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ABNT 4340 STEEL GRINDING WITH GEOMETRY INTERRUPTED BY CONVENTIONAL GRINDING WHEEL

Marcel Yuzo Kondo
UNESP-FEG/GUARATINGUETÁ
e-mail: **yuzokondo@gmail.com**

Manoel Cléber de Sampaio Alves
UNESP-FEG/GUARATINGUETÁ
e-mail: manoelcsa@feg.unesp.br

Eduardo Carlos Bianchi
UNESP-FEB/BAURU
e-mail:bianchi@feb.unesp.br

Paulo Roberto de Aguiar
UNESP-FEB/BAURU
e-mail:aguiarpri@feb.unesp.br

Hamilton José de Mello
UNESP-FEB/BAURU
e-mail:hamilton@feb.unesp.br

Cleverson Pinheiro
UNESP-FEG/Guaratinguetá
e-mail:cleversonpi@gmail.com

Abstract. *Grinding is the one of the last steps in machining process where better dimensional and geometrical tolerances can be achieve, maintaining up superficial quality. ABNT 4340 hardened steel is largely in automotive and aeronautical industries. This work aimed the understanding of the influence in superficial roughness caused by different kind of lubrication, interrupted cutting geometry and cutting depth in ABNT 4340 hardened steel flat grinding. Taguchi's design of experiments method is used to set the combinations of lubrication kind, interrupted cutting geometry and cutting depth, evaluating the superficial roughness parameters Ra and Rt in flat grinding experimentation. After testing the combinations and throw the Taguchi's results analyses, the parameters lubrication type, interrupted cutting and cutting depth hasn't show significant influence in the Ra an Rt superficial roughness values. This means that conventional type for Minimum Quantity Lubrication (MQL) substitution is possible without any kind of lost of superficial quality. This also implies in reducing the environmental and financial costs of flat grinding machining process.*

Keywords: *Flat grinding machining, Minimum quantity of lubrication MQL, Taguchi's Method, Interrupted cutting*

1. INTRODUCTION (TIMES NEW ROMAN, BOLD, SIZE 10)

Grinding is a precision process, one of the last steps in machining processes, where better dimensional and geometrical tolerances can be achieved, maintaining up superficial quality. In this process the chip formations occurs through the action of abrasive grits bonded by resin in a wheel.

A largely used steel in industries, such as automobile, aeronautical and machine and equipment, is the ABNT 4340 hardened steel. This steel is usually employed in structural pieces, in drive shaft manufacturing or other uses when good resistance and tenacity combinations are needed. According to Alves et al. (2012) these properties are obtained through hardening and tempering but also a dimensional change are made in the pieces. After the hardening and tempering grinding processes is required for eliminations of dimensional distortions and to provide satisfactory surface finish.

The most common measures that could be used for surface roughness are R_t, R_z and R_a. R_t roughness is the SI parameter to measure the maximum surface roughness, being the difference between peak high and valley depth within the sample length. R_a roughness is the arithmetic average of all profile ordinates from a mean line within a sampling length after filtering out form deviations. R_z roughness is another parameter for surface roughness. Is the arithmetic average of maximum peak-to-valley readings over five adjacent individual samplings lengths (MARINESCU et al. (2006)).

Little information is found about interrupted cutting in grinding machining. Kurt and Köklü (2012) investigated the wheel and cutting parameters influence on shape error in grinding with interrupted cutting. According the authors, grinding is a high-energy rate metal cutting process in which serious concavities are formed due to thermal deformation. This shape error may cause equipment fail when sealing is required, such as in valves. The authors used Taguchi's design of experiments method to select optimum process conditions in interrupted cutting grinding. To analyze the interrupted cutting affects in shape error them grinded samples with machining circular pockets. The optimum process conditions founded were 80 mesh (wheel grain size), 10 μm (grinding depth), 22 m/min (table speed) and 1 mm (cross feed).

According Silva et al. (2007), high disposal costs of emulsion-based cooling fluids, utilized in conventional cooling system, and the growing need to develop environmentally correct production techniques justified the search for alternatives to the grinding process with fluid. One of the alternatives shown by the authors is the method of minimum quantity lubrication (MQL), where small amounts of lubricant are sprayed in a compressed air flow. Authors like Tawakoli et al. (2010), Barczak et al. (2010), Alberdi et al. (2011), Euzébio (2012), Hadad et al. (2012), Hadad and Sadeghi (2012), Silva et al. (2013), Razuk (2014) and Batako and Tsiakoumis (2014) also studied the MQL to replace the conventional lubrication system in grinding processes.

