ANALYSIS OF THE INFEED RATE INFLUENCE IN GRINDING PROCESSES WITH CONVENTIONAL WHEEL

Eduardo Carlos Bianchi
São Paulo State University - UNESP - Bauru, Department of mechanical engineering
e-mail: bianchi@feb.unesp.br, Bauru, SP, Brazil

Rodrigo Eduardo Catai
São Paulo State University – UNESP - Guaratinguetá, Department of mechanical engineering
e-mail: rcatai@zipmail.com.br, Guaratinguetá, SP, Brazil

Carolina Grimm Franzo
São Paulo State University – UNESP - Bauru, Department of mechanical engineering
e-mail: carolgf@uol.com.br, Bauru, SP, Brazil

Rodrigo Daun Monici
São Paulo State University - UNESP - Bauru, Department of mechanical engineering
e-mail: rodrigo.monici@embraer.com.br, Bauru, SP, Brazil

Paulo Roberto de Aguiar
São Paulo State University - UNESP - Bauru, Department of electrical engineering
e-mail: aguiarpr@feb.unesp.br, Bauru, SP, Brazil

Abstract. *The development of new worldwide tendencies such as market globalization has led the grinding processes to be very important each day in the industries. So it is essential to study deeply the variation of the parameters in the grinding process to make it profitable. In this work it will be presented a comparative analysis of three different infeed rates of the conventional grinding wheel on the workpiece manufactured with D2 hardened steel. Synthetic Emulsion of 5% and neat oil have been employed, observing that a possible increase in the infeed rate is related to shorter grinding time, which turns the process more attractive economically. Minimal quantity of lubrication (MQL) and an optimized nozzle with 5mm diameter were used to carry out the tests. The parameters analyzed were roundness, superficial roughness, wheel wear, tangential force and scanning electronic microscopy (SEM). The results showed that the increasing infeed rate could lead the process to consume less time without compromising the quality of the workpiece profile, which can bring a great profitable process. The best cutting fluid were neat oil, even though it is the most harmful to the workers' health and to the environment.*

Keywords*. Manufacturing, Cylindrical Plunge Grinding, Infeed Rate.*

1. Introduction

The grinding process has being considered the most important on manufacturing, because it is a high accuracy and high importance process, once it is unacceptable to loose one workpiece on this stage of manufacturing, since the material aggregated value is already high at this stage due to the large number of processes that have preceded the grinding itself (Oliveira, 1989).

According to Malkin (1989), about 20 to 25% of the manufacturing costs, are related to the grinding. According to Knapp (1999), in order to reach low grinding costs it becomes necessary to reduce vibration between the wheel and workpiece, which is a restriction to increase infeed rates on cylindrical plunge grinding.

In this paper it will be presented a literary review about the cutting fluid, neat oil and emulsion 5%, conventional grinding wheel (aluminum oxide - Al_2O_3) and the effects that infeed rate variation can cause on the final workpiece. The main parameters that will be measured on this work are the tangential grinding force, roundness, superficial roughness, wheel wear and Scanning Electronic Microscopy (SEM). In short, results, analysis and conclusions concerning the variations of the three infeed rates employed on this work, will be presented.

2. Objectives

The main objective of this article is to compare the effects of the variation on three different infeed rates (0.12mm/min, 0.25mm/min e 1.00mm/min) on cylindrical plunge grinding using conventional wheel (aluminum oxide - Al_2O_3). It was used D2 steel on the workpieces material and neat oil and 5% emulsion were employed as cutting fluids.

So, it attempts to determine which of the three infeed rates would be the best one for the present grinding process, as well as what would be the most adequate cutting fluid for that purpose. Thus, this will make the process as profitable as possible and without wastages, by for instance shortening the grinding time.

3. Cutting fluids and Al_2O_3 conventional grinding wheel

For a good cutting fluid it is essential that the fluid is capable of providing lubrication, refrigeration and chip removal. Lubrication is responsible for the decrease of the friction between the workpiece and grinding wheel, reducing the heat generation and cutting forces. Refrigeration can lead to low temperatures on the workpiece which will avoid thermal damages such as cracks and finally, the removal of the chips generated on the cutting zone avoiding the contact of the workpiece with the chips, which could damage the final roughness.

