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"EXPERIMENTAL INVESTIGATION AND OPTIMIZATION OF MILLING PARAMETERS AFFECTING SURFACE ROUGHNESS, CUTTING FORCE, AND TEMPERATURE IN MSS 416 AND MSS 420"

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ABSTRACT

With chromium as the main alloying element, usually in the range of 12–15%, martensitic stainless steels have structural similarities with carbon and low-alloy steels. While AISI 420 has at least 12% chromium and is stronger and harder than AISI 416, AISI 416 is a general-purpose martensitic stainless steel with up to 12% chromium. Many parts, including nuts, bolts, bushings, shafts, valves, pumps, turbine blades, and cutlery, employ AISI 416. AISI 420, on the other hand, is mostly used in applications like cutting blades, surgical and dental instruments, dies, plastic molds, steel balls, and hand tools that call for exceptional hardness and wear resistance. These materials are challenging to manufacture despite their wide range of industrial uses because they create stiff, continuous chips and hefty accumulated edge during cutting, making process optimization and tool selection difficult. While the turning of martensitic stainless steels has been the subject of several studies, little is known about the CNC milling of AISI 416 and AISI 420, especially under dry machining settings. The current study uses dry CNC milling as a sustainable machining method in light of the health risks and environmental effects of cutting fluids. There were six phases to the experimental inquiry. Phase 1 examined how cutting parameters affected surface roughness (Ra) and cutting force (Fc) during dry CNC milling of AISI 416 and AISI 420. Cutting parameters were optimized in phases two and three using Taguchi L9 and L27 orthogonal array designs, respectively. Phases' outcomes. consistent depth of cut, showed that for both MSS classes, spindle speed had the most impact on surface roughness and cutting force, followed by feed rate. Spindle speed, feed rate, and depth of cut all had an impact on surface roughness, according to Phase 3 optimization utilizing the L9 Taguchi technique. On the other hand, depth of cut had the most impact on cutting force, followed by feed rate and spindle speed. The depth of cut had the most impact on the cutting temperature, while spindle speed and feed rate also had a big impact.

Key Words: *AISI , Taguchi L9 , Spindle Speed , Feed Rate , Cutting force , CNC Milling.*

I. INTRODUCTION

Stainless steel is the name given to a family of corrosion- resistant steels that contain at least 10.5% chromium. Just as there are different engineering and structural carbon steels that meet different weldability, toughness, and strength requirements, there is also a wide range of SS with higher levels of strength and corrosion resistance. This is due to the controlled addition of alloying elements, each of which provides specific characteristics regarding ability and strength to withstand various environments. Available SS grades can be classified into five main families: austenitic, ferritic, duplex, martensitic and precipitation hardening stainless steel.

1.1 Martensitic Stainless Steel

Martensitic stainless steels belong to the 400 series stainless steel. Grade 416 is the basic and the most widely used one. It normally contains 11.5 to 13 percent chromium, 0.1 percent manganese, 0.15 percent carbon, and other minor

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constituents. MSS 416 is also a popular grade. High chromium and manganese with molybdenum and sulfur/selenium are used for the manufacturing of screws and gears. MSS is primarily developed to meet the characteristic requirements of high strength, hardness, corrosion, and wear resistance. MSS grades are ferromagnetic as they can retain their magnetic properties even after the magnetic field is removed.

MSS is similar to carbon or low alloy steel. By adding carbon, it can be hardened and strengthened by heat treatment like carbon steel. In the annealed state, around 275 MPa tensile yield strength is obtained and hence it is usually cold worked or cold formed in this condition. Increasing carbon content increases hardness and potential strength, but reduces toughness and ductility.

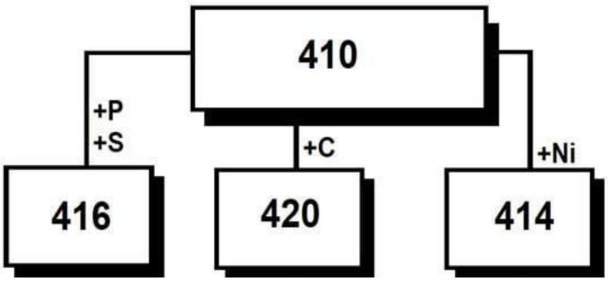

Figure 1.1 Martensitic stainless steel grades.

