Influence of cutting data on surface quality when machining 17-4 PH stainless steel

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Abstract. The aim of the research presented in this paper is to analyse the cutting data influence upon surface quality for 17-4 PH stainless steel milling machining. The cutting regime parameters considered for the experiments were established using cutting regimes from experimental researches or from industrial conditions as basis, within the recommended ranges. The experimental program structure was determined by taking into account compatibility and orthogonality conditions, minimal use of material and labour. The machined surface roughness was determined by measuring the Ra roughness parameter, followed by surface profile registration in the form of graphics which were saved on a computer with MarSurf PS1Explorer software. Based on Ra roughness parameter, maximum values were extracted from these graphics and the influence charts of the cutting regime parameters upon surface roughness were traced using Microsoft Excel software. After a thorough analysis of the resulting data, relevant conclusions were drawn, presenting the interdependence between the surface roughness of the machined 17-4 PH samples and the cutting data variation.

1. Introduction

17-4 PH (ARMCO 17-4PH) is a precipitation hardening martensitic stainless steel characterized by a high resistance to mechanical stress, good corrosion resistance, good toughness, facile heat treatment and good weldability [1, 2]. This type of stainless steel offers a number of advantages that makes it suitable to be used in the manufacture of various parts of industrial equipment such as centrifugal air compressor impellers and turbo-engine components (cases, clamping discs of the impeller blades, fixing parts, etc.). Due to operating and safety conditions for these parts, they require a high degree of attention in order to achieve the necessary surface quality.

The machining of stainless steels generates a high cutting temperature, which reduces tool life and also influences the workpiece surface quality [3, 4]. Obtaining the prescribed surface quality is very important for the part functionality and for its functional maintenance [3].

During machining, the factors influencing the surface quality of the machined surfaces are: the semi-product characteristics, the cutting tool geometrical parameters, the cutting regime parameters, the characteristics of the cooling-lubricating fluid, the rigidity of the technological system etc. [5].

The major challenges created during conventional and non-conventional machining of 17-4 PH stainless steel are given by its high strength and toughness [6].
1.1. Objective
The main objective of the experimental research presented in this paper is to analyse the influence of some cutting regime parameters – axial depth of cut, \( a_p \), radial depth of cut, \( a_e \), feed rate per tooth, \( f_z \), and cutting speed, \( v_c \), – upon surface quality of 17-4 PH martensitic stainless steel in case of down end-milling machining.

1.2. Research program
The main steps taken into consideration for the research program were: defining the cutting regime parameters, preparation of the 17-4 PH samples, milling processing of 17-4 PH samples, roughness (Ra) measurement, surface profile registration, making the influence charts of each cutting parameter upon surface roughness.

2. Material characteristics
The material used for the proposed experimental research is 17-4 PH martensitic stainless steel. In order to determine the effective characteristics of this stainless steel, material samples were subjected to a spectral analysis – Energy Dispersive Spectroscopy Analysis, EDS. The qualitative and quantitative elements revealed by the spectral analysis of the 17-4 PH samples are presented in table 1 and figures 1 and 2.

| C (%) | Cr (%) | Ni (%) | Cu (%) | Mn (%) | P (%) | S (%) | Si (%) | Nb+Ta (%) | Fe (%) |
|-------|--------|--------|--------|--------|-------|-------|--------|----------|--------|
| 0.07  | 15-17  | 3-5    | 3-5    | max. 1 | max. 0.04 | max. 0.03 | max. 1 | 0.15-0.45 | Rest   |

Figure 1. The dispersion of some components of 17-4 PH material sample.

Figure 2. Effective metallographic structure of 17-4 PH sample.
A brief analysis of the EDS results reveals the following: a uniform dispersion of Si, Fe, Cr and Ni elements; Cu in precipitates form at grain boundaries; the fact that the material is a martensitic stainless steel with a heterogeneous microstructure, partially recrystallized with martensite grains of points 7-8 which alternate with coarse grains of points 1-2, and precipitates rich in Cu at grain boundaries.

The effective hardness of the 17-4 PH material was also determined (see table 2).

### Table 2. Hardness of 17-4 PH samples.

| Variation range (HRC) | Average value (HRC) |
|-----------------------|---------------------|
| 43.48 – 43.93         | 43.7                |

3. **Physical experiment**

This section of the paper will present the experimental research details in terms of input, technological means, process and registration of the experimental data.

#### 3.1. Experiment setup

The experimental conditions are as follows:

- Processing type: down end milling.
- 17-4 PH samples.
- Machine tool: CNC center in 5 axes, type DMU 40 eVo linear.
- Cutting tool: solid carbide end-mill cutter type Protostar 45 DIN 6527L.
- The cutting regime parameters – axial depth of cut, \( a_p \), radial depth of cut, \( a_e \), feed rate per tooth, \( f_z \), and cutting speed, \( v_c \) – and the kinematic adjustment parameters – spindle speed, \( n \), and feed speed, \( v_f \) – taken into account for the experimental research (see table 3).

