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Analysis of Diametrical Wear of Grinding Wheel and Roundness Errors in the Machining of Steel VC 131

Due to the high industrial competitiveness, the rigorous laws of environmental protection, the necessary reduction of costs, the mechanical industry sees itself forced to worry more and more with the refinement of your processes and products. In this context, can be mentioned the need to eliminate the roundness errors that appear after the grinding process. This work has the objective of verifying if optimized nozzles for the application of cutting fluid in the grinding process can minimize the formation of the roundness errors and the diametrical wear of grinding wheel in the machining of the steel VC 131 with 60 HRc, when compared to the conventional nozzles. These nozzles were analyzed using two types of grinding wheels and two different cutting fluids. Was verified that the nozzle of 3mm of diameter, integral oil and the CBN grinding wheel, were the best options to obtain smaller roundness errors and the lowest diametrical wears of grinding wheels.

***Keyword**: Optimized application, diametrical wear, roundness errors, cutting fluid*

Introduction

According to Bianchi et al. (1999), the grinding process is known as one of the most complexes tooling processes, due to the great number of variables involved, whereas such process should be employed in finishing operations, in which good final quality, low roundness errors of the piecework are expected, being that the reduction of the diametrical wear of grinding wheel should always be looked for to reduce the costs of the process.

According to Malkin (1989), the grinding process requires a significant energy quantity for the material removal. Such energy, once transformed into heat, is concentrated within the cutting region. The high temperatures may provide situations in which the surface burning, the superficial heating and micro-structural transformations might occur, allowing the retemper of the material, since most grinding processes occur in tempered steels, with the formation of non-retempered martensite, providing undesirable and uncontrollable residual tensions, reducing the strength limit to the exhaustion of the tooled component. Besides, the uncontrolled expansion and retraction of the mechanical piece during the grinding operation are the most outstanding causes of roundness errors.

Starting from the principle that an effective cutting fluid application at the grinding region may reduce the roundness errors in tolled workpieces, this work has the purpose of verifying if optimized nozzles (5mm, 4mm, 3mm of fluid outlet diameter), proposed by Webster (1995), may minimize the diametrical wear of grinding wheel and the formation of roundness errors, when compared to conventional nozzles (original from the grinding machine). Such nozzle will be evaluated using two types of grinding wheels and two different cutting fluids. In this way, the obtained roundness errors will be analyzed at the end of the process for all nozzles, in order to verify whether or not there was an influence from the nozzle, the cutting fluid or from the grinding wheel on the obtained errors. After this, the diametrical wear of grinding wheel generated by the best optimized nozzle (that of lowest roundness errors) will be compared with the obtained to the conventional nozzle to all the types of fluids and grinding wheels.

Cylindrical Errors

According to Shaw (1994), one single workpiece is never perfectly cylindrical, since all workpieces might show roundness errors, which are the main causes for such non-perfect cylindrical situation. To Jedrzejewski & Modrzycki (1997), the roundness error may be understood as any divergence between the built workpiece and the workpiece theoretically required with specified tolerance, whereas the amount of errors in a machine expresses a measurement of its accuracy.

From the types of errors usually found in a workpiece, the roundness error (Figure 1) is, according to ASME (1982), the one that occurs when its opposite radiuses are different at any position from the surface of the workpiece. They are present in the cylindrical workpiece, which passed through some manufacturing stage; many of them ready to be used.

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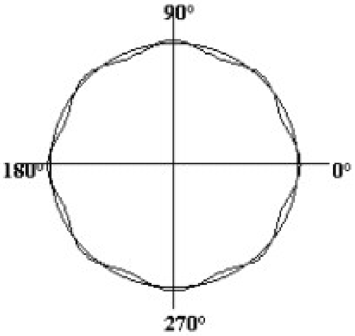

Figure 1. Example of a workpiece with roundness error (Taylor-Hobson, 2001).