Tawakoli et al. (2009) evaluated the minimum quantity lubrication technique (MQL) in plunge surface grinding of hardened steel 100Cr6, comparing the performance between two another types of lubrication, dry grinding and conventional. They analyze the variables grinding forces and surface roughness. The 100Cr6 steel had the better surface finish in MQL system explained by more effective lubrication and cooling of the abrasive grains in the workpiece-tool interface, which facilitates the slipping of chips on the tool surface. The tangential grinding forces found were lower in MQL than other lubrication systems, while normal forces showed no change. The authors conclude that the MQL system is able to penetrate more effectively the region of contact between the grinding wheel and the workpiece.

This study aims to analyze the influence of lubrication type, the interrupted cutting and grinding wheel cutting depth on the flat grinding of hardened steel ABNT 4340 by measuring the roughness R_a and R_t.

2. EXPERIMENTAL DESCRIPTION

The conditions used for grinding experiments of ABNT 4340 quenched and tempered steel, 60 HC hardness, are showed in Table 1. Taguchi's method was used to analyze the influence of the input parameters A – lubrication type, B - interrupted geometry and C - cutting depth, evaluated in 4 levels. The design of the experiment is a L16 (4*3) Taguchi Orthogonal Array Design where the combination of parameters are independent each other. The values of the parameters in each level are shown in Table 2 and the combinations tested can be seen in Table 3.

Table 1. Grinding conditions.

Grinding mode	Flat Grinding	Cutting depth	5, 10, 15 and 20 μm
Grinding Wheel	Norton 38A220-KVS Al_2O_3	Grinding Fluid (conventional)	QUIMATIC ME-1 soluble oil (1:39)
Grinding Machine	SULAMERICA 1055E Conventional Flat Grinding Machine	Grinding Fluid (MQL)	ACCU-LUBE Lb-1100 lot 314/12
Wheel Speed	30 m/s	Dressing tool	Multigrit diamond dressing tool
Work Speed	0.021 m/s	Dressing Speed	30 m/s

Table 2. Input values for experimental procedure

Parameters	Levels			
	1	2	3	4
Lubrification type	conventional	MQL (low)	MQL (medium)	MQL (high)
Interrupted cutting	0	1	2	3

Cutting depth	10 µm	15 µm	20 µm	5 µm

The fluid flow in conventional lubricating was 49 L/min. Three flow rates, low, medium and high were tested in MQL. For MQL (low) the flow varied between 32 and 80 ml/h, for MQL (medium) of 96-156 ml/h and for MQL (high) 291-345 ml/h. The reason of the variation presented in the flows is explained by the difficulty of adjusting a constant flow in the MQL equipment.

Aiming to create discontinuities in the surfaces to be grinded, the samples were prepared with grooves, creating the interrupted cutting condition. For level 1 of the condition B (interrupted cutting), the piece have one cutting interruption, for level 2 the samples had two discontinuities, for level 3 three discontinuities and for level 4 the samples had three grooves that caused four interruptions. In figure 1 can be seen the dimensions of the specimens used and in figure 2 are the samples used in the tests.

Table 3. Input combination for experimental procedure (Taguchi Method)

Test (A_B_C)	Parameter		
	A (Lubrication type)	B (Interrupted cut)	C (Penetration depth) (µm)
1_1_1	Conventional	0	10
1_2_2	Conventional	1	15
1_3_3	Conventional	2	20
1_4_4	Conventional	3	5
2_1_2	MQL (low)	0	15
2_2_1	MQL (low)	1	10
2_3_4	MQL (low)	2	5
2_4_3	MQL (low)	3	20
3_1_3	MQL (medium)	0	20
3_2_4	MQL (medium)	1	5
3_3_1	MQL (medium)	2	10
3_4_2	MQL (medium)	3	15
4_1_4	MQL (high)	0	5
4_2_3	MQL (high)	1	20
4_3_2	MQL (high)	2	15
4_4_1	MQL (high)	3	10