### Table 3. Ranges of the cutting regime parameters and of the kinematic adjustment parameters.

| Axial depth of cut, \( a_p \) (mm) | Radial depth of cut, \( a_e \) (mm) | Feed rate, \( f_z \) (mm/tooth) | Cutting speed, \( v_c \) (m/min) | Spindle speed, \( n \) (rev/min) | Feed speed, \( v_f \) (mm/min) |
|-----------------------------------|-----------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 1 – 2.5                           | 9 - 18                            | 0.04 – 0.1                    | 30 - 60                       | 500 - 1000                    | 100 - 200                     |

The elements of the surface roughness measuring technological system are: a roughness tester MarSurf PS1 (see fig. 3) and specialised software for data acquisition and processing MarSurf PS1Explorer.

![Figure 3. The roughness tester MarSurf PS1 in working position.](image)
3.2. Experimental data
Under the presented working conditions, twenty experiments were conducted (E1, E2, ..., E20). After each processing experiment, the Ra roughness parameter for the machined surfaces was measured on a contact length of 5.6 mm.

The cutting regime parameters used during processing and the values measured for the Ra roughness parameter associated with some representative experimental cases are shown in table 4.

Table 4. Cutting regime parameters used during processing and average values measured for the Ra roughness parameter for representative experimental cases.

| Exp. no. | Axial depth of cut, ap (mm) | Radial depth of cut, ae (mm) | Feed rate, fz (mm/tooth) | Cutting speed, vc (m/min) | Ra (μm) |
|----------|-----------------------------|-----------------------------|--------------------------|--------------------------|---------|
| E9       | 1                           | 12.73                       | 0.05                     | 45                       | 0.6428  |
| E10      | 2.5                         | 12.73                       | 0.05                     | 45                       | 0.7844  |
| E11      | 1.58                        | 9                           | 0.05                     | 45                       | 0.6664  |
| E12      | 1.58                        | 18                          | 0.05                     | 45                       | 1.0304  |
| E13      | 1.58                        | 12.73                       | 0.04                     | 45                       | 0.6626  |
| E14      | 1.58                        | 12.73                       | 0.08                     | 45                       | 0.7748  |
| E15      | 1.58                        | 12.73                       | 0.05                     | 30                       | 0.6708  |
| E16      | 1.58                        | 12.73                       | 0.05                     | 60                       | 0.6304  |
| E17      | 1.58                        | 12.73                       | 0.05                     | 45                       | 0.7707  |

The performed experiments (E1–E20) revealed that the Ra maximum values belong to the following closed interval: Ra € [0.6304; 1.0406] μm.

4. Results processing and discussion
The variation of the Ra roughness parameter in relation with the cutting regime parameters considered for the experimental research – axial depth of cut, ap, radial depth of cut, ae, feed rate per tooth, fz, and cutting speed, vc, – is shown in figures 4, 5, 6 and 7.

Figure 4. Variation of surface roughness, Ra, in relation to the axial depth of cut, ap.
Figure 5. Variation of surface roughness, Ra, in relation to the radial depth of cut, ae.

Figure 6. Variation of surface roughness, Ra, in relation to the feed rate, fz.

Figure 7. Variation of surface roughness, Ra, in relation to the cutting speed, vc.
After the study of the obtained variation graphs, we can determine that the influence of each cutting regime parameter on the surface roughness value, in terms of constant values for the other cutting regime parameters taken into account, is as follows: the surface roughness, $Ra$, increases by 22.03% when the axial depth of cut, $ap$, increases by 150%; the surface roughness, $Ra$, increases by 54.62% when the radial depth of cut, $ae$, increases by 200%; the surface roughness, $Ra$, increases by 16.93% when the feed rate per tooth, $fz$, increases by 200%; the surface roughness, $Ra$, decreases by 6.02% when the cutting speed, $vc$, increases by 100% – with an increase of 14.89% on the first interval ($vc$ ∈ [30; 45] m/min) and a decrease of 18.2% on the second interval ($vc$ ∈ [45; 60] m/min).

5. Conclusions
This paper presented an experimental investigation on cutting data influence upon surface roughness when down end-milling of 17-4 PH stainless steel. The research was performed in order to enrich the existing studies regarding 17-4 PH material machinability.

The conclusions associated with this experimental research are:

Based on the analysis of the variation charts, it can be concluded that the greatest influence on surface roughness (Ra) is exercised by the radial depth of cut; the roughness value increasing with the growth of this cutting parameter. The smallest influence on surface roughness is exercised by the cutting speed.

The Ra roughness parameter value is increasing with the growth of axial depth of cut and feed rate cutting parameters.

The cutting regime parameters – axial depth of cut, $ap$, radial depth of cut, $ae$, feed rate per tooth, $fz$, and cutting speed, $vc$, – have nonlinear influence on the Ra roughness parameter and this fact requires a higher degree of attention on the produced phenomenon, more studies for other intervals being required.

Further research will be focused on the development of a Ra roughness parameter mathematical prediction model for down end-milling machining of 17-4 PH in terms of cutting regime parameters.

6. References
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