Importance of the Cutting Fluid on the Prevention of Roundness Errors

According to Minke (1999), the high friction levels generated during the grinding process may be considered as an extremely important factor, which contributes to the roundness errors formation and to the workpieces' final status; in this way, the employment of cutting fluids with higher friction reduction capacity, also able to reduce the heat generated in such operation is extremely important to the inhibition of the zone affected by the heat. To minimize the furthering of such zone is extremely important to the improvement of the grinded workpiece's quality in all observed aspects, and the roundness is one of the observed aspects, in order to establish such quality.

The cutting fluids are substances used in tooling processes and their constitution is relatively simple, whereas their replacement is done at long-term. The cutting fluids appear as part of workpieces' manufacturing processes through the chips removal, within a context involving the operating machine, the cutting tools, the workpieces output and the cutting fluid.

According to Minke (1999), the high rates of heat generation during the grinding process are eliminated through the straight action of cutting fluids, contributing in a decisive way for the non-occurrence of superficial thermal damage to the workpiece. Besides the cooling process, the cutting fluids also contribute to the workpieces' lubrication, acting on the maintenance of the final superficial integrity of the grinded workpiece, making clear that the cutting fluids appear as a very important technical parameter.

Some basic pre-requirements are necessary to cutting fluids, whereas the lubricating capacity is responsible for the reduction of friction between tool and workpiece, consequently providing smaller heat generation and a low cutting force. Another pre-requirement is the cutting fluid's cooling power, which avoid the workpiece to reach temperatures excessively high, this way avoiding thermal damages. The utilization of cutting fluids in the tooling process, in some cases may reduce costs, increase production and generate profits, once the adequate choice for the type of cutting fluid to be used is performed. The cutting fluid should also follow the tooling specific conditions, this way allowing its maximum performance (Motta & Machado, 1995).

The Influence of the Fluids Application System on the Prevention of Roundness Errors

According to Webster (1995, 1999), the performance of cutting fluids will be improved with the improvement and management of their application system. It means that the pump, the nozzle shape and the tubing system should be faced as a vital system of aid to the task of the grinding process, this way obtaining workpieces with smaller roundness errors, being aware of the following aspects:

Nozzle shape: the nozzle should be projected in order to guarantee the coherence of the cutting fluid jet. Webster (1995) developed a round-shaped new nozzle based on the nozzle developed by Rouse et al. (1952), for hoses of firemen (Figure 2). In Figure 2, C_r is the contraction ratio; D is the cutting fluid feeding hose diameter and D_n is the cutting fluid nozzle outlet diameter.

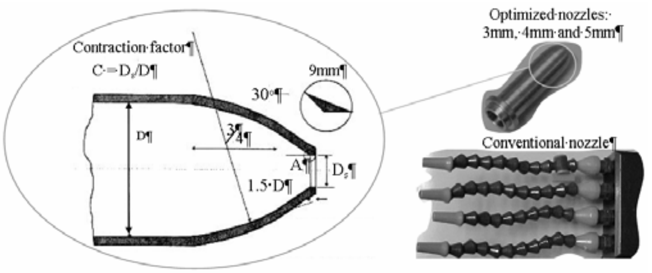

Figure 2. Optimized nozzle with different diameters based on Rouse et al. (1952) apud Webster (1995) and Conventional nozzle with 5mm of diameter (Webster, 1995).

The conventional nozzles for the cutting fluid inlet have one or two convex internal walls, which allow the separation of the fluid flux (Webster, 1995). The separate fluid flux is turbulent and shows an outlet pressure drop, which will significantly affect the jet coherence. On the opposite way, the round-shaped nozzles have concave internal walls, which guarantee higher jet coherence.

The cutting fluid nozzle project should take into consideration the nozzle inlet and outlet geometry and an adequate superficial finishing for the reduction of losses by friction as well as the elimination of live corners and a high contraction ratio (Webster, 1995). The following parameters should also be taken into consideration: the nozzle positioning, the minimum required flow in order to avoid the superficial burning of the workpiece, the nominal capacity of the cutting fluid pump, the use of tubing with adequate and flexible diameter in order to reduce the load loss and the pressure drops, as result of accentuated curves along the feeding line.

