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Optimization of Process Parameters for CNC Turning of AISI 52100 Using Taguchi Method

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Abstract: The global environmental awareness is increased, and environmental regulations become more stringent, the negative effects of cutting fluids on the environment are becoming more apparent. At present, in high-productivity manufacturing enterprises, the supply, maintenance and recycling costs of cutting fluids account for 13%-17% of the manufacturing cost of the workpiece. In Computer Numerical Control turning of hard materials such as steels, cast iron and super alloys, involves high cutting forces, leads to more power consumption and decreasing tool life which may increases the machining cost. To make machining process environment friendly with minimizing cost of machining, dry cutting is the best solution. Current research work presents optimization of process parameters (cutting speed, feed rate and depth of cut) to minimize cutting forces and surface roughness for dry CNC turning of stainless steel (AISI 52100) using Titanium Aluminum Nitride (TiAlN) coated tungsten carbide tool. Design of experiments is conducted using well known Taguchi 's L27 orthogonal array to collect cutting forces and surface roughness data. Optimization of process parameters for cutting forces is done using Taguchi method in Minitab software. The predictive model and optimization of surface roughness is done using Response surface methodology (RSM) in Minitab software. The significance of process parameters on responses is studied using developed model. The depth of cut is found to have more significance on cutting forces, followed by cutting speed. The feed rate is found to have more significance on surface roughness, followed by cutting force.

Keywords: Surface Roughness, CNC turning, Taguchi method, Noise Radius, Minitab, Machining Force.

1. Introduction:

At present, in high-productivity manufacturing enterprises, the supply, maintenance and recycling costs of cutting fluids account for 13%-17% of the manufacturing cost of the workpiece, while the tool costs only account for 2%-5%. The industrial sector accounts for about one-half of the world 'stotal energy consumption and the consumption of energy by this sector has almost doubled over the last 60 years [1]. Global environmental awareness is increased, and environmental regulations become more stringent, the negative effects of cutting fluids on the environment are becoming more apparent. According to statistics, twenty years ago, the cost of cutting fluid was less than 3% of the cost of the workpiece. In CNC turning of hard materials such as steels, cast iron and super alloys involves high cutting forces, leads to more power consumption and decreasing tool life which may increase the machining cost. To make machining process environment friendly with minimizing cost, Dry cutting is the best solution. Dry cutting without any cutting fluid during processing is a green manufacturing process that controls the source of environmental pollution. Dry machining is done with the hard coating for cutting tools shown as in Figure 1. These hard coatings are thin films that range from one layer to hundreds of layers and have the thickness that range from few nanometers to few millimeters. A good surface finish and longer tool life were achieved using coated tool. Results showed coated tool gives better surface roughness values rather than uncoated tool.

2. Literature Review:

A literature review is a summary of a subject field that supports the identification of specific research questions. A literature review needs to draw on and evaluate a range of different types of sources including academic and professional journal articles, books, and web-based resources.Arafa S Sodh et al. (2023), addressed the increasing interest in TC21 Ti-alloy within the realm of materials engineering and aimed to analyze its machinability aspects. To efficiently achieve this goal with minimal experimental trials, the researchers utilized the orthogonal array (OA) L9 Taguchi approach. This method involved investigating three cutting parameters at three different levels.

Figure 1 Dry Turning Process

The optimal cutting conditions were determined through the experimental work conducted based on these parameters. [1] **Md Tanveer et al. (2023),** did a research study to find the most suitable cutting parameters for machining hardened steel on a (CNC) lathe machine. They also explored the influence of on ceramic tools while performing dry cutting operations. To enhance the results of hard-turning, a multi-objective optimization (MOO) model based on integrated fuzzy TOPSIS was employed. The findings of the study demonstrated that a combination of speed of cutting at 98 m/min, feed at 0.1 mm/rev, and doc at 0.2 mm produced the most favorable multi-objective outcomes. Furthermore, the ANOVA analysis indicated that the feed rate significantly affected the response variables.[2]

