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EXPERIMENTAL INVESTIGATION ON ROUGHNESS OF DRILLED SURFACES RESULTED FROM ENVIRONMENTALLY CONSCIOUS MACHINING

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Abstract:
In this paper we present our experimental results on how feed (f), length of drilling (L_0) and the volume of lubricant influences the average surface roughness of the borehole. Research on machining with minimal volume lubrication is in progress since 2006 at the Department of Production Engineering, College of Nyíregyháza in cooperation with Department of Production Engineering, University of Miskolc.
Keywords: Environmentally Friendly Machining, Dry Machining, Minimal Volume Lubrication, Surface Roughness, Factorial Experimental Design

1. INTRODUCTION

Practical realization of directive for minimizing the environmental pollution gradually comes to the front in the field of production in the European Union. This leads to the necessity of analyzing problems being associated with operation of cooling and lubricating systems used in cutting technologies [1,2,6].

Purpose of our experiments is investigating the impact of cutting technological parameters on cutting process when grey cast iron is drilled with outer lubrication. Effect of the volume of lubricant and feed was measured on:

- thrust and torque demand [3],
- wear of tool (corner and flank wear [4],
- mean surface roughness of the machined surface .

We evaluated measurements of experiments on drilling with minimal volume lubrication by means of factorial experiment so that we determine relationships between technological parameters of drilling and values of surface roughness in holes.

We took into account results on minimal lubrication of Department of Production Engineering, University of Miskolc [5].

2. NECESSITY OF SURFACE ROUGHNESS MODELS

Surface roughness is an important measure of the technological quality of a machined surface influences manufacturing cost very much. The quality of the surface plays a very important role in the performance of drilling as a good-quality drilled surface significantly improves fatigue strength or corrosion resistance [8].

So, the value of the desired surface roughness is usually specified for an individual part, and specific processes are selected in order to achieve the specified finish. Surface specification can also be a good reference point in determining the stability of a production process [8]. In manufacturing industries, manufacturers focused on the quality and productivity of the product. To increase the productivity of the product, computer numerically machine tools have been implemented during the past decades. Surface roughness is one of the most important parameters to determine the quality of product. This is the case at worm gear drives as well [9], [10] and at electro discharge machining [11]. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent. Several factors will influence the final surface roughness in a drilling operation, such as controllable factors (spindle speed, feed rate and depth of cut) and uncontrollable factors (tool geometry and material properties of both tool and workpiece). The 'trial and error' method [8] is not effective and efficient and the achievement of a desirable value is a repetitive and empirical process that can be very time consuming.

The major causes behind development of surface roughness in continuous machining processes like drilling are:

- regular feed marks left by the tool tip or cutting edge on the finished surface,
- vibration in the machining system, and
- built-up edge formation, if any.

In order to solve the problem, the Factorial Design Method technique is used to describe the cutting conditions is developed. This method can find the best conditions required for the machining independent variables such as speed, feed and depth of cut that would result in the best machining response. Thus, manufacturers can improve the quality and productivity of the product with minimum cost and time.

3. EXPERIMENTAL CIRCUMSTANCES

Twist drill type Ø10,2 K20 GÜHRING WRDG DIN 6537 (monolite hard metal, coated by TiAlN) was used for experiments. The material of the specimen was grey cast iron EN-GJL-200 (MSZ EN 1561) which 30 mm long holes were drilled in.

The outer minimal volume lubrication was achieved by „NOGA MINI COOL" lubricating equipment. The lubricant was conveyed to the outer surface of the twist drill. The volume current of the coolant and lubricant was continuously adjustable between 10cm^3/h and 250cm^3/h. „OMV cut XU" type chlorine free oil was used in our experiments. Universal milling machine, type: MU-250 was applied for performing experimental machining series with following parameters:

- Revolution number of main spindle: n = 2250rev/min
- Feeds: f_1 = 0,18mm/ford , f_2=0,35mm/rev
- Cutting speed: v_c = 72,06m/min
- Volume current of coolant and lubricant: $\dot{V}_{olaj}$ = 10cm^3/h and 28cm^3/h
- Feed speed: v_{f1} = 405mm/min, v_{f2} = 675mm/min
- Mean time of machining: t_1 = 0,074min, t_2 = 0,044min
- Length of one drilling: l_w=30mm

A KISTLER 9271 type compact dynamometer was applied for measurement of thrust (F_f) and the torque (M_c).

