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EXAMINATION OF ALUMINIUM FINE TURNING PROCESS WITH TAGUCHI METHOD

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Abstract - The surface roughness of machined parts is a criterion as important in terms of the quality of a product as is geometrical sizes and their tolerance. The quality of a machining process can be characterized by the measurement of the machined surface. During the manufacturing process the aim is to achive as small surface rougness as possible and to produce quite homogeneous surface. Changing the cutting parameters, the raw material, the parameters of the cutting tool in the course of fine turning process it can be determined the optimum conditions with the help of Taguchi methods. In this paper optimization is performed related to the Ra and Rz surface roughness parameters, and examinations were made in order to estimate the various effects on the measurement results.

Keywords: surface rougness measurement, aluminium fine turning, Taguchi method

1. INTRODUCTION

Basically the cutting experiments are expensive and time consuming, so it is advisable to reduce the number of experiments as much as possible. In these cases Taguchi methods are an often used solution.

Rao et al. [1] investigated the turning of AISI 1050 tempered steel carbon steel (hardness: 484 HV) with a ceramic insert (Al_2O_3+TiC; - KY1615 -) by Taguchi method (L_{27} design with 3 levels and 3 factors). They described the main effects with empirical formulae, performed a significance test of the parameters set for the cutting force, and average surface roughness and made statements about the optimum. They established that the feed rate has significant influence on cutting force and surface roughness. Cutting Speed has no significant effect on the cutting force as well as the surface roughness.

Bouacha et al. [2] hard turned AISI 52100 bearing steel (hardness: 64 HRC) with a CBN tool. Their research, an L_{27} Taguchi standard orthogonal array was adopted as the experimental design. In their work the main objectives are firstly focused on delimiting the hard turning domain and investigating tool wear and forces and surface roughness behaviour evolution versus variations of workpiece hardness and cutting speed. Their results show that the higher the feed rate and cutting depth the higher the cutting force is, whereas the higher the cutting speed the lower the cutting force is. The surface roughness is highly affected by feed rate, whereas the cutting speed has a negative effect and the depth of cut a negligible influence.

Suresh et al. [3] investigated the dynamic characteristics of the turning of AISI 4340 steel with CVD (chemical vapor deposition) coated (TiC/TiCN/Al_2O_3) hard metal tool. In their investigations was used $L_2$7 Taguchi method. They obtained linear equations for the calculation of the resultant average surface roughness, cutting force and the specific cutting force. It is concluded that the feed rate had the highest influence on surface roughness, cutting speed, and followed by depth of cut. The cutting force and specific cutting force are most influenced by feed, less influenced by depth of cut, while they were least affected by cutting speed.

Gaitonde et al. [4] examined the machinability of copper (CuZn39Pb3) (hardness: 66 HRB). They performed their experiments with minimal quantity lubrication (MQL) with a hard metal tool of material K10 (TCGX 16 T3 08-Al H10) and they used in their work so-called L_9 Taguchi method. They varied cutting speed, feed and the amount of minimal lubrication (ml/h), while depth of cut was kept at a constant. They found that there is a considerable interrelationship between the amount of the lubricant and cutting speed and the machinability is very sensitive to a change in feed. They determined optimal cutting conditions where specific cutting force and average surface roughness are minimal.

Fetecau and Stan [5] turned two kinds of polytetrafluoroethylene (PTFE) based composite materials: PTFE CG 32-3, containing 32% carbon and 3% graphite, and PTFE GR 15, containing 15% reformed graphite. Their plan of experiment followed the standard orthogonal array L_{27} (four process variables, feed rate depth of cut, cutting speed and insert radius). In their work equations were built up in order to estimate the average surface roughness parameters. They found that the surface roughness was significantly influenced by the feed rate, the insert radius, and the interaction of feed rate and insert radius. The surface roughness increased with the increase of the feed rate, and decreased with the increase of insert radius. The analysed of the S/N ratio, they got the optimal surface roughness.