Higher carbon grades can be heat treated to a hardness of 60 HRC. Best results for corrosion resistance are achieved when it is heat treated, i.e. hardened and tempered. MSS, made by adding nitrogen and nickel, has lower carbon percentage than conventional grades. These steels have improved weldability, corrosion resistance and toughness.

1.2 Grade MSS 416 and MSS 420

MSS 416 is a general-purpose martensitic grade containing 11.5% chromium that provides excellent corrosion resistance and can be further improved by various processes like tempering, hardening, and polishing. Tempering and Quenching will improve the hardness of the MSS 416 grade.

MSS 420 is high carbon steel grade with a minimum 12 % of chromium. Similar to other stainless steels, MSS 420 can be heat treated. It provides excellent corrosion resistance during metal polishing, hardening, surface grinding, and excellent ductility in the annealed state. This grade has the largest hardness (50 HRC) among all SS grades containing 12% chromium.

II. OBJECTIVES OF RESEARCH WORK

The main objectives of the research work are described below:

1. To estimate the effect of spindle speed, Depth of cut and feed on surface roughness, cutting force, and temperature during the milling of MSS 416 and MSS 420 by a 15-run experiment.
2. To optimize the cutting parameters of MSS 416 and MSS 420 grades using L9 OA Taguchi method.
3. To validate the results of experiments by comparing them with predicted values.

III. LITERATURE REVIEW

Peksen and Kalyon (2025) conducted experiments for the machining parameter optimization during the turning operation of MSS 430 grade. This study examines statistically and experimentally the machinability of AISI 430 stainless steel on a lathe using three different feed rates (0.75, 1.5 and 2.25 mm/rev), and three different cutting speeds (80, 140 and 200 m/min) and two tool inserts with a different coating.

Sonawane and Sargade (2024) investigated the multi-objective optimization of Duplex stainless steel 2205 (DSS)

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during dry turning operation. The responses taken are cutting force, nose wear, and surface roughness. The GRA-based Taguchi method is employed for analysis and estimation of optimum values. Analysis of variance results of GRG shows that, the combined quality characteristic is influenced in the order of feed followed by speed and cutting tool material.

Patel et al. (2023) analyzed the impact during the Ultrasonic assisted turning (UAT) and conventional turning (CT) operation on MSS 420 by choosing the cutting parameters spindle speed and feed having 3 levels each. Chip morphology, surface roughness, and power consumption are the responses taken for study. The results show a decrease of about 43% for R_a values and 3.13% for power consumption. Continuous type chip is observed for CT process and discontinuous chip formation in UAT process

Sterpin et al. (2019) conducted experiments for optimizing cutting parameters for machining the MSS Grade X20Cr13 using the Taguchi-based GRA method. The impact of the MQL method with and without Ranque Hilsh vortex tube (RHVT) on surface roughness and tool life is evaluated for different feed, speed, DOC and cooling method. The GRA method has proven that, the MQL-RHVT method gives the best results.

Sharan and Kumar (2019) developed an optimal turning model for AISI 4140 MSS using the L9 OA Taguchi method. Feed, Speed, and DOC are the factors selected at low, medium, and high levels. The output response is the Rockwell hardness of the material. Carbide inserts are used for turning operation. ANOVA results indicate that DOC has the greatest effect on hardness, followed by speed and feed.

Ramu et al. (2018) identify the optimal cutting parameters during the CNC turning operation of the stainless steel grade 316 L. Based on the obtained GRG, it can be concluded that DOC has a significant effect on the R_a, and material removal rate (MRR). The optimal results are also estimated using the GRG value.

Palanisamy et al. (2018) attempted to make a machinability study for the CNC turning of PH Stainless Steel with parameters feed, cutting speed, and nose radius. The selected responses are surface quality, cutting force, and micro hardness. The results indicate that the responses are mostly affected by feed and then cutting speed. Good surface quality and minimum cutting force are obtained at a lower feeds and higher cutting speeds. Variation in nose radius shows less effect on micro-hardness.