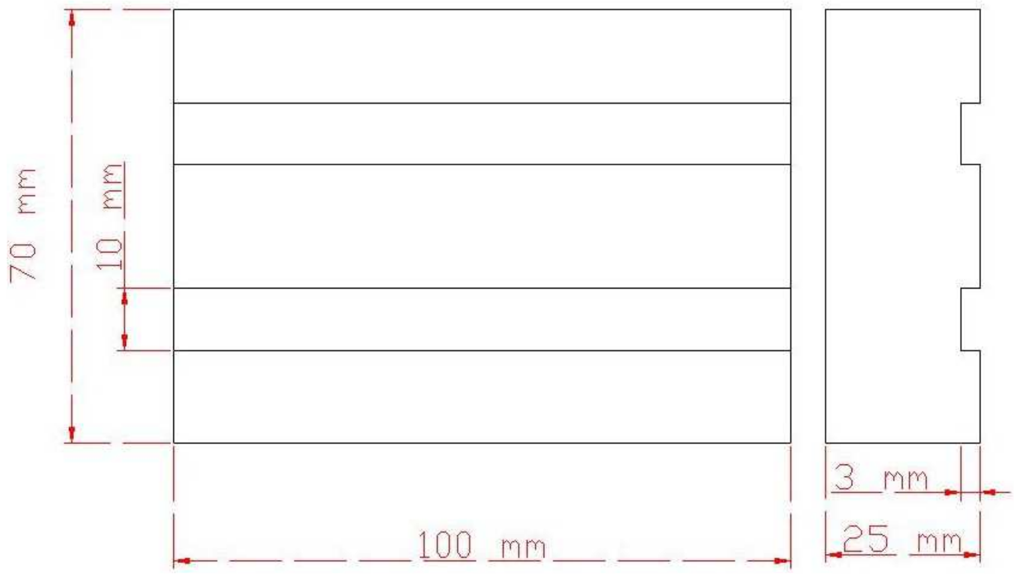

Figure 1. Sample dimensions

The grinding cutting direction is perpendicular to the grooves present in the specimen, thus forcing an interrupted cutting condition as shown in Figure 3.
Using the Taguchi's design of experiments method, 16 different test configurations were proved, each with three repetitions. The dressing of the grinding wheel was performed before each procedure by withdrawing 40 µm each pace until all grinding wheel surface was free from residues from the previous operation. The combinations were set as a L16 (4*3) experiment where 4 is the number of levels and 3 the number of factors.

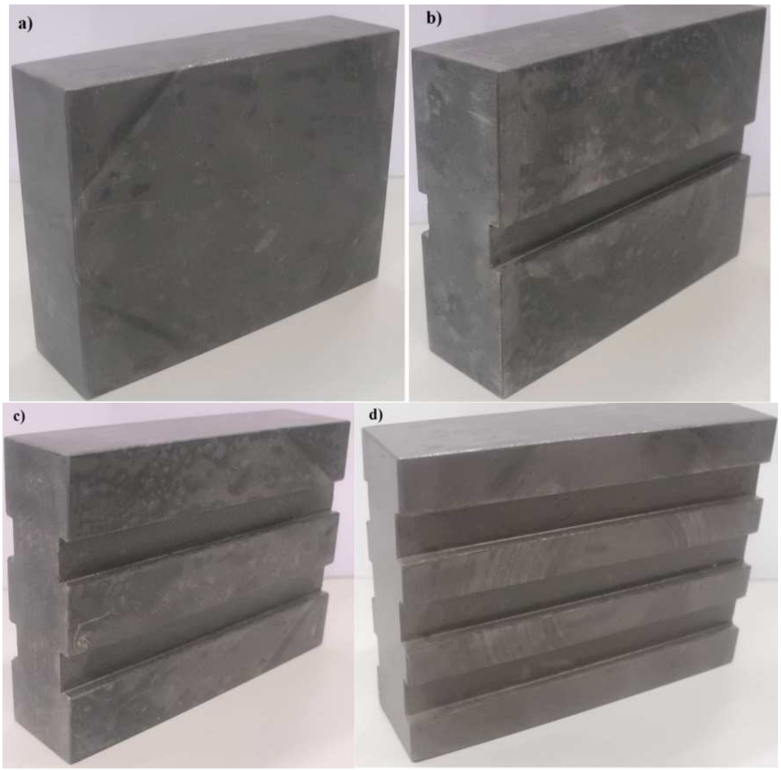

Figure 2. Specimens used and number of cutting interruptions - a) Zero interruption; b) One interruption; c) Two interruption; d) Three interruption.

The surface quality was verified by obtaining the roughness R_a and R_t roughness through the MarSurf M 300 + RD 18 Mahr. The measurement was performed in the perpendicular direction to the cutting direction, with three replicates for each test performed.