VikashMarakini et al. (2022), utilized a blend of Taguchi design of experiments and the machining settings with the goal of enhancing of AZ91 alloy. They employed the Taguchi L9 design to determine cutting conditions for dry face milling, and then fine-tuned the multiple objectives using Grey Relational Analysis. The effect of individual parameters on both attributes and the grey relational grade was assessed using, performed separately for each attribute. Furthermore, an analysis of variance was conducted to evaluate the impact of variables on surface hardness and roughness. To validate the findings, confirmation experiments were carried out, confirming the projected trends based. This investigation demonstrated the successful synergy between Taguchi design and Grey Relational Analysis in tackling challenges related to surface characteristics.[3]

Pytlak and colleagues (2021), introduced an innovative method for hard turning of cemented 18 HGT steel. They enhanced the wipers' geometry using CBN (cubic boron nitride) and considered cutting depth, feed rate, and cutting velocity as critical factors to achieve optimal results. To attain cost-effective manufacturing and reduce cutting pressures, Sieben and his team (2010) applied the (DACE) technique to experimentally demonstrate the AISI 6150 steel, utilizing PCBN (polycrystalline cubic boron nitride) tools. They comprehensively analyzed various criteria, including feed rate, cutting depth, and cutting velocity, to evaluate the hard turning process.[4]

Cappellini et al. (2020), conducted a study with a focus on improving surface layers during hard cutting of AISI 52100 steel discs. They employed PCBN (Polycrystalline Cubic Boron Nitride) inserts for this purpose. The study revealed that exceeding the austenizing temperature resulted in the burial of martensite, leading to the formation. The key parameters investigated. The surrounding white under a microscope. Additionally, it was noted that the tool gradually reduced the thicknesses of the layers. Higher cutting speeds or feed rates led to thicker white layers, while lower speeds or feed rates produced thinner layers. [5]

D. PhilipSelvaraj et al. (2020), the objective was to assess (cutting rate, fr, and doc) on the roughness surface of AISI 309 Austenitic treated steel. The researchers utilized Taguchi's technique to collect data and employed a tungsten carbide cutting tool coated with TiC and TiCN to analyze the cutting characteristics of AISI 304 steel bars. The analysis encompassed Symmetrical displays, (ANOVA). The outcomes were verified through certification tests, confirming the reliability of the conclusions pertaining to surface roughness. [6]

R. Ramanujam et al. (2019),The initial phase of the study involved the application of "attractive quality limit assessment" and Taguchi's L27 symmetrical design. The process parameters, comprising speed of cutting, feed and depth, were adjusted based on diverse performance considerations, with a focus on surface roughness and power usage. The composite's attractive quality value served as a reference to ascertain the most suitable machining parameters, ensuring effective control by monitoring the progress. The test outcomes were validated, demonstrating the potential for enhancing machining performance based on exploratory findings [7]

Siva Surya Mulugundam et al. (2017),The objective is to optimize the material removal rate and surface roughness while machining EN19 steel using ANOVA. The influence and contribution of cutting parameters such as cutting speed, feed rate and depth of cut are estimated through dry and wet machining using ANOVA. The Minitab software is used to form the design of experiments with L9 orthogonal array. The values of the material removal rate (MRR) and the surface roughness (SR) are calculated, through sum of squares the percentage contribution are calculated and by main effects plots influencing levels of cutting parameters are justified. The results of this study indicates that the depth of cut and cutting speed has the most significant effect on MRR and SR for dry machining and the depth of cut for wet machining. [8]

Jitendra Sharma and Ajay Kumar Agarwal (2017) have presented the mechanical manufacturing industries are regularly challenged for achieving higher productivity and high-quality products in order to remain competitive. The desired shape, size and finished ferrous and non-ferrous materials are conventionally produced through turning the preformed blanks with the help of cutting tools that moved past the work piece in a machine tool. Among various cutting processes, turning process is one of the most fundamental and most applied metal removal operations in a real manufacturing environment. [9]

2,1Research Objectives:

- Optimization of CNC turning operation
- Increasing Performance

3, Experimentation:

In the present research work the methodology adopted was to select the process parameters for response, conduct experiential runs provided by Taguchi ‘s L27 orthogonal array, Optimization process parameters for cutting force using Taguchi Method, Optimization of process parameters for surface roughness using RSM and to develop predictive model of surface roughness. Research methodology flow chart is shown in Fig.2.

Experimentation has been done to achieve the objectives of the research work. Sequence of experimental work carried out as described below: on CNC lathe for turning of hard material AISI 52100 steels using TiAlN coated tool insert.