According to Webster (1995, 1999), the angle of the cutting fluid nozzle has small influence on the fluid cooling performance, since its flow is adequately positioned, at the cutting region. However, the increase on the distance between the nozzle and the cutting region reduces the application efficiency, especially when nozzles with low jet coherence are used. Consequently, the cutting fluid nozzle should be positioned the closer as possible from the workpiece to be grinded.

Cutting fluid jet velocity (v_j): this velocity should be equal to the grinding wheel's peripheral velocity in order to allow the air barrier provided by its rotation to be overcome. The unitary relation between the jet velocity and the cutting velocity (v_s) should be used for most applications, except in cases where the required power and the cutting fluid pump cost are excessively high. Webster (1995) also investigated the relation between the jet outlet velocity and the cutting velocity by means of laboratory tests, where the heat flow was measured with the three cutting velocities, whereas the used jet outlet velocities ranged from values lower and higher than this velocity.

One observes that a higher heat flow denotes a more effective cooling of the configuration (v_j/v_s). The results show that the heat flow is kept constant from the v_j/v_s value and equal to one. Hydrodynamic pressure measurements may be used to optimize the application of the cutting fluid, regarding the nozzle positioning and the outflow velocity. In addition, the positive pressure occurrence at the cutting region shows that the evaporation effect from the cutting fluid film is occurring and consequently, the material removal rate must be reduced (Webster 1995).

According to Kovacecic & Mohan (1995), the improvement on the lubricating/cooling effect at the grinding region as result of the cutting fluid application at high speed, is responsible for the grinding process optimization, through the reduction of the grinding wheel's pasting as well as its more effective cleaning. Besides, high application speeds allow the grinding wheel to be re-sharpened, through the removal of grains already worn out and poorly anchored from its surface. The high used outflows improve the removal of heat by convection, avoiding the complete evaporation of the cutting fluid film at the grinding zone. The fluid performance is improved with the increase of its application velocity. As result, the reduction of cutting forces as well as the reduction of the grinding wheel's wear and the burning incidence are obtained, allowing a general improvement of the grinding process.

Experimental Methodology

The assays were performed using a CNC SULMECÂNICA cylindrical grinding machine, model RUAP 515 H-CNC. The material of test specimens was the VC 131, tempered and quenched, 60HRc, in a cylindrical shape. Were performed 100 grinding cycles at workpiece (whereas each grinding cycle removed 0.1 mm from the diameter of the workpiece), for all tested nozzles (conventional, 3 mm, 4 mm and 5 mm diameters nozzles at the cutting fluid jet outlet). Two cutting fluids were used (5% synthetic emulsion and integral oil) and two grinding wheels (one aluminum oxide conventional grinding wheel specified 38A46KVS and one CBN superabrasive grinding wheel specified B151K150V17M3, manufactured with vitrified alloy).

For all optimized nozzles, the unitary relation proposed by Webster (1995) was used, with which such researcher assures that the best results are obtained. Such unitary relation consists of keeping the nozzle's fluid outlet velocity equal to the grinding wheel's cutting tangential velocity, which has always been 33m/s.

The dressing in the conventional grinding wheel was made with a recover degree Ud equal to 5 and the drawing of the superabrasive-grinding wheel was performed by a "fleeze". It is worth emphasizing that three assays repeatability for each condition were performed. After the assays, the roundness errors were measured in a roundness measurer (TAYROND 31C), where 5 measurements per each workpiece were made (Figure 3).

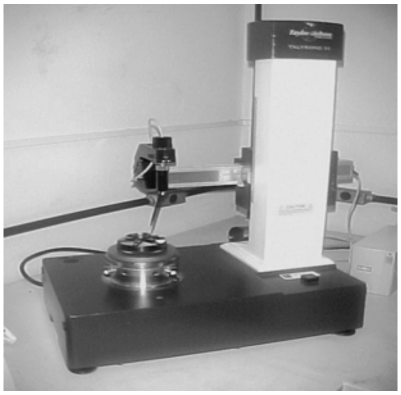

Figure 3. Machine of measure the roundness errors (TAYROND 31C).