The influence of these parameters was performed using the Taguchi method and processed in the commercial statistic software Minitab 17.0. The chosen options for calculation of the signal to noise ratio was smaller is better.

Figure 3. Flat grinding test of ABNT 4340 quenched and tempered steel.

3. RESULTS AND DISCUSSION

The Figure 4 presents the results found for R_a values in the experiments, while in Figure 5 are found the means values for R_t roughness.

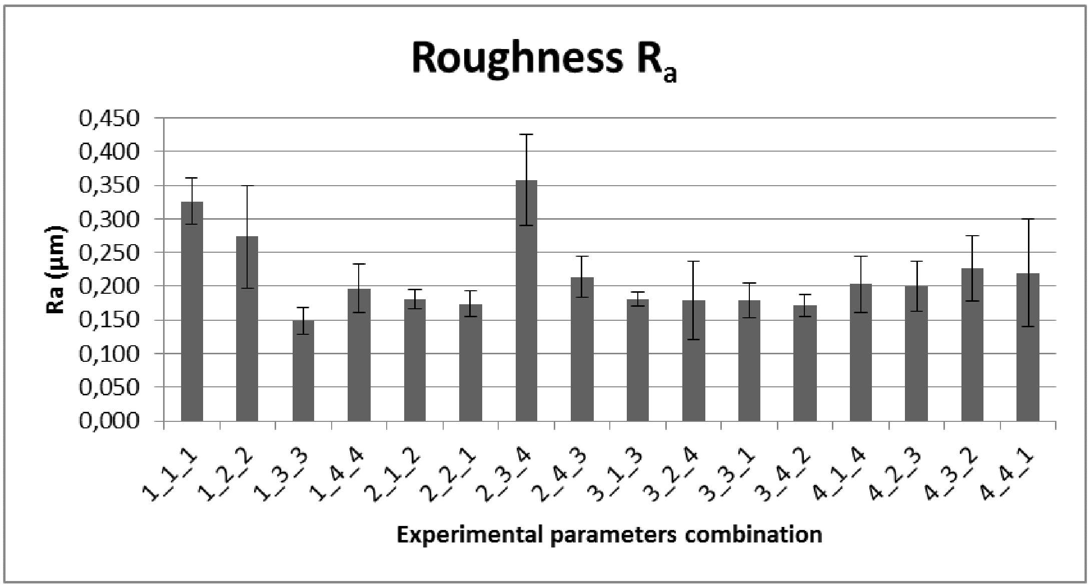

Figure 4. Mean R_a roughness values.

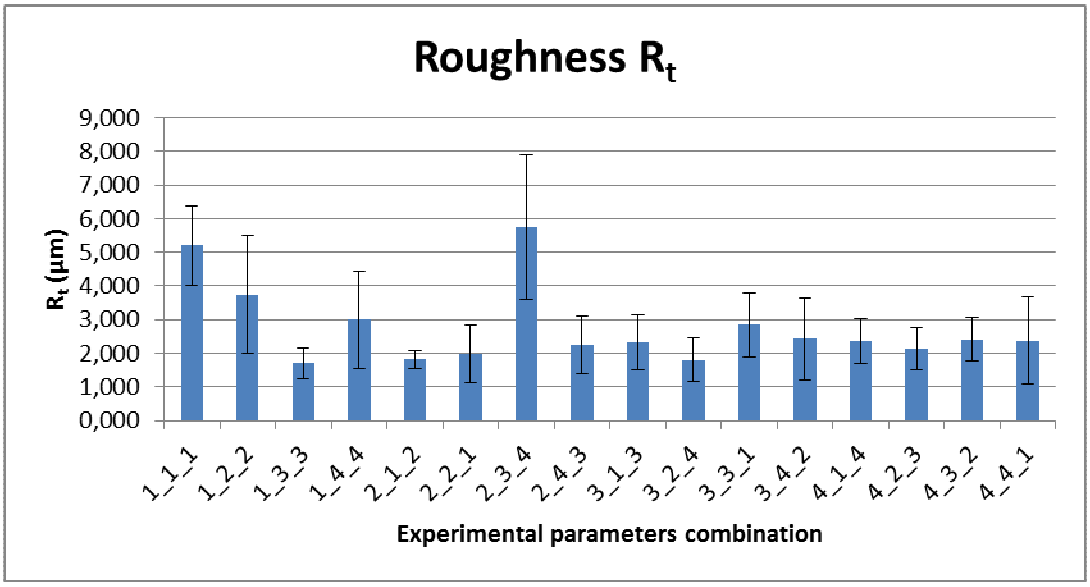

Figure 5. Mean R_t roughness values.

