Study on the influence of cutting parameters on surface quality when machining a CoCrMo alloy

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Abstract. Due to their good biocompatibility, mechanical properties and corrosion resistance, the Co-Cr alloys are one of the metallic materials used for manufacturing medical implants. When talking about manufacturing, it is well known that a significant constraint for this type of products is their surface quality. For this reason, various researches focus on the way the required surface quality of a part can be achieved with the minimum cost and resources. The aim of the research presented in this paper is to analyse the cutting regime parameters influence upon part surface quality when dry turning a CoCrMo alloy by using TiAlN PVD coated cutting inserts. The research results consist of the interdependence between the surface Ra and Rz roughness parameters of the machined CoCrMo samples and the cutting data variation and of a prediction mathematical model of the Ra roughness parameter in terms of cutting regime parameters.

1. Introduction

Today, the excellent biocompatibility and bio-functionality of the ceramics and polymers has led to the replacement of the metallic materials from some medical implants. However, biocompatible metals are still used for implants which require a high strength, hardness and durability as hip and knee implants, and future trends seem to combine these metals with ceramics and polymers in order to achieve the desired implants performances [1-3].

Cobalt-chromium-molybdenum, CoCrMo, alloys together with titanium alloys and stainless steels are the metallic materials most used in the medical industry for manufacturing medical devices and implants used in dentistry and orthopaedics [4-7]. While for the titanium alloys and stainless steels various researches on their machinability have been conducted, for the Co-Cr alloys in general, and for CoCrMo alloys, in particular, experimental studies are still necessary in order to complete the already performed research [3, 5, 8]. When talking about medical implants, their surface quality is a very important factor for their functionality and osseointegration [3, 9]. On machined parts, the surface quality is determined by factors such as material characteristics, cutting data, tool geometry, cutting fluid, etc. [5, 10, 11].
1.1. Objective
The objective of the research presented in this paper is to analyse the influence of the cutting regime parameters – depth of cut, \(a_p\), feed rate, \(f\), and cutting speed, \(v_c\) – upon surface quality of a CoCrMo alloy in case of dry turning using TiAlN PVD coated inserts and to obtain a prediction model of the Ra surface roughness parameter in relation with these cutting parameters.

1.2. Research program
The stages of the research program were: determining some effective characteristics of the CoCrMo alloy, defining the necessary cutting parameters, material processing (longitudinal turning), roughness measurement, surface profile registration, experimental data processing, and determination of the roughness parameters variation and of the prediction mathematical expression for the Ra roughness parameter.

2. Physical experiment
In this section, data regarding the analysed material – CoCrMo alloy, the processing experiment and the experimental results will be presented.

2.1. Material characteristics
The material used for this experimental research is a CoCrMo alloy with a high content of Chromium (see chemical composition shown in table 1) used in medical practice for manufacturing implants for dentistry and orthopaedic applications.

Table 1. Chemical composition of CoCrMo alloy (%)[1, 12].

|   | Cr   | Mo   | Ni   | Fe   | C     | Si   | Mn   | W    | P    | S    | N    | Al   | Bo   | Co   |
|---|------|------|------|------|-------|------|------|------|------|------|------|------|------|------|
|   | 27–30| 5-7  | max. | 2.5  | max.  | 0.35 | max. | 1    | max. | 0.2  | max. | 0.02 | max. | Bal  |

Because the material hardness has a major influence on its machinability, prior to determine the cutting regime parameters, the effective hardness of the material was determined. Five measurements were made and an average value was obtained (see table 2).

Table 2. Hardness of CoCrMo alloy samples.

| Measured values (HRC) | Average value (HRC) |
|-----------------------|---------------------|
| I         | II       | III      | IV      | V       |        |
| 43.7      | 47.3     | 46.6     | 45.8    | 45.3    | 45.6   |

2.2. Experiment details
The technological system used for the experiment had the following elements:

- Machine tool: precision lathe type SN 320;
- Cutting tool: PCLNR 2525M-12X-JHP lever lock tool with rhombic CNMG 120404-VL TiAlN PVD coated inserts with \(r = 0.4\) mm (see figure 1);
- Workpiece(s): CoCrMo 08 samples (see figure 2);
- Roughness tester: Insize ISR-C002 with special software for data registration and processing (see figure 3).
The cutting regime parameters used for the research experiment were established taking into account the material properties, the cutting tool manufacturer recommendations and the capability of the machine tool (see table 3).