According to Motta & Machado (1995), the employment of the cutting fluids on manufacturing in some cases might reduce costs, increase the production and bring profits, as long as the right type of cutting fluid is chosen, which has to attend the specific conditions of grinding process. On this way it will be allowed the greatest fulfillment.

The effective application of cutting fluids can also increase the grinding wheel's life, to improve the roughness, to improve the dimensional precision and to reduce the consumed power. Besides, the employment of the cutting fluid on grinding processes has become more important as the removal ratio are increased and the demand for quality is larger (Baradie, 1996).

Moreover, the abrasive wheel grains can be made by natural or synthetic materials, generally they must be harder than the workpieces. The natural abrasives grains include aluminum oxide (natural corundum and emery), granalha and diamond. The conventional abrasives are synthetics materials based upon aluminum oxide or silicon carbide, but the main requirement of an abrasive grain is that it must to be harder than the material to be worn (Malkin, 1989).

4. Effects of infeed rate variation

According to tests performed by Lee & Kim (2001), the tangential grinding forces increases with the infeed rates of the wheel against the workpiece.

In relation to the roundness, according to works performed by Biera et al. (1997), the lower is the infeed rate, the lower is the roundness error. According to the author, the roundness error is straightly related to the infeed rate, although the sparkout effects might minimize it or even eliminate it.

Still, according to Biera et al. (1997), roundness error might be explained by the vibration forces generated by the unstable spindle wheel motor or simply because the wheel itself, but such things do not implicate on final grinding results.

Secondly Lee & Kim (2001), the roughness increases with the increase of the infeed rates. On the other hand Hara (1999), said that there is no direct relation between roughness and infeed rate. This author justifies this fact with the sparkout effects, where there is no infeed rates variation during about 10 seconds, which can minimize the roughness effects. In other words, before the sparkout occurrence it is probable to note the roughness difference.

5. Methodology

The tests were performed in an external cylindrical grinder model RUAP 515 H-CNC manufactured by SulMecânica enterprise, where D2 steel workpieces, approximately 60 HRc hardness were employed.

The only on-line acquired variable was the grinding tangential force, and its acquirement was achieved as follows: the electric power of the grinding wheel drive motor was acquired by a piezelectric transducers, then passed through a signal conditioning circuit, which delivered the proper voltage. Next, this voltage was received by the data acquisition board A/D and then analyzed by LabView 5.0 data acquisition software, in which the required computation was performed in order to obtain the grinding tangential force value (F_{tc}), once P_e is the motor electric power, n is the grinding wheel rotation and d_s the grinding wheel diameter.

$$F_{tc} = \frac{2.P_e}{d_s.n} \tag{1}$$

The roughness measurement was performed employing a roughness machine labeled Taylor Hobson, model Sultronic 3+ and the G ratio measurement was performed measuring the tool profile, marked on a 1010 steel bar.

For the Scanning Electronic Microscopy (SEM) performance, a Jeol - JXA - 840A - Electron Probe Microanalyzer machine was employed, and during SEM, 1500 times zooming for both grinding fluids were made, and for the most critical infeed rates, which were extreme speeds of 0.12mm/min and 1.00mm/min respectively.

The roundness errors were measured in a Taylor Hobson Polyrond 31C machine, and for each workpiece 6 measurements at different workpieces section were performed.

Before the beginning of each test, the conventional grinding wheel preparation was performed through a dressing operation with a diamond single tip dresser. The grinding wheels were dressed with the value of U_d (dressing overlap ratio) = 1.

For each test condition, one type of fluid (neat oil and 5% emulsion), one aluminum oxide conventional grinding wheel and one of the respective infeed rate: 0.12mm/min, 0.25mm/min or 1.00mm/min were employed, and each test had three times repetition.

Each test was composed by 40 manufacturing cycles (150.1mm^3 of removed material from workpiece), and hundreds of grinding force values were acquired by the data acquirement software for each manufacturing cycle. However, for the drawing of grinding tangential force graphics, only the maximum value of each one of the 40 grinding cycles was considered, which was equal to 150.1mm^3 of removed material volume. From this procedure, 40 maximum scores of tool effort were then obtained, generating a graphic with 40 total scores, once each score means the tool maximum effort concerning its respective manufacturing cycle.