Anthony and Jeyapandiarajan (2018) performed the hard turning study for the cutting parameter optimization of AISI D2 Steel (55 HRC). Multi-performance optimization is done using the GRA methodology. The optimum values of all eight machining variables are identified from the GRG obtained.

Correa et al. (2017) stated that the tool life of super MSS when compared with MSS is low at higher DOC and speed. An investigation for estimating the tool wear of TIN/TICN/TIC coated carbide tool for machining super martensitic (S41426) and Martensitic (S41000) grade steel is conducted. SEM analysis shows that, for S41000 grade steel diffusion and abrasion are the main causes of wear. For S41426 grade it is abrasion and attrition.

Bissey et al. (2016) have presented the effects of machining on the corrosion behavior, mechanical properties, and microstructure, of MSS grades with low carbon content. It is observed that microstructure is affected by the machined surface. Depending on the cutting conditions, sub boundary formation of particles or miniaturization of the microstructure is observed. The hardness is increased due to this condition. The average pit surface area is also increased by microstructure improvement.

Kacal and Yildirim (2016) conducted a cutting parameter optimization study of AISI D6 steel (60 HRC) during high-speed machining operation using the GRA methodology. The responses taken are wear, surface quality, and machining force. Feed is identified as the prominent factor affecting the response values. Optimum values are determined using the GRA method.

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Sahu and Choudhury (2015) have presented surface roughness optimization using the Taguchi method and tool wear prediction of hard turning tools. Studies include the comparison of the performance of TiN-coated and uncoated multilayer tools during the high-speed turning of AISI 4340 steel using the Taguchi approach. DOC, feed, and cutting speed are selected as cutting parameters. Tool wear prediction and surface morphology analysis are done using a scanning electron microscope (SEM). The results shows the better performance of coated tools than uncoated tools and the optimum condition is obtained at lower feed rates and higher spindle speeds.

Philip et al. (2014) have concluded that tool wear in turning of two grades of nitrogen alloy DSS is mostly influenced by cutting speed. On the other hand, the feed will prominently affect the cutting force and surface quality. TiCN and TiC coated carbide inserts are used for the turning operation of specimens. Experiment is conducted at three levels of cutting speed and feed, with a constant DOC. Optimization of cutting parameters is done using the Taguchi approach.

Koyee et al. (2014) applied Taguchi Fuzzy Combined Multi- Attribute Decision Making (FMADM) during turning. Good surface finish will be obtained at optimal cutting conditions. Turning of standard duplex EN 1.4462, ultra-duplex EN 1.4404, and ultra-duplex EN 1.4410 SS have been done using this method during the experiment. The results prove that this method will produce better surface quality at optimal cutting conditions than the one obtained during the experiment

IV. EXPERIMENTAL WORK

4.1 Work Material Selection

MSS 416 and MSS 420 are the work piece materials used for investigation. The mechanical properties and chemical composition of the specimens used are illustrated in Tables 3.1 and 3.2 respectively. Figure 3.1 shows the photograph of MSS 420 work piece material used for the study.

Table 1 Chemical composition - MSS 416 and MSS 420

Alloy	Cr	Ni	C	Mn	Si	Mo	P	Cu	Fe
AISI 416	11.94	0.519	0.131	0.816	0.36	0.24	0.024	0.077	Balance
AISI 420	12.34	0.271	0.201	0.741	0.56	0.21	0.027	0.108	Balance

Table 2 Annealed mechanical properties of MSS 416 and MSS 420

Alloy	Tensile Strength (MPa)	Yield Strength (MPa)	Elongation %	Hardness (HRC)
AISI 416	510	290	34	38-45
AISI 420	586	310	29	53-57

The dimensions of the work piece used in this study are 100 mm long, 80 mm wide and 50 mm thick rectangular block. The specimens are procured from Sree Krishna Metals, Coimbatore.

4.2 Experimental Setup

CNC dry milling test was performed using a BFW make BMV 40 T20 vertical machining center. The spindle motor of the machining center has a power of 10 kW and it works in a range of 60-6000 rpm spindle speed.