The average roughness (R_a) of surface of drilled holes was measured by SJ-201 (Mitutoyo) type equipment. The values of roughness were measured along 5 contour lines on 30 mm long test specimen. Main data of this measurement where length of measurement value was l_n = 12,5mm and base length was l = 2,5mm.

All measurements were repeated three times with the same parameter set. Measured data was evaluated by mathematical statistical methods (mean values, standard deviation, relative deviation). Mean values were analyzed as function of the length of drilling, the best fit curve was determined by correlation analysis and correlation index was calculated.

Table 1. Specimen serial numbers and different combinations of technological parameters

Serial number	Feed, *f*, mm/ford	Length of drill, L_o, m	Volume current of oil, $\dot{V}_{oil}$, cm^3/h
1	0,18	0,03	0,0
2	0,35	0,03	0,0
3	0,18	30,0	0,0
4	0,35	30,0	0,0
5	0,18	0,03	10,0
6	0,35	0,03	10,0
7	0,18	30,0	10,0
8	0,35	30,0	10,0
9	0,18	0,03	28,0
10	0,35	0,03	28,0
11	0,18	30,0	28,0
12	0,35	30,0	28,0

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4. RESULTS AND EVALUATION OF SURFACE ROUGHNESS MEASUREMENTS

12 experiments were performed with the method of factorial experiment design for investigating the mean value of the surface roughness of the drilled hole. Table 1 shows minimal and maximal values of experimental parameters. We note on the length of drill that L_o=0,03m means that roughness was measured after the first 30 mm long drill, then drilling was continued with unchanged parameter settings with the same twist drill and after 5 m long drilling we measured again the roughness by preparing a new 30 mm long test specimen, and so on until we reached the 30 m length of drill (L_o=30m).

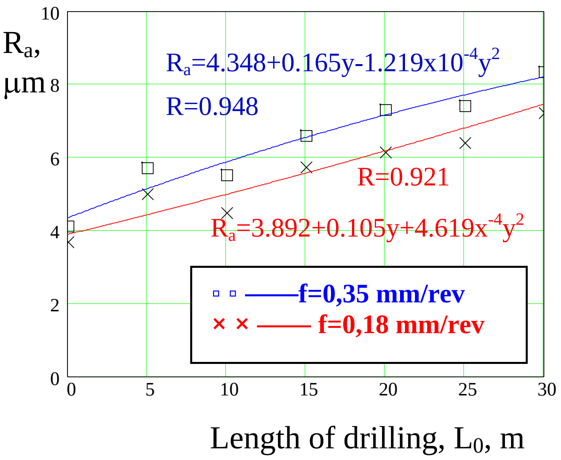

Figure 1. Measured values of surface roughness (Ra) in case of V=10 cm³/h minimal volume lubrication

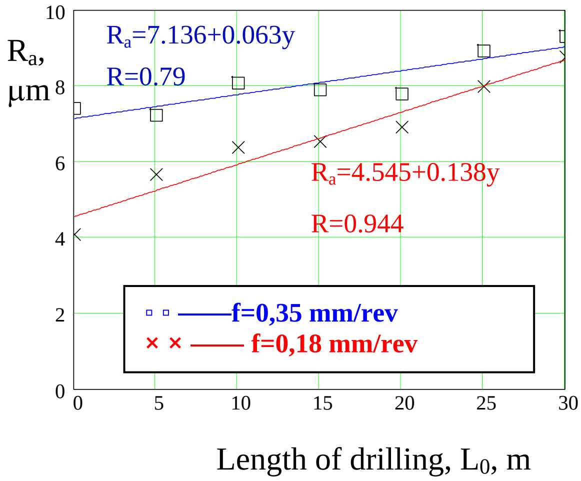

Figure 2. Measured values of surface roughness (Ra) in case of V=28 cm³/h minimal volume lubrication