The cutting depth (a=4mm), the grinding width (b=3mm), the fluid outlet velocity (V_{sf}=30m/s) and the grinding wheel peripheral velocity (V_s=30m/s) were kept steady. The tests were performed employing Coolant Minimum Quantity (fluid outflow velocity equal to the grinding wheel's) and an optimized fluid outlet nozzle with 5mm diameter.

6. Results and discussion

6.1. Grinding tangential force results

It is important to highlight that each point shown on the graphic means the arithmetic average from the maximum scores obtained for the three repetitions of the performed tests.

Figures 1 and 2 show that the removed volumes of material 9.5mm^3, 37.5mm^3, 84.8mm3 and 150.1mm^3 match respectively to exactly 10, 20, 30 and 40 grinding cycles.

Figure 1 shows the grinding tangential force results obtained for the three different infeed rates employed with neat oil. The highest grinding force obtained for the neat oil was 70.5N, since the infeed rate is 1.00mm/min, whereas this infeed rate was the one, which generally brought the highest grinding forces, rather than the grinding forces obtained for the velocity of 0.12mm/min, which were the lowest ones.

The same behavior, the highest grinding force values were obtained with the highest infeed rates and the lowest ones, for velocity of 0.12mm/min, and the highest grinding value for tests employing emulsion as fluid was 81N as shown by Figure 2. Therefore, the fact that there is a higher abrasive tool effort at more aggressive infeed rate conditions is taken for granted.

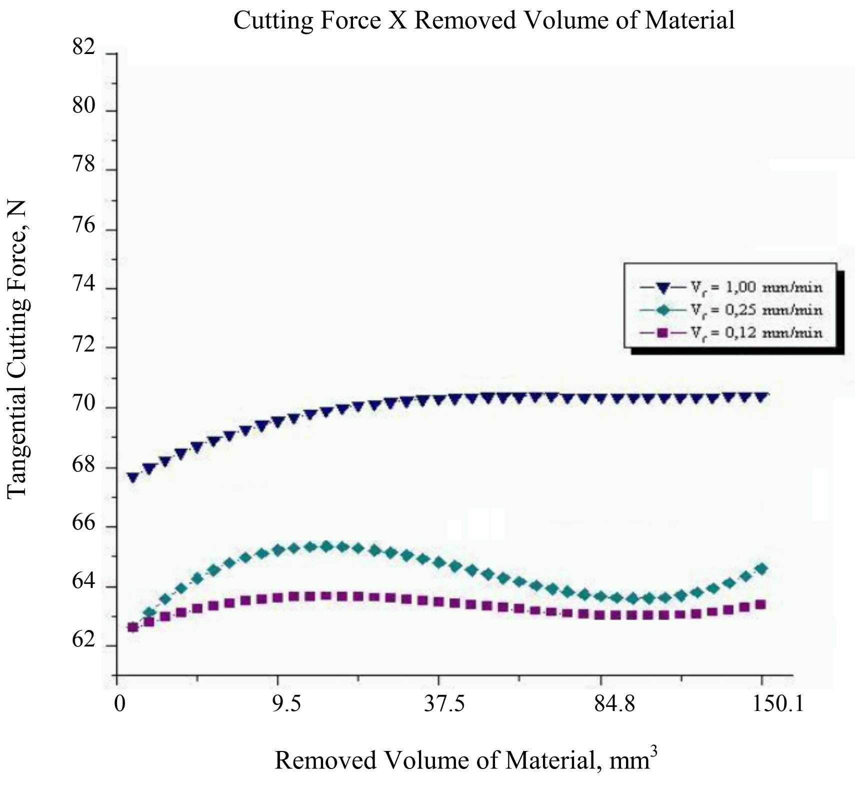


Figure 1. Comparison between grinding forces for the neat oil.

