearing area curve (BAC).

4. Conclusion

In this work, the impact of the reduction in the abrasive grain size during belt grinding on the surface texture of 16MC4 casehardened steel is studied here. It can be inferred from the outcome of our research that the belt grinding process can be used in practice effectively and the reduction in the size of abrasive grains is proportional to the improvement of the surface texture. This process makes it possible to achieve a very low roughness on the surface of a workpiece and a "polished mirror" state in the range of several micrometers up to a few tens of nanometers. The roughness of the order has been found: *Ra* = 0,02 µm and *Rz* = 0,24 µm. So, the belt grinding enables a glossy surface to be obtained, the roughness to be reduced and the required precision to be formed. Finally, the belt grinding of the abrasive grains size reduction with minimum quantity lubrication (*MQL*) is a promising finishing process and increases its effectiveness. In some cases and according to the application, dry belt grinding is also feasible.

Acknowledgement

This research was supported by the Mechanical Engineering, Materials and Structures Laboratory approved in 2020 by Ministerial Order N° 05 on 18 February 2020, a laboratory of excellence at the University of Tissemsilt, General Directorate of Scientific Research and Technological Development (DGRSDT), Ministry of Higher Education and Scientific Research, ALGERIA.

Appendix

Symbols	Description
Ra	Arithmetic average of roughness profile
Rz	Maximum height of the profile
Rpk	Reduced peak height
Rk	Core roughness depth
Rvk	Reduced valley depth
Rsm	Mean spacing of the profile elements
RΔq	Root mean square (RMS) slopes
Sa	Arithmetic mean roughness of the surface
Sz	Maximum surface height
μ	Friction coefficient
f_{ab}	Wear rate
δ_i	Penetration depth
R_i	Curvature radius
α_i	Attack angle
Rp	Maximum profile peak height
Rv	Maximum profile valley depth
Rsk	Asymmetry factor (Skewness)
Rku	Sharpness factor (Kurtosis)
Mr1	Material portion corresponding to the upper limit position of the roughness core profile (material portion 1)
Mr2	Material portioncorresponding to the lower limit position of the roughness core profile (material portion 2)
Vc	Cutting speed
f	Feed rate
ap	Depth of cut
Ln	Evaluation length
R^2	Coefficient of determination

References

[1] C. Cheng, J. Li, Y. Liu, M. Nie and W. Wang, "An online belt wear monitoring method for abrasive belt grinding under varying grinding parameters,"*Journal of Manufacturing Processes 50*, pp.80–89, 2020.

[2] C. Cheng, J. Li, Y. Liu, M. Nie and W. Wang,"Deep convolutional neural network-based in-process tool condition monitoring in abrasive belt grinding,"*Computers in Industry 106*, pp.1–13, 2019.

[3] S. Mezghani and M. El Mansori,"Abrasiveness properties assessment of coated abrasives for precision belt grinding,"*Surface & Coatings Technology 203*, pp.786–789, 2008a.

[4] S. Mezghani, M. El Mansori, A. Massaq and P. Ghidossi,"Correlation between surface topography and tribological mechanisms of the belt-finishing process using multiscale finishing process signature,"*C. R. Mecanique 336*, pp.794–799, 2008b.

[5] S. Mezghani, E. Sura and M. El Mansori, "The effect of belt-finishing process variables on the topography of finished surfaces,"*Trib. Trans, 51(4)*, pp.1-9, 2008c.

[6] A. Khellouki, H. Maiz, J. Rech and H. Zahouani,"Application of the method of design of experiments to characterize the belt finishing process,"*–4th International Conference 'Integrated Design and production*, Casablanca, Morocco, 2005.

[7] A. Khellouki, H. Maiz, J. Rech and H. Zahouani,"The effect

of abrasive grain's wear and contact conditions on surface texture in belt finishing,"*Wear 263*, pp.81–87, 2007a.

[8] A. Khellouki, H. Maiz, J. Rech and H. Zahouani,"Influence of the belt-finishing process on the surface texture obtained by hard turning,"*Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture 221 (7)*, pp.1129-1137, 2007b.

[9] W. Grzesik, J. Rech and T. Wanat,"Surface integrity on hardened steel parts produced by hybrid machining sequences,"*Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 31, no. 2, pp.654–661, 2008.

[10] W. Grzesik, J. Rech and T. Wanat, "Surface finish on hardened bearing steel parts produced by superhard and abrasive tools,"*Int J Mach Tool Manu 47(2)*: pp.255–262, 2007.

[11] L. Zou, X. Liu, Y. Huang and Y. Fei,"A numerical approach to predict the machined surface topography of abrasive belt flexible grinding," *Int J Adv Manuf Technol 104*, pp. 2961–2970, 2019.

[12] W. Grzesik, J. Rech and K. Żak,"High-Precision Finishing Hard Steel Surfaces Using Cutting, Abrasive and Burnishing Operations,"*Procedia Manufacturing*, Vol. 1, pp.619–627, 2015a.