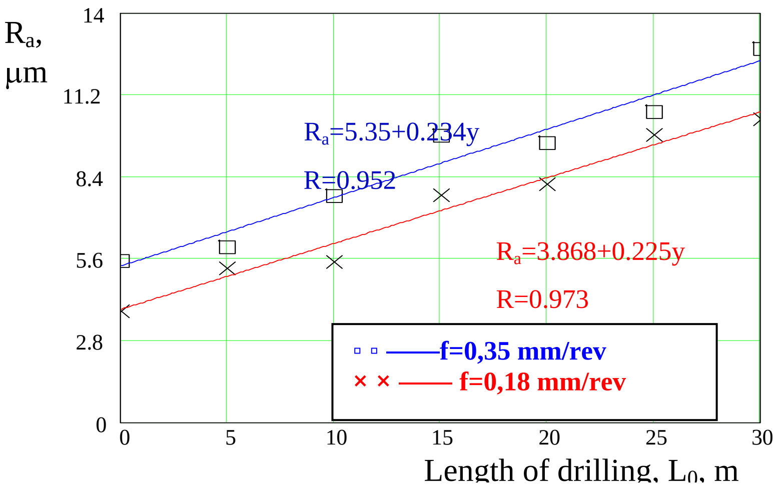

Figure 3. Measured values of surface roughness (Ra) in case of dry machining

Figures 1-5. shows surface roughness measurement results when experimental parameter values are between externals in the Table 1. From figures it can be concluded that roughness always increases with length of drilling, but rate of increase is significantly larger in case of dry machining. Figures 1-3 also shows if the feed rises from f=0,18mm/rev to f=0,35mm/rev then surface roughness increased (got worse) and this change is larger in case of dry machining than in case of minimal volume lubrication.

Impact of minimal volume lubrication to the surface roughness is demonstrated on Figures 4-5. Reader can see that surface roughness can be significantly decreased when the outer minimal volume lubrication present (either 10 or 28cm³/h volume current) related to the dry machining. At both feed values the 10cm³/h volume of lubricant results in better surface roughness than 28cm³/h.

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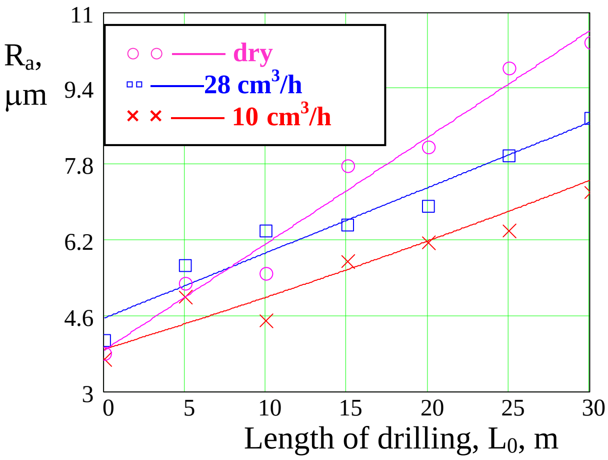

Figure 4. Measured values of surface roughness (Ra) in case of feed f=0,18 mm/rev

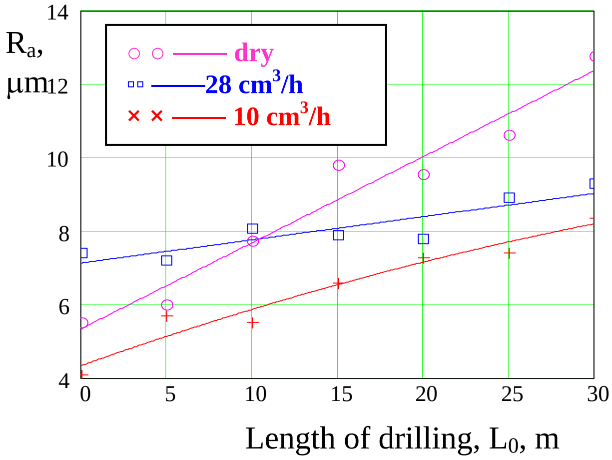

Figure 5. Measured values of surface roughness (Ra) in case of feed f=0,35 mm/rev