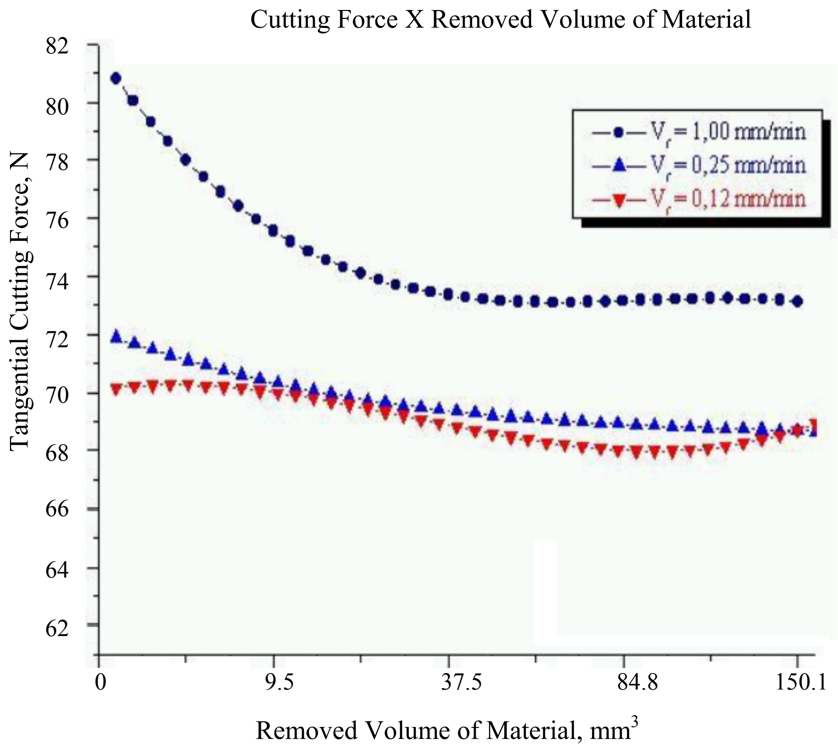


Figure 2. Comparison between grinding forces for 5% emulsion.

Analyzing Figures 1 and 2 comparatively, the tool efforts are much higher when emulsion is employed. The lower values obtained for the oil are due to this fluid high lubricating capacity, what makes the grinding wheel more easily to “slip” on over the manufactured workpiece.

6.2. Grinding wheel diametric loss results

The aluminum oxide conventional grinding wheel diametric losses were acquired through its wear marking after each test on a SAE 1010 steel. The diametric loss data acquirement was performed through an analogical/digital displacement measurer, providing data from the difference between the largest and the smallest workpiece radius. Figure 3 shows the diametric loss values obtained for the assays performed with emulsion and neat oil in function of the different infeed rates.

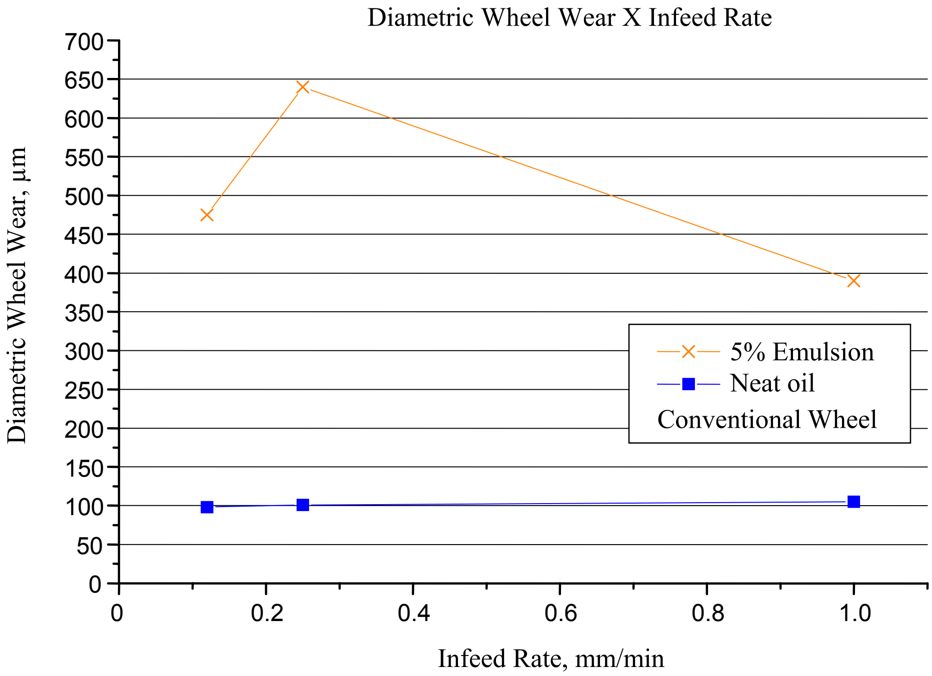


Figure 3. Grinding wheel diametric loss for all infeed rates.