Mankova et al. [6] examined the chip deformation of coated and uncoated drills with the Taguchi method (L_9) and built a mathematical model with the machining parameters as input.

Hessainia et al. [7] tested steel (42CrMo4, hardness: 56 HRC) under dry hard turning. The cutting tool used was an uncoated ceramic, (70% of Al_2O_3, 30% of TiC, insert code: SNGN 120408 T01020). The experimental design was L_{27} Taguchi design. The input parameters were the vibration of tool and the cutting parameters, the output parameters were Ra and Rz. The optimum point was determined where the surface roughness and the vibration were minimized. It was concluded that the feed rate and the cutting speed had significant effect, and the depth of cut and vibrations had no statistically significant effects on the surface roughness.

Zebala and Kowalczyk [8] examined WC-Co material (the Cobalt content were 10, 15, and 25 wt%) with Mitsubishi triangular PCD tool (TNGA 160408). Their research plan was based on the L_9 Taguchi method. Two empirical models were developed to calculate surface roughness and cutting force. The first model was based on the power function; the second was based on the polynomial function according to modified RSM equations.

Das et al. [9] investigated the machinability of AISI 4140 steel with PVD-TiN coated Al_2O_3 + TiCN mixed ceramic inserts under hard dry turning. The surface roughness and flank wear of insert were examined by L_{27} Taguchi method. Equations, which depend on the cutting parameters, were built up to calculate surface roughness parameters and flank wear. They results showed, the surface roughness is principally affected by feed and the depth of cut has a negligible impact. Whereas cutting speed has a negative effect for all surface roughness parameters. When increasing cutting speed, flank wear (VB) of the tool insert increases and causes immediate deterioration of the machined surface quality.

Optimization of bone drilling using Taguchi (L_9) method was examined by Pandey and Panda [10]. The goal of tests were to minimize the temperature and force simultaneously.

The authors and their colleagues have already published articles on the machinability of die-cast aluminium parts, widely used in industry. They built phenomenological models to estimate surface roughness parameters and determined an optimum point [11], [12], [13]. They examined the changing of the statistical parameters of surface roughness separately as a function of cutting parameters, the machined materials, tool edge material and tool geometry [14].

In this paper two types of die-cast aluminium alloys were fine turned with diamond tools (PVD, CVD-D), having different nose angles (35°, 55°, 80°) by Taguchi method.

2. METHODS AND MATERIALS

In this study the finish turning of two types of die-cast aluminium alloys often used in the industry was examined. During the manufacturing of the workpiece the performance of diamond tools with different shape of cutting tool edges and edge materials was characterized.

2.1. The materials used

Two types of alloys widely used in industrial mass production were examined (AS12 and AS17). These alloys combine excellent mechanical features with their technological advantages. The advantage of the AS12 eutectic alloy is its excellent castability while the advantages of the AS17 (hyper-eutectic) alloy is improved hardness and wear resistance (due to primary silicon forming during the cooling process). The chemical composition of the materials is given as a weight percentage. For AS12 the Al content is 88.43%, the Si content is 11.57%, and AS17 the hardness is 64 ± 2 $HB_{2.5/62.5/30}$. For AS the Al content is 74.35%, the Si content is 20.03%, the Cu content is 4.57%, the Fe content is 1.06%, and the hardness is 1143 $HB_{2.5/62.5/30}$.. The size of material that was used for a cutting experiment is Ø110 × 40 mm.

2.2. The tools used

Our tests were carried out with commercially available diamond tools (code: DCGW 11T304). Tools of two types of edge material were applied: polycrystalline synthetic diamond (PCD), chemical vapour deposition synthetic diamond (CVD). These tools have conventional (ISO) shapes. Three type of tools were used in each material depending on their nose angles, such as 35°, 55°, 80°.