The cutting conditions applied in the grinding tests were: cutting speed (v_s)=33m/s; workpiece diameter (d_w)=60mm; spark-out time of 8 seconds; plunge speed (v_f)=1.5mm/min; h_{eq}=0.025µm; grinding wheel penetration (a)=100µm, grinding width (b)=3mm. The figure 4 shows the grinding process. After measure the roundness errors, was chosen the best optimized nozzle. This nozzle was compared with the conventional nozzle, in order to evaluate the diametrical wear provoked by these in the conventional and superabrasive grinding wheel to all the cutting fluids.

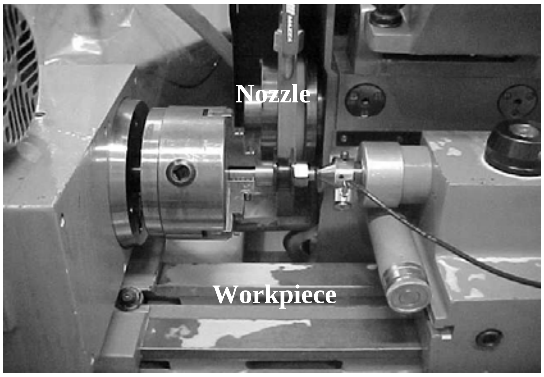

Figure 4. The cylindrical grinding process.

Results and Discussion

Table 1 shows the expressive difference between the obtained outflow values, with the several nozzles, fluids and grinding wheels combinations. One verifies that the 3 mm nozzle showed jet velocity of 34.7 m/s, high enough to overcome the aerodynamic barrier with the volume consumption of 17.9% of cutting fluid, if compared to volumes of cutting fluid consumed by the conventional nozzle, and such nozzle obtained jet velocity of only 21.47 m/s, not high enough to overcome the aerodynamic barrier from the rotation of the grinding wheel.

With regard to the different used nozzles, the optimized nozzle with 3 mm fluid outlet diameter was the one showing, on the average, the lowest roundness errors for all assayed conditions, regardless the type of cutting fluid and the grinding wheel employed.

Table 1. Outflow values obtained by the grinder cooling system.

Nozzle diameter (mm)	Pressure (kgf/cm^2)	Outflow (l/min)	Jet velocity (m/s)	Maximum outflow of pump (l/min)	Jet maximum velocity (m/s)
3	4.0	13.99	33	14.70	34.70
4	4.5	24.88	33	25.50	33.84
5	5.0	38.88	33	38.90	33.03
Conventional	5.5	125.40	33	82.00	21.47

Figure 5 shows an example of the best behavior of such nozzle, if compared to the others. This figure shows 15 measurements, regarding the roundness errors for the following nozzles: 5mm, 4mm and 3mm, whereas in this graphic, each point represents one roundness error measurement.

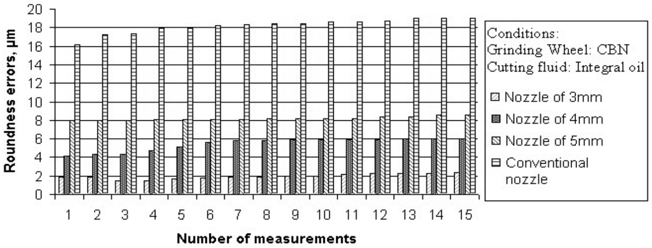

Figure 5. Comparison between results for all nozzles, the integral oil and the CBN grinding wheel.

Figure 6 shows the roundness errors obtained for the 3 mm nozzle (the best nozzle), where the type of the grinding wheel and the cutting fluid varied. In this figure, 10 measurements were taken into consideration, which are presented in a graphic, in which each point represents one roundness error measurement.