[13] M. M. Rahman and K. Kadirgama,"Material removal rate and surface roughness on grinding of ductile cast iron using minimum quantity lubrication,"*International Journal of Automotive and Mechanical Engineering (IJAME)*, Vol. 11, pp.2471-2483, 2015.

[14] W. Wang, F. Salvatore and J. Rech,"Characteristic assessment and analysis of residual stresses generated by dry belt finishing on hard turned AISI52100,"*Journal of Manufacturing Processes 59*, pp.11–18, 2020.

[15] W. Wang, F. Salvatore, J. Rech and J. Li,"Comprehensive investigation on mechanisms of dry belt grinding on AISI52100 hardened steel,"*Tribology International 121*, pp.310–320, 2018.

[16] A. Jourani, B. Hagège, S. Bouvier, M. Bigerelle and H. Zahouani,"Influence of abrasive grain geometry on friction coefficient and wear rate in belt finishing,"*Tribology International 59*, pp.30–37, 2013.

[17] A. Jourani, "Three dimensional modelling of temperature distribution during belt finishing,"*Int. J. Surface Science and Engineering*, Vol. 9, No. 2/3, pp.231–246, 2015.

[18] A. Hamdi, S.M. Merghache, B. Fernini and T. Aliouane, "Influence of polymer contacting rollers on surface texture finish in the belt grinding process,"*Int J Adv Manuf Technol 113*, pp.1377–1388, 2021.

[19] K. Serpin, S. Mezghani and M. El Mansori,"Multiscale assessment of structured coated abrasive grits in belt finishing process,"*Wear 332-333*, pp.780–787, 2015a.

[20] K. Serpin, S. Mezghani and M. El Mansori,"Wear study of structured coated belts in advanced abrasive belt finishing,"*Surface & Coatings Technology 284*, pp.365–376, 2015b.

[21] J. Rech, G. Kermouche, W. Grzesik, C. Garcia-Rosales, A. Khellouki and V. Garcia-Navas, "Characterization and modelling of the residual stresses induced by belt finishing on a AISI52100 hardened steel,"*Journal of materials processing technology 208*, pp.187-195, 2008.

[22] W. Wang, J. Li and W. Fan, "A numerical approach to analyze ground surface texture based on abrasive belt topography,"*Proceedings of Asia International Conference on Tribology*, pp.193–195, 2018.

[23] A. Hamdi, T. Aliouane and D. Bouzid,"Technological Parameters of belt grinding process of hard steel,"*Mechanics and Mechanical Engineering*, Vol. 21, no. 4, pp.843–853, 2017.

[24] W. Grzesik, K. Żak and P. Kiszka,"Comparison of surface textures generated in hard turning and grinding operations,"*Procedia CIRP 13*, pp.84–89, 2014.

[25] N. Belkhir, D. Bouzid and V. Herold,"Correlation between the surface quality and the abrasive grains wear in optical glass lapping,"*Tribology International 40*, pp.498–502, 2007.

[26] W. Grzesik, J. Rech and K. Żak,"Characterization of surface textures generated on hardened steel parts in high-precision machining operations,"*Int J Adv Manuf Technol 78*, pp.2049–2056, 2015b.

[27] J. Kenda, G. Kermouche, F. Dumont, J. Rech and J. Kopac,"Investigation of the surface integrity induced by abrasive flow machining on AISI D2 hardened steel,"*Int. J. Materials and Product Technology*, Vol. 46, no. 1, pp.19–31, 2013.

[28] A. Jourani, "Three dimensional modelling of temperature distribution during belt finishing,"*Int. J. Surface Science and Engineering*, Vol. 9, No. 2/3, pp.231–246, 2015.

[29] C. Courbon, C.F. Valiorgue, C. Claudin, M. Jacquier, F. Dumont and J. Rech, "Influence of some superfinishing processes on surface integrity in automotive industry,"*Procedia CIRP 45*, pp.99–102, 2016.

[30] V. Bhemuni and S. Rao Chalamalasetti, "Statistical Model for Surface Roughness in Hard Turning of AISI D3 Steel,"*Jordan Journal of Mechanical and Industrial Engineering*,Volume 8, Number 6, pp. 393–401,2014.

[31] A. Sureshchandra Maheshwari and R. Ratnakar Gawande, "Improving Surface Quality of AA 6351 by the Stiff Burnishing Technique,"*Jordan Journal of Mechanical and Industrial Engineering*, Volume 10, Number 4,pp. 245–251, 2016.

[32] A. Hamdi, S.M. Merghache and T. Aliouane,"Effect of cutting variables on bearing area curve parameters (BAC-P) during hard turning process,"*Archive of Mechanical Engineering*, 67(1): pp.73–95, 2020.

[33] W. Grzesik and K. Żak,"Modification of surface finish produced by hard turning using superfinishing and burnishing operations,"*Journal of Materials Processing Technology 212*, pp.315–322, 2012.

[34] A. Jourani, M. Dursapt, H. Hamdi,J. Rech and H. Zahouani,"Effect of the belt grinding on the surface texture: Modeling of the contact and abrasive wear,"*Wear 259*, pp.1137–1143, 2005.