According to Figure 3, one notices that the grinding wheel diametric wear for the neat oil was straightly relative to the infeed rate, in other words, for the tool's more aggressive conditions, there is a higher diametric loss. Such behavior may be explained according to the grinding tangential force results, where the highest infeed rates followed the toll's higher efforts.

For the 5% emulsion, the results should have been alike those obtained with neat oil, taking into consideration that the losses values should be higher for the highest infeed rates, however, it is probable that some problem with the diametric loss acquirement have occurred for 1mm/min velocity assay, once the diametric loss for this assay should be higher than for the assay with infeed rate of 0.25mm/min. Such thing might be due to the high accuracy of the equipment employed for the measurement.

However, one also notices that the lowest friction brought by the neat oil reduces 4 up to 5 times average the grinding wheel diametric wear, when compared to values obtained for the emulsion.

6.3. Superficial average roughness results

The roughness, as the grinding wheel diametric wear and the roundness, was measured after the performance of all tests.

Figure 4 shows the roughness values for the three different infeed rates, whereas for each workpiece, three different roughness measurements at different positions were performed. Therefore, each point shown in Figure 4 means the roughness average obtained for the three workpieces and for the three measurements performed for each of the tests.

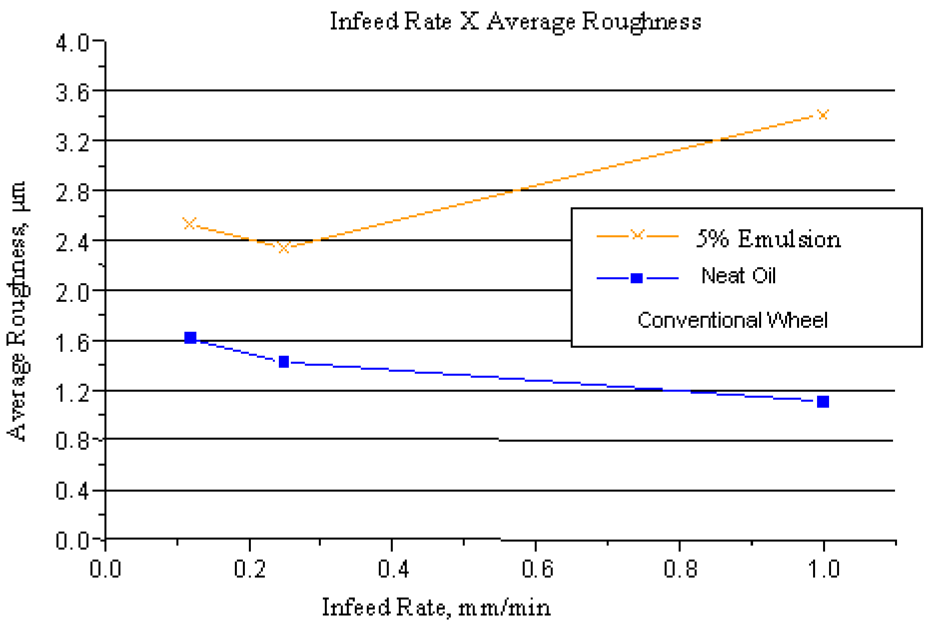


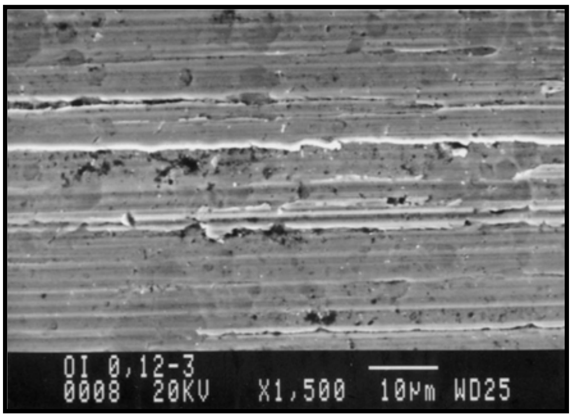
Figure 4. Roughness for different grinding wheel infeed rates.

There is no characteristic behavior for the roughness results. Through the literature found, there were two different standpoints concerning the roughness behavior. According to Lee & Kim (2001), the roughness should be higher than for softer conditions for higher infeed rates. Hara (1999) states that the roughness effect could be fully inhibited, due to the fact that tests have involved 8 seconds sparkout regions, in other words, no characteristic behavior could be observed.