| Exp. no. | Depth of cut, $a_p$ (mm) | Feed rate, $f$ (mm/rev) | Cutting speed, $v_c$ (m/min) |
|----------|-------------------------|------------------------|----------------------------|
| E1       | 0.5                     | 0.03                   | 31.4                       |
| E2       | 0.5                     | 0.04                   | 31.4                       |
| E3       | 0.5                     | 0.05                   | 31.4                       |
| E4       | 0.5                     | 0.06                   | 31.4                       |
| E5       | 0.5                     | 0.07                   | 31.4                       |
| E6       | 0.25                    | 0.05                   | 31.4                       |
| E7       | 0.375                   | 0.05                   | 31.4                       |
| E8       | 0.5                     | 0.05                   | 31.4                       |
| E9       | 0.625                   | 0.05                   | 31.4                       |
| E10      | 0.75                    | 0.05                   | 31.4                       |
| E11      | 0.5                     | 0.05                   | 25.1                       |
| E12      | 0.5                     | 0.05                   | 31.4                       |
| E13      | 0.5                     | 0.05                   | 40.2                       |

2.3. Experimental data
During the physical experiment, thirteen machining experiments were conducted using the cutting parameters shown in table 3. After processing each sample, the Ra roughness parameter for the
machined surface was measured, the following settings being used: cut-off value, \( \lambda_c = 0.8 \) mm; number of cut-offs = 5; evaluation length, \( L_e = 4 \) mm; R-C filter.

The recorded values were transferred to the ISR-C002 roughness tester software where profile and roughness curves and also other roughness parameters are shown (see figure 4). The Ra and Rz roughness parameters values associated with the experimental cases are shown in table 4.

![Figure 4. Roughness parameters and roughness curve for E5 experimental case.](image)

### Table 4. Ra and Rz roughness parameters.

| Exp. no. | Ra parameter (\( \mu \)m) | Rz parameter (\( \mu \)m) |
|----------|--------------------------|--------------------------|
| E1       | 0.769                    | 3.575                    |
| E2       | 0.834                    | 4.801                    |
| E3       | 0.884                    | 5.286                    |
| E4       | 0.948                    | 5.791                    |
| E5       | 0.973                    | 5.978                    |
| E6       | 1.011                    | 3.662                    |
| E7       | 0.611                    | 4.599                    |
| E8       | 0.884                    | 5.286                    |
| E9       | 0.955                    | 5.321                    |
| E10      | 0.985                    | 5.344                    |
| E11      | 0.961                    | 5.791                    |
| E12      | 0.884                    | 5.286                    |
| E13      | 0.646                    | 3.364                    |

3. Results processing

3.1. Roughness parameters variation

The variation of the Ra and Rz roughness parameters in relation with the cutting parameters considered for the experimental research is shown in figures 5-7.
Figure 5. Variation of surface roughness Ra and Rz parameters in relation to the feed rate, \( f \).

From the interdependence graphs between Ra and Rz roughness parameters and the feed rate, it can be observed that when the feed rate increases by 133.3\%, the Ra parameter increases by 37.24\% and the Rz parameter increases by 67.22\%.

Figure 6. Variation of surface roughness Ra and Rz parameters in relation to the depth of cut, \( d_p \).

From the interdependence graphs between Ra and Rz roughness parameters and the depth of cut, it can be observed that when the depth of cut increases by 200 \%, the Ra parameter increases by 61.21\% and the Rz parameter increases by 45.93\%.

Figure 7. Variation of surface roughness Ra and Rz parameters in relation to the cutting speed, \( v_c \).
From the interdependence graphs between Ra and Rz roughness parameters and the cutting speed, it can be observed that when the cutting speed increases by 60.16 %, the Ra parameter decreases by 32.78% and the Rz parameter decreases by 41.91%.

3.2. Ra parameter prediction model

The Ra roughness parameter prediction model was obtained from the experimental data as a regression equation where the cutting parameters were considered as independent variables. This model is presented in equation (1) and the predicted values and the differences between them and the experimental values are shown in figure 8.

\[
Ra = 0.826 + 0.7528 \times a_p + 6.42 \times f - 0.02136 \times v_c
\]

The feed rate was the most dominant factor on surface roughness. The average absolute error between the experimental values of Ra surface roughness parameter and the predicted ones is 3.363%.

![Figure 8. Experimental and predicted data of Ra surface roughness parameter.](image)

4. Conclusions

This research paper presented an experimental study on the cutting parameters influence upon surface roughness when dry turning of a CoCrMo alloy and it was performed in order to complete the existing studies on CoCrMo alloy machinability.

After the analysis of the experimental data, it can be observed that the Ra and Rz roughness parameters values are increasing with the growth of the feed rate and depth of cut cutting parameters and are decreasing with the growth of the cutting speed.

Based on the experimental values, a prediction model for the Ra roughness parameter was developed in terms of cutting regime parameters. This regression function shows that the highest influence on the Ra value is given by the feed rate (regression coefficient = 6.42), followed by the depth of cut (regression coefficient = 0.7528) and the cutting speed (regression coefficient = –0.02136). It can be observed that the cutting parameters have a nonlinear influence on the Ra roughness parameter values.

The correlation between the predicted variables (Ra predicted) and the response variables (Ra experimental) is a good one, the average absolute error between these values being 3.363%.
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