Figure 6 is showing the main effects for means and main effects for signal to noise (SN) ratios found by Taguchi's Method.

The analysis of the means could leads to a conclusion that the change of levels of a factor could have influence in R_a results. This conclusion needs to be confirmed by analyses of the variance found in Table 4 and Table 5. The following tables, Table 4 and Table 5, present the analyses of variance for the mean of R_a and for SN ratios for the same superficial roughness, respectively.

For a 3 degree of freedom (DF) of source and the DF 6 of residual error the F – value, with 5% of significance, is F=4,757. All the F –values of Tables 4 and 5 are lower than the critical tabulated value F = 4,757. In these conditions the following conclusion could be made. The change of sources levels hasn't significant influence in the results of R_a.

In Table 6 and Table 7 is found the results of analysis of variance for the mean of R_t and SN ratio for the R_t values. The same conclusions taken for R_a superficial roughness are valid for the R_t superficial roughness.

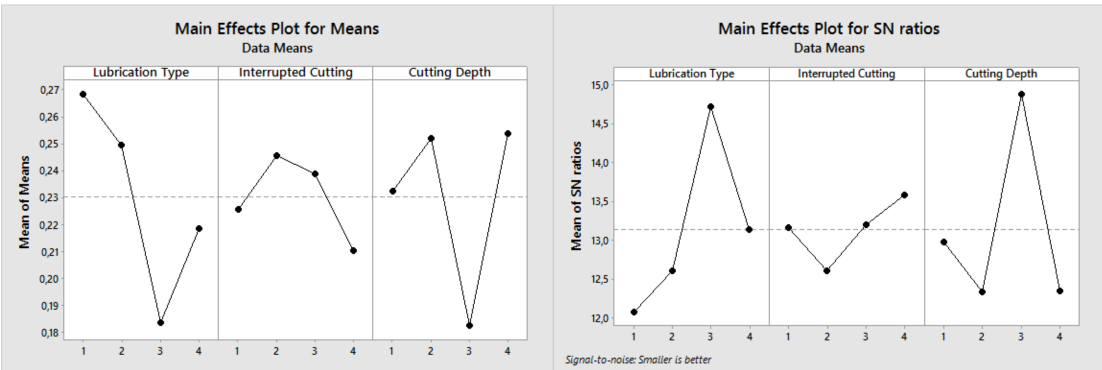

Figure 6. Main Effects for a) Means and b) SN ratios.

Table 4. Analysis of variance for R_a means.

Source	DF	F - value	p - value
Lubrication type	3	0.42	0.745
Interrupted cutting	3	0.07	0.972
Cutting depth	3	0.34	0.801
Residual error	6	-	-

Table 5. Analysis of variance for SN ratio for R_a values.

Source	DF	F - value	p - value
Lubrication type	3	0.34	0.799
Interrupted cutting	3	0.04	0.988
Cutting depth	3	0.37	0.775
Residual error	6	-	-

Table 6. Analysis of variance for R_t means.

Source	DF	F - value	p - value
Lubrication type	3	0.65	0.610
Interrupted cutting	3	0.05	0.983
Cutting depth	3	0.31	0.821
Residual error	6	-	-

Table 7. Analysis of variance for SN ratio for R_t values.

Source	DF	F - value	p - value
Lubrication type	3	0.47	0.715
Interrupted cutting	3	3.04	0.115
Cutting depth	3	1.22	0.380
Residual error	6	-	-

The change of lubrication type, interrupted cutting and the cutting depth hasn't significant influence in the superficial quality of the grinded pieces. An important conclusion is that the values for R_a and R_t are the same for both lubrication type, conventional and MQL. In other words the conventional lubrication for MQL substitution is possible analyzing only the superficial quality parameters.

4. CONCLUSION

This paper aimed the study of superficial quality in grinding machining with different lubrication type, interrupted geometry and different cutting depth.

After all experiments the conclusion is, by the analyses of R_a and R_t, the parameters hasn't shown influence in the values of superficial roughness. With this result, looking just the superficial roughness, conventional lubrication for MQL substitution can be made in grinding machining. It's a great result because the fluid used in conventional lubrication has high financial and environmental costs and the substitution for MQL could bring a reduction in grinding costs.

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6. RESPONSIBILITY NOTICE

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