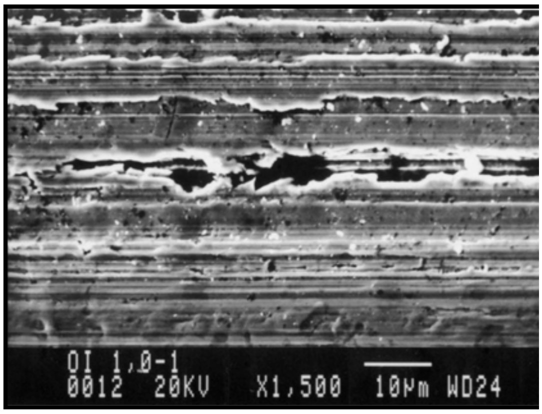
Another important fact shown in Figure 4 is the great dispersion between values for neat oil and 5% emulsion. One can notice that when neat oil is employed as grinding fluid for grinding operations, the workpiece final dressing could be meaningfully better, following workpieces with better superficial dressing.

6.3. Scanning Electronic Microscopy (SEM) results

Figure 5 shows the photos from the scanning electronic microscopy (SEM) obtained for grinding workpieces with speeds of 0.12 mm/min e 1.00 mm/min, when neat oil is employed as grinding fluid. Figure 6 shows the tests performed with 5% emulsion. We would like to highlight that, for comparative purposes, both figures have the same zoom, which was of 1500 times.

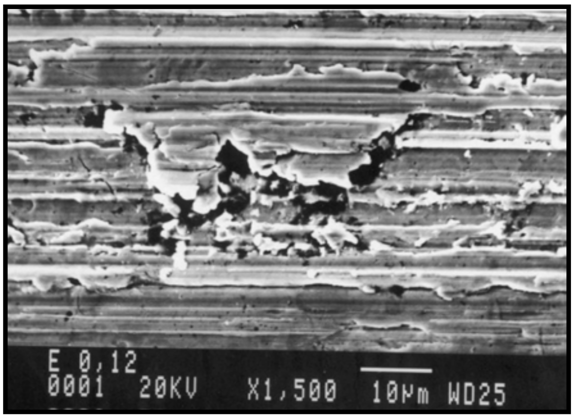


(a)

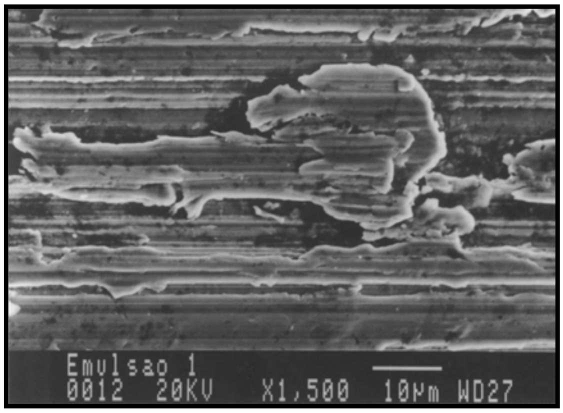


(b)

Figure 5. 1500 times zoom SEM analysis for grinding with neat oil. (a) 0.12 mm/min infeed rate; (b) 1.00 mm/min infeed rate.



(a)



(b)

Figure 6. 1500 times zoom SEM analysis for grinding with 5% emulsion. (a) 0.12 mm/min infeed rate; (b) 1.00 mm/min infeed rate.

Analyzing Figures 5(a) and 5(b), the fact that the workpiece with the worst dressing is obtained for speed of 1,00mm/min, once there is a great discordance between the lines left by the grinding wheel. The workpiece with the best dressing is the one from Figure 5b, where the infeed rate is of 0.12mm/min. It is also observed that for the infeed rate of 1.00mm/min, a higher superficial roughness was obtained as well, what confirms the data obtained for the SEM tests.

When infeed rates of 0.12mm/min and 1.00mm/min are compared to one another for emulsion as grinding fluid (Figures 6(a) and 6(b)), it is observed that the best manufactured surface was obtained for infeed rate of 0.12mm/min, even though this difference is relatively small, whereas this statement may be verified through the roughness average values for those tests, which were respectively 3.55µm e 3.80µm.