2.3. Taguchi design of experiments

During the examination of the finish turning of the material and the cutting capacity of tools several parameters can be changed, such as type of raw material, the material and shape of cutting tools, and cutting parameters. Cutting experiments are considered expensive, so it is advisable to reduce the number of experiments as much as possible. Taguchi L_{36} experimental design was used, where the cutting parameters (such as v_c, m/min; feed rate, f, mm and depth of cut , a_p, mm), the types of raw material, the types of cutting edge material and the nose angles of cutting tool were changed systematically.The values set in the experimental runs are in Table 1.

Table 1. Levels of the input parameters

No.	Input factors	Level 0	Level 1	Level 2	Type
1	v_c, mm/min	500	1250	2000	quantitative
2	f, mm	0.2	0.5	0.8	quantitative
3	a_p, mm/rev	0.05	0.085	0.12	quantitative
4	tool geometry	35°	55°	80°	qualitative
5	tool material	PCD	CVD		qualitative
6	raw material	AS12	AS17		qualitative

2.4. The devices/equipment used

The lathe used in the experiment was EuroTurn 12 B CNC with 7kW spindle power, and a maximum rpm of 6000. Surface roughness was measured with a Surftest SJ301 surface tester (measuring setup: λ_c = 0.8 – cutoff length, N=5 – number of sampling length). Surface roughness was measured 12 times (at 30 degrees) at each experimental point. The values in the article are the averages of these 12 measurements.

3. RESULTS AND DISCUSSION

Six parameters were changed systematically in order to produce parts. Totally 36 manufacturing process were performed, and the surface roughness (Ra, Rz) of each produced part were measured 12 times. The means of measured Ra and Rz values for the related parameter setting can be seen in Fig. 1 and Fig. 2, respectively. It can be stated that the effects are similar in both cases. The largest effect on the measured values has the feed rate, the higher the feed the higher the surface roughness. There Ra and Rz values strongly depends on the tool geometry and the cutting speed, also. The raw material (i.e. AS12 or AS17), the tool material and the depth of cut have small effects on the results.

There are some interactions between the factors. One of them is the interaction between the tool geometry and the raw material (Fig. 3), and the tool geometry and the tool material (Fig. 4). The graphs show that the surface roughness of the part does not depend on the raw material or on the tool material if the tool geometry is set to 80 °. The reason is that the tool having 80 ° nose angle has got the smallest end cutting edge angle, therefore larger edge length is in depth of cut which presses the surface of the workpiece creating smaller surface roughness.

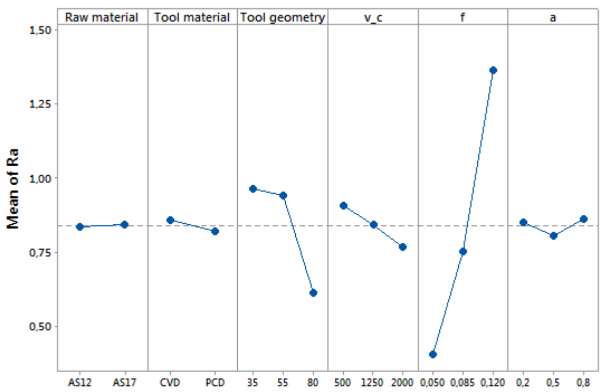

Fig. 1. Main effect plot for the Ra mean values

Summarizing, to achive the minimum for the surface roughness for the tool geometry have to be chosen 80 °, for the cutting speed 2000 mm/min and for feed rate 0.05 mm/rev.

4. OPTIMIZATION

During our study the aim is not only to achive minimum values for surface roughness parameters, but to