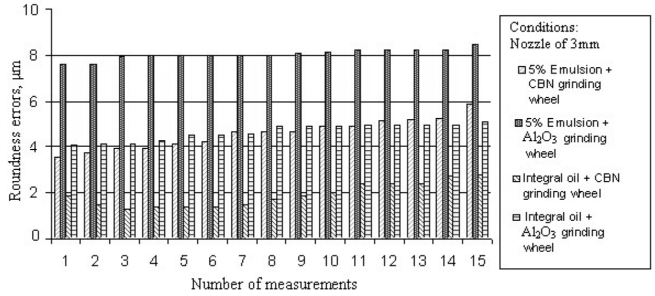

Figure 6. Results obtained for the 3 mm nozzle.

With regard to the type of cutting fluid, the integral oil was the one showing the lowest roundness errors, on the average, for all tested nozzles, due to its higher lubricating capacity, comparing to the emulsion. The grinding wheel with the best average performance for all tested conditions and for both cutting fluids was the CBN grinding wheel, due to its higher capacity for removing heat from the cutting region.

According to the Figure 7, that brings the comparison of the diametrical wears of grinding wheels to all de cutting fluids, the lowest diametrical wears of the grinding wheels were obtained by the nozzle of 3mm, for both cutting fluids tested.

The optimized application of cutting fluid provided an effective reduction of the diametrical wear of the grinding wheel, for the reduction of the mechanical solicitation in the surface of the same ones, through of the reduction of the attrition and generation of heat in the cutting area. The largest fluid presence in the cutting zone provided a larger useful life of the tools, because the same ones obtained larger behavior of material removal for the largest durability of the abrasive grains. The higher pressure of injection of cutting fluid and absence of relative speed between the jet of fluid and the tool, promoted by the optimized method, allowed that the fluid was present in great amount in the cutting area and through of their properties of lubrication and refrigeration were allowed the considerable increase of the revenue of the process.

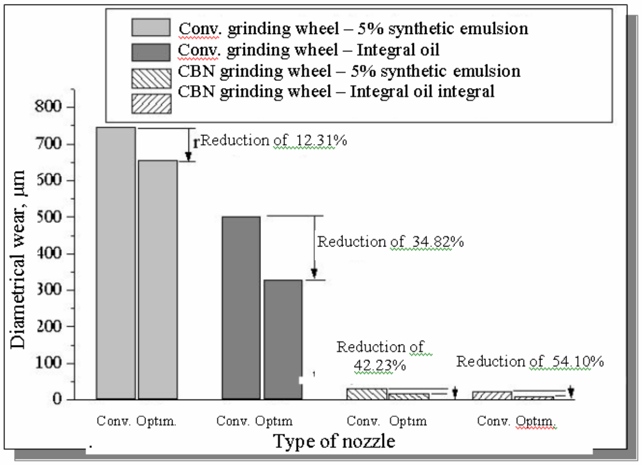

Figure 7. Diametrical wears to the conventional and optimized nozzles.

Conclusions

From the analysis of several types of tested nozzles, cutting fluids and grinding wheels, one concludes that:

- The 3 mm nozzle penetrates into the aerodynamic barrier and spouts fluid into the grinding region, where the highest temperature in the grinding operation is found.
- The use of integral oil allowed the reduction of roundness errors and diametrical wear of grinding wheel due to its higher lubricating power, reducing the friction and the heat generation in the grinding zone.
- The type of the grinding wheel influenced the roundness errors and the rate of wear of grinding wheel. The use of the CBN grinding wheel allowed the reduction on the roundness errors values and of the rate of wear of tool, for all types of the tested fluids; such fact did not occur for the conventional grinding wheel. The best performance of the CBN grinding wheel is especially due to: the higher hardness of its grains, reducing wear and furthering cutting operation, reducing heat at the cutting region and to the higher thermal conductivity of the grains, allowing a lower energy partition.
- Regarding the choice for the type of the cutting fluid, the first choice would be the use of cutting oil. However, among all tested fluids, the cutting oil is the most insalubrious.

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