Figures 6(a) and 6 (b) show that there is a great superficial deformation and/or a greater crushing area, when compared to Figures 5(a) and 5(b), which grinding fluid was the neat oil. Such fact happened because the neat oil has an outstanding lubricating property. This way, the generated forces are smaller, what provides lower vibrations at the grinder, bringing about a better dressing.

So, we can assure that the dressing with neat oil as grinding fluid seems to be even more interesting when compared to with the 5% emulsion, once the workpieces manufactured with the emulsion showed side furrows and flows of material slightly sharper, due to the lower lubricating capacity of this grinding fluid.

6.4. Roundness results

The roundness values were taken at different sections from the workpiece, selected by chance. In Figure 7, each point from the graphic means the average of the three repetitions performed for each condition tested, whereas for each repetition, six roundness error measurements were performed. Therefore, each point from the graphic means the average of 18 roundness values.

Figure 7 shows a comparison between the roundness error average values for the several grinding fluids. Although the first point from the graphic indicated a higher roundness error for tests performed with neat oil, it is observed that there is a meaningful difference for the other values, in which the emulsion shows a higher roundness error.

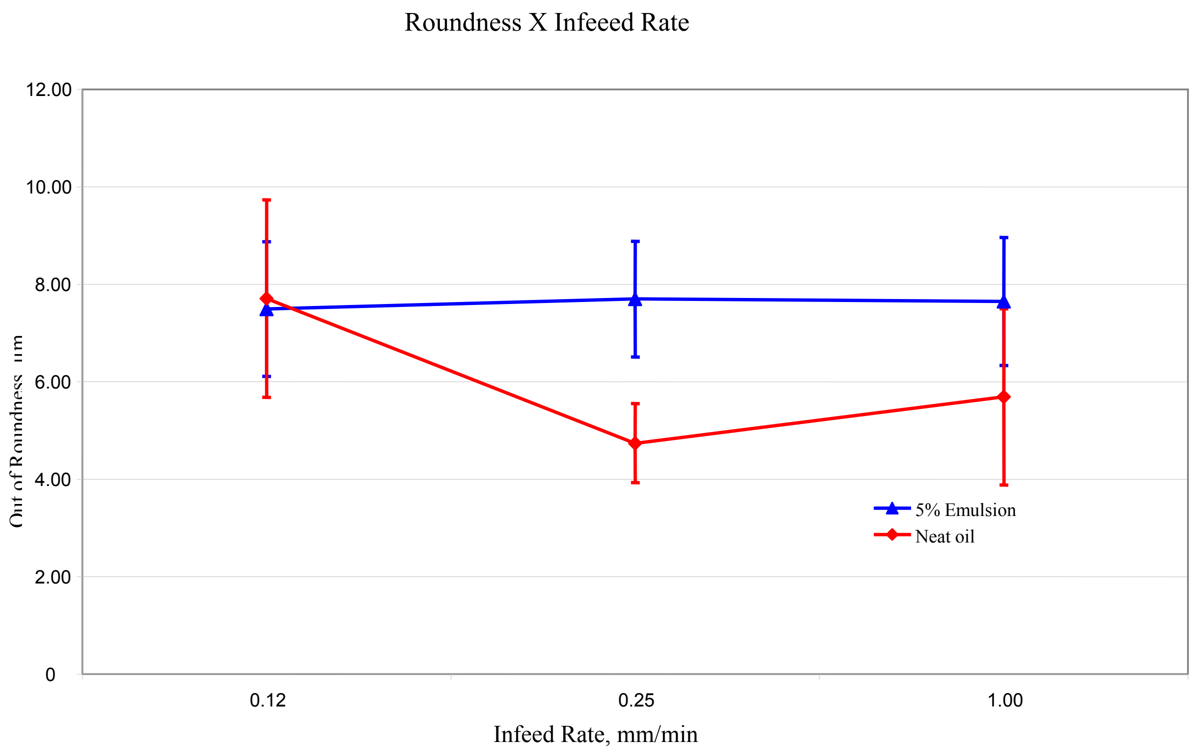


Figure 7. Comparison between grinding fluids for the roundness error.

Except for scores of infeed rates of 0.12mm/min for the neat oil, the other ones show increasing behavior, what would lead us to think that the higher the infeed rate is, the higher the roundness error would be. It is believed that some type of problem might have occurred with the ground workpieces at this rate for the neat oil.