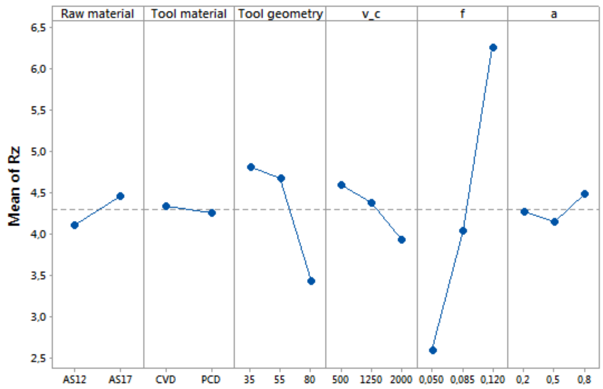

Fig. 2. Main effect plot for the Rz mean values

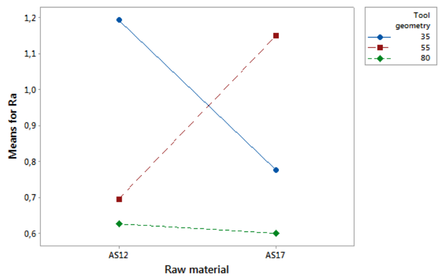

Fig. 3. Interaction plot for the Ra mean values between raw material and tool geometry

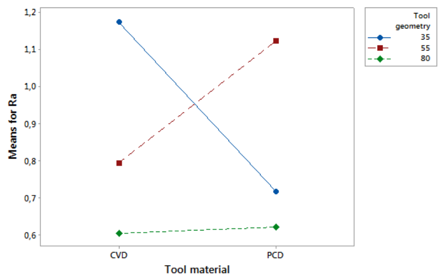

Fig. 4. Interaction plot for the Ra mean values between tool material and tool geometry

make the production process robust. It means that the turned surface let as homogeneous as it can be, and output let not be depended on the process parameters (i.e. cutting parameters, raw material, tool material). Therefore Taguchi optimization were performed. The analysis was prepared for Ra and Rz values, the smaller the better type optimization was created. The signal to noise ratios were calculated as follows:

S/N=-10$\cdot$ $\log_{10}$[mean of sum of squares of measured data]

The calculated S/N ratios are in Fig. 5 for Rz values. The graphs for Ra show similar results, where the larger is S/N ratio the better the turned surface. The optimum setting can be easily determined: the tool geometry is 80°; the cutting speed is 2000 mm/min; the feed rate is 0.05 mm/rev. The setting of the other three parameters can be chosen freely.

The results show that the cutting speed, the feed rate and the nose angle have significant effects on the cut surface roughness during fine turning, while the edge material, workpiece material and the depth of cut do not affect the technology.

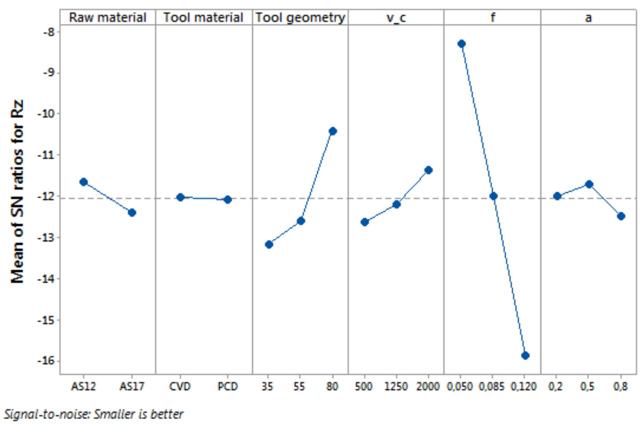

Fig. 5. S/N ratio plot for the Rz values

5. CONCLUSIONS

In this research the fine turning of two types of die-cast aluminum alloy and the cutting capacities of six types of diamond tools were investigated. In summary, the following can be stated:

- A relatively large amount of information can be obtained from a relatively small number of experimental runs with the use of the Taguchi method, and it is enough to create optimization.
- The cutting speed, feed and nose angle have the largest influence on surface roughness.
- The settings of the other tree input parameters (such as edge material, raw material and depth of cut) are independent from the results of the fine turning process in this study.
- The optimum point is as follows: v_c = 2000 m/min, f = 0.05 mm, nose angle is 80°.

The Taguchi method in the field of design of experiments is an excellent technique for seeking optimum point in cutting research.

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