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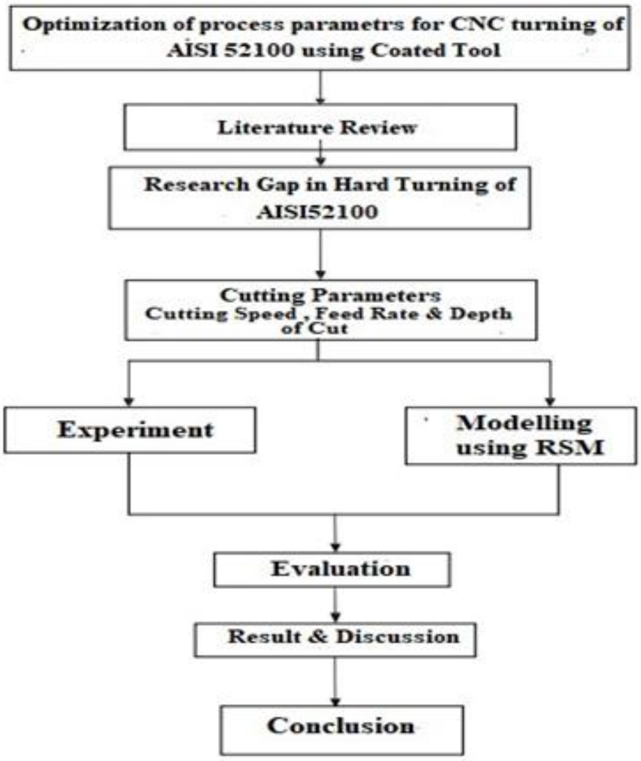

Figure-3 Research work methodology

Table-1: Chemical composition of AISI 52100

C	Si	Mn	P	S	Cr	Mo	Ni	Fe
0.4	0.25	0.7	0.035	0.04	0.8	0.25	1.85	95.675

Table-2: Mechanical Properties of AISI 52100

Elastic modulus (GPa)	Yield strength (MPa)	Poisson ratio	Rockwell hardness
205	710	0.96	62

4. Result and Discussions:

Experimental data of cutting force and surface roughness has been collected; then it was used to optimize the parameters to minimize the cutting force and surface roughness. Optimization results are discussed here.

4.1 Optimization of process parameters for cutting force using Taguchi method:

Variables with remarkable effects on the cutting force are obtained by analyzing the experimental variables with ANOVA and calculating the percent contribution.

4,2Analysis of experiment factors:

Analysis of the influence of each variable (v, f, and d) on the cutting force is performed with S/N response table, using the Minitab 21 software package. The S/N response table for the cutting force is presented in Table 3. It shows the calculated S/N ratios of experimental factors in each level. The experimental factor with the strongest influence was determined depending on the value of delta, as shown in Table 3.

Table-3: S/N Response table for the cutting force (Smaller is better)

Level	v	f	d
1	51.29	52.17	49.34
2	53.49	53.31	53.54
3	54.40	53.71	56.30
Delta	3.11	1.54	6.96
Rank	2	3	1

Delta equals to the difference between the maximum and the minimum S/N ratios for a particular experimental factor. Higher the value of delta, the more influential the experimental factor. The experimental factors and their interactions were sorted according to the values of delta. The experimental factors with a value of delta larger than the mean effect were selected as the key factors for this study. From Tables 3 and 4, the strongest influence was exerted by the depth of cut (d) and the cutting speed (v), respectively, meaning that the response table presented in Table 4 also gave the same results for the influence of the factors.

Table 4 Response Table for Means

Level	v	f	d
1	392.7	435.7	298.7
2	494.7	492.0	491.8
3	574.0	533.7	670.9
Delta	181.4	98.0	372.2
Rank	2	3	1

5, Conclusion:

Optimization model have been presented to determine the machining parameters leading to minimum cutting forces during machining. The optimization model has been developed using Taguchi method to find the values of machining parameters leading to minimum cutting forces. Analysis of the influence of each variable (v, f, and d) on the cutting force is performed with S/N response table, ANOVA, main effect plot and interaction plot using the Minitab 21 software package.

Higher the value of delta, the more influential the experimental factor. The strongest influence was exerted by the depth of cut (d) and the cutting speed (v), respectively. The P value was first examined, and the P values of factors d and v were 0 and 0.001, respectively.

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