Concerning the grinding fluids, it is believed that since the emulsion has low lubricating quality of the manufactured region, it ends by bringing higher grinding tangential forces and higher vibrations on the machine. This vibration is responsible for the highest roundness errors shown by workpieces ground with the emulsion.

Concerning the infeed rate variation, it was observed a slight tendency for the increase of the roundness error with the increase of the infeed rate as concluded by Biera et al (1997). The fact of the error difference to be so small might be justified by the long sparkout time (8 seconds), what brought on more regularity on the workpieces, this way decreasing the roundness error.

7. Conclusions

According to the obtained graphics, the employment of neat oil allowed the decrease of the grinding force, the roughness and the grinding wheel diametric wear values. Such results are related to its high lubricating power, decreasing the friction and the heat generation at the grinding zone. Therefore, for industries, the employment of neat oil as grinding fluid in order to obtain high quality superficial dressings and lower tool’s wear is actually the most adequate. However, we must highlight the great importance for the usage of protective equipment, having in mind the risks this oil might bring to the operator’s health.

Concerning the obtained roughness values, no variations that could show a behavior related to the infeed rate were found, in other words, there is no higher roughness due to the higher infeed rates, once the sparkout invalidates this effect. However, for tests performed with neat oil brought much lower roughness due to its lubricating effect if compared to the 5% emulsion.

Through scanning electronic microscopy, no workpiece imperfection, such as micro-cracks, was found.

The roundness error was a parameter not much affected by the sparkout effect, once it showed increasing behavior with the increase of the infeed rate and higher roundness errors are found for workpieces ground with the emulsion. Such fact is admissible, once the roundness is straightly related to the vibrations from the system, and the system, in turn, to the intensity of the process tangential forces.

Therefore, it is believed that higher infeed rates may be employed with no damage to workpieces in grinding processes at all, as long as sparkout operation is kept in order to guarantee the desired workpiece good dressing and accuracy.

Concerning the several infeed rates, which were analyzed in this research, great advantage employing 1.00 mm/min is observed, once the grinding tangential force values increase a little when compared to infeed rate of 0.12 mm/min. It was also observed that the difference of diametric loss and roughness for lower infeed rate values was not very meaningful. Concerning the industries production line, the rate of 1.00 mm/min could be very profitable due to the fact of the manufacturing time to be meaningfully shorter, the tests for lower infeed rate took as long as 30 minutes, while tests for more severe infeed rates took no longer than 16 minutes.

8. Acknoledgments

The authors wish to thank the financial support given to this research by FAPESP.

9. References

BARADIE, M. A. El., 1996, "Cutting fluids: Part I. Characterization". Journal of Materials Processing Technology, n. 56, Irlanda, p. 786-787.

BIERA, J., VIÑOLAS, J., NIETO, F.J., 1997, "Time-Domain Dynamic Modeling of the External Plunge Grinding Process", Int. J. Machining Tools Manufacturing, Vol. 37, No. 11, pp. 1555-1572.

HARA, C. M., 1999, "Uma Contribuição para o Monitoramento de Retificação Cilíndrica de Mergulho". Tese de Doutorado - UNICAMP, Campinas – São Paulo, Brasil.

KNAPP, B. R., 1999, "Benefits of Grinding with Variable Workspeed". Thesis in Mechanical Engineering, Pennsylvania State University, 63p.

LEE, E. S., KIM, N. H., 2001, "A Study On The Machining Characteristics In The External Plunge Grinding Using The Current Signal Of The Spindle Motor". International Journal of Machining Tools & Manufacture.

MALKIN, S., 1989, "Grinding Mechanisms" e "Grinding Temperatures and Thermal Damage", In: MALKIN, S. Grinding Technology: theory and applications of machining with abrasives. 1.ed. Chichester, Ellis Horwood Limited.

MOTTA, M. F. e MACHADO A. R., 1995, "Fluidos de corte: tipos, funções, seleção, métodos de aplicação e manutenção". Revista Máquinas e Metais, p. 44-56.

OLIVEIRA, J. F. G., 1989, "Tópicos avançados do processo de retificação". Apostila – Escola de Engenharia de São Carlos Universidade São Paulo, São Carlos, 94p.