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Optimisation of parameters affecting surface roughness of Co28Cr6Mo medical material during CNC lathe machining by using the Taguchi and RSM methods

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ABSTRACT

This study involves modelling of experimental data of surface roughness of Co28Cr6Mo medical alloy machined on a CNC lathe based on cutting parameters (spindle rotational speed, feed rate, depth of cut and tool tip radius). In order to determine critical states of the cutting parameters variance analysis (ANOVA) was applied while optimisation of the parameters affecting the surface roughness was achieved with the Response Surface Methodology (RSM) that is based on the Taguchi orthogonal test design. The validity of the developed models necessary for estimation of the surface roughness values (*Ra*, *Rz*), was approximately 92%. It was found that for *Ra* 38% of the most effective parameters is on the tool tip radius, followed by 33% on the feed rate whereas for *Rz* tool tip radius occupied 43% with the feed being at 33% rate. To achieve the minimum surface roughness, the optimum values obtained for spindle rpm, feed rate, depth of cut and tool tip radius were respectively, 318 rpm, 0.1 mm/rev, 0.7 mm and 0.8 mm.

1. Introduction

With the advancing technology, chip-based machining (turning, milling, drilling etc.) methods still conserve their importance. Steel materials used in manufacturing industries keep improving progressively. Steel enjoys its diverse applications in areas such as food industry, health sector, automotive industry and space craft industry. It is for this reason that researches involving machinability of steel materials, their manufacturing efficiency and cost reduction are still among the most important studies [1].

Turning is the most common type of machining in today's chip-based manufacturing industry. It is for this reason that there are numerous studies in academic and industrial worlds on topics dealing with optimisation of factors affecting turning operation such as minimum roughness, tool wear, tool temperature measurements, and vibration etc.

Yallese et al. [2] specified statistical models of cutting forces in dry turning operation of AISI H11 hot workpiece steel (50 HRC). To achieve this, they carried out 27 experiments and specified effects of parameters like cutting speed, feed rate and depth of cut. They developed mathematical models on MINITAB (multi linear regression and RSM) and determined the most effective parameter affecting cutting forces. Ultimately; they came out with the result that the most important factor affecting the components of the cutting forces is depth of cut.

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In another study by Gupta [3], calculations of surface roughness, tool wear and power in turning operation were made based on the cutting speed, feed rate and cutting time.

Then the data obtained from a total of 27 experiments were modelled by using RSM, neural networks (NN) and Support Vector Regression (SVR) methods. Error comparison for these methods was made as well. As a result, it was found that, models developed with neural networks and SVR methods give better results than regression and RSM methods.

Aouici et al. [4] conducted a study where they used CBN tools to machine AISI H11 steel (X38CrMoV5-1) and under cutting force conditions they measured tool wear and values of the surface roughness. By using these values, the researchers studied effects of cutting speed, feed rate and cutting time by making use of ANOVA and RSM. In that study, it was found that in tool wear, the most influential factor is cutting time interval while for surface roughness, the feed rate was the most effective parameter.

Suresh et al. [5] investigated effects of cutting speed, feed rate, depth of cut and machining time on cutting forces, tool wear and surface roughness during turning operation of an AISI 4340 hardened steel by using the RSM method. They stressed that in order to minimise cutting force and surface roughness, it is necessary that high cutting speed, low feed rate, low depth of cut and short machining time are employed whereas minimisation of tool wear requires low feed rate and low cutting speed.

In their study, Chavoshi and Tajdari [6], machined AISI 4140 steel with CBN cutting tool on a lathe and with hardness (H) and cutting speed as variables, they measured *Ra* values. The feed rate and depth of cut were kept constant. By using regression and artificial neural networks methods, the researchers developed an approximate model that gives an optimum surface roughness. They found that hardness has significant effect on surface roughness.

In a study by Shihab et al. [7], where hardened AISI 52100 steel was subjected to dry turning process, the result of which micro hardness and surface roughness values were calculated based on cutting speed, feed rate and depth of cut. They also investigated the effects of cutting parameters on the quality of surface roughness. In order to determine the degree of importance for the input parameters, ANOVA analysis was employed while modelling of surface roughness and the micro hardness was achieved with central composite design-based (CCD) RSM. It was finally determined that the most dominant parameter for surface roughness is feed rate while for micro hardness the most effective parameter is cutting speed.

In another study by Aruna et al. [8], Taguchi and RSM optimisation methods were used for the purpose of optimising cutting parameters with respect to the data obtained from high speed lathe machining of INCONEL 718 material, a nickel based super alloy by making use of cermet cutting tools. It was then determined that the most effective parameter affecting surface roughness and tool wear is the cutting speed.

Sahoo [9] conducted an experimental study to investigate effects of cutting speed, feed rate and depth of cut on the formation of surface roughness for AISI 1040 steel when the material was machined on a CNC turning machine (lathe). ANOVA analysis was used in order to specify the role of three input parameters and genetic algorithm was used for the purpose of optimising the parameter results.

In another study by Ranganath et al. [10], experimental method and Taguchi, RSM and complete factorial methods were used to study the effects of cutting speed, feed rate and depth of cut on surface roughness of various materials during machining. They found that RSM method reveals better results as compared to the other methods.

Prediction of optimum cutting parameters and operating conditions for the annealed Co28Cr6Mo ASTM F 1537 steel that has low machinability, high mechanical properties, is resistant against corrosion and temperature and generally used as prosthesis in medical field is considered as a significant problem that needs to be tackled by the manufacturing experts in the related field.

In order to fill this literature gap, this study has opted to work on the topic and is targeting to determine optimum cutting parameters that will enable achieving the minimum surface roughness when machining annealed Co28Cr6Mo ASTM F 1537 steel under dry machining conditions. The surface roughness values obtained after subjecting the Co28Cr6Mo ASTM F 1537 steel to longitudinal CNC turning were measured. To determine effects of the cutting parameters used in the experiments on different surface roughness, ANOVA, surface response methodology and Taguchi orthogonal design method were used in the analyses.

2. Experimental work

2.1. Machining conditions and roughness measurements

In the experimental study an annealed Co28Cr6Mo ASTM F 1537 steel having hardness of 40 HRC was used. The specimen with dimensions of Ø50 × 500 mm was prepared. Turning process was carried out on a TC25-L type Sogotec CNC lathe and surface roughness values were measured on a SJ-201 mitutoyo device (with cut-off distance of 2.5 mm). The tests were conducted under dry machining conditions and in every test a new cutting bit was used to machine longitudinally along the work-piece. The tool holder used was MTJNR-L 2525 M16, cutting bits were TNMG 160404 MT, TNMG 160408 MT and TNMG 160412 MT form produced by Taegutec company and cladded with TiCN by the PVD method and at the quality of TT 8020. With the recommendations from the manufacturer cutting parameters given on Table 1 were specified then the

Table 1
Cutting parameters and their levels.

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
n	Rotational speed	rpm	318	477	636
f	Feed rate	mm/rev	0.1	0.15	0.25
a	Depth of cut	mm	0.5	0.7	0.9
r	Tool tip radius	mm	0.4	0.8	1.2