The following functions were fit by polynomial approximation to the experimental data of surface roughness:

$$Ra = k_0^{Ra} + k_1^{Ra} f + k_2^{Ra} L_0 + k_3^{Ra} \dot{V}_{oil} + k_{12}^{Ra} f \cdot L_0 + k_{13}^{Ra} f \cdot \dot{V}_{oil} + +k_{23}^{Ra} L_0 \cdot \dot{V}_{oil} + +k_{123}^{Ra} f \cdot L_0 \cdot \dot{V}_{oil} \quad (1)$$

where:

$k_0^{Ra} = 2.4083$ $k_1^{Ra} = 8.528$ $k_2^{Ra} = 0.21$ $k_3^{Ra} = 0.11$

$k_{12}^{Ra} = 0.069$ $k_{13}^{Ra} = -0.647$ $k_{23}^{Ra} = -0.011$ $k_{123}^{Ra} = 1.963 \cdot 10^{-3}$

The domain of function defined by formula (1) is the parameter interval given in Table 1. Inserting parameter values into formula (1) values of surface roughness can be calculated and demonstrated. Figure 6. shows calculated roughness values. It can be seen on the figure that surface roughness is smaller when the amount of the lubricant is larger, and it becomes larger when the length of drilling and feed increases.

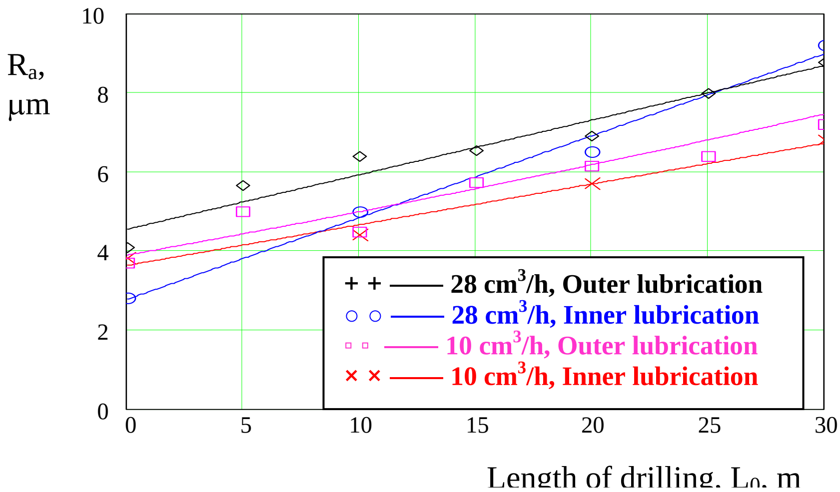

Figure 7. Surface roughness in cases of outer and inner lubrication and feed f=0,18 mm/rot

Figure 7. shows the comparison the impact of inner [5] and outer minimal volume lubrication to the surface roughness. It can be concluded that better surface roughness can be achieved by inner lubrication in the range of 10-28 cm3/h volume of lubricant (in case of inner lubrication the cooling and lubricating effect is more uniform, continuous, the lubricant get directly to the cutting edges, in case of outer lubrication cooling and lubrication is intermittent). In cases of both outer and inner lubrication we can observe that surface roughness of cut hole got larger when the volume of lubricant was increased from 10 cm3/h to 28 cm3/h [5]. This phenomenon requires further investigation.

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5. CONCLUSIONS

We can conclude results of our experiments and evaluation as follows:

- It succeeded to ensure appropriate cutting conditions with outer lubrication when cutting gray cast iron.
- Drilling with minimal volume lubrication is more favourable than dry machining, because it ensures more effective cooling, improves the tool-chip interaction and maintains the edge of the tool.
- Surface roughness of the cut hole can be decreased by applying outer minimal volume lubrication with 10-28 cm^3/h volume instead of dry machining. Surface roughness of the hole increases with increase of feed.
- Better surface roughness can be achieved with inner minimal volume lubrication than outer minimal volume lubrication in the range of 10-28 cm^3/h.
- Improvement of surface roughness raises mainly from the tool wear decrease resulted by the minimal volume lubrication. Decrease of wear of cutting edge increases the life time of the tool, the productivity, because it allows larger feed and cutting speed.
- Formulas determined by full factorial experiment design are good for calculating the effect of cutting parameters to the surface roughness of the hole.

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