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Figure 4.1 Experimental Setup

Table 3 Parameters and Levels for test

Input parameter	Level 1	Level 2	Level 3
Spindle speed [rpm]	1000	1500	2000
Feed [mm/min]	30	60	90
Depth of cut [mm]	0.3	0.6	0.9

In this phase of the experiment, optimization of the cutting parameter is done using Taguchi method. The rank in Taguchi analysis indicates the effect of individual parameters on R_a, and F_c. Minitab 19 statistical software is used for the analysis.

V. RESULT & ANALYSIS

5.1.1 Impact of Cutting parameter on R_a

Figures 5.1 shows the impact of spindle speed on R_a values corresponding to feed values during CNC dry milling operations of MSS 416 and MSS 420 grades.

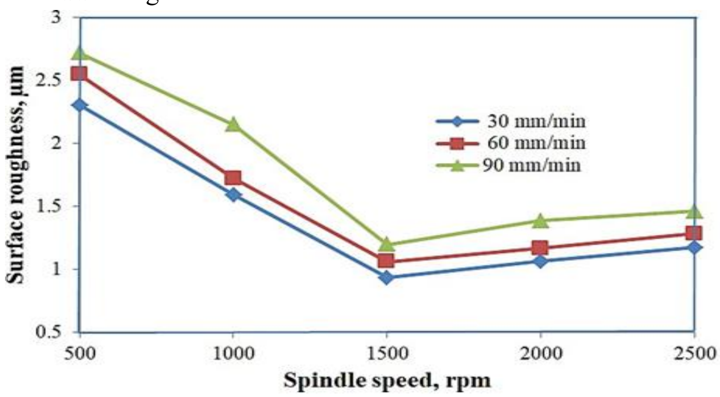

Figure 5.1 Spindle speed vs. Surface roughness graph for MSS 416

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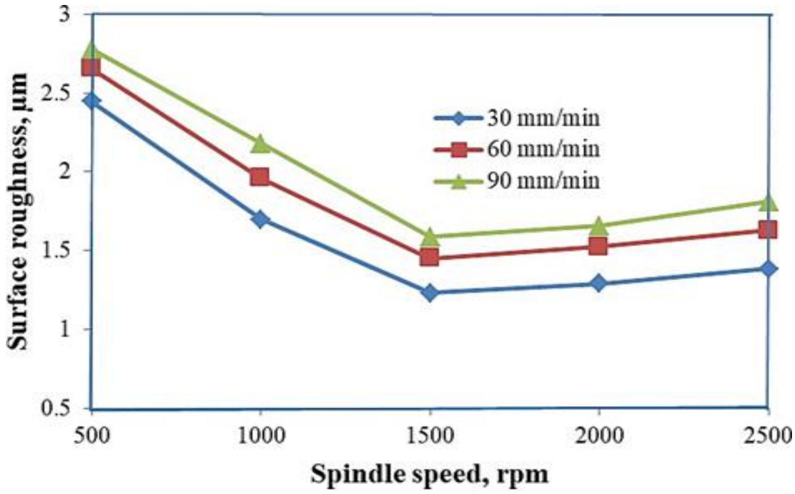

Figure 5.2 Spindle speed vs. Surface roughness graph for MSS 420

From Figures 5.2 it is clear that R_a values for both MSS grades are decreasing for spindle speed values up to 1500 rpm. By increasing the value of the spindle speed from 500 to 1500 rpm, the amount of surface roughness decreases due to the reduction of BUE formation.

The R_a value increases for spindle speed values between 1500 and 2500 rpm due to the higher tool wear rates occurring at this spindle speed. Cutting edge geometry usually deteriorates due to tool wear. Therefore, milling a work piece with a worn tool requires a higher cutting force, which increases the surface roughness. The minimum R_a values are noticed at 1500 rpm spindle speed for both the MSS grades.

5.1.2 Impact of Machining Parameters on F_c

Figures 5.3 represent the impact of spindle speed on F_c during machining of MSS 416 and MSS 420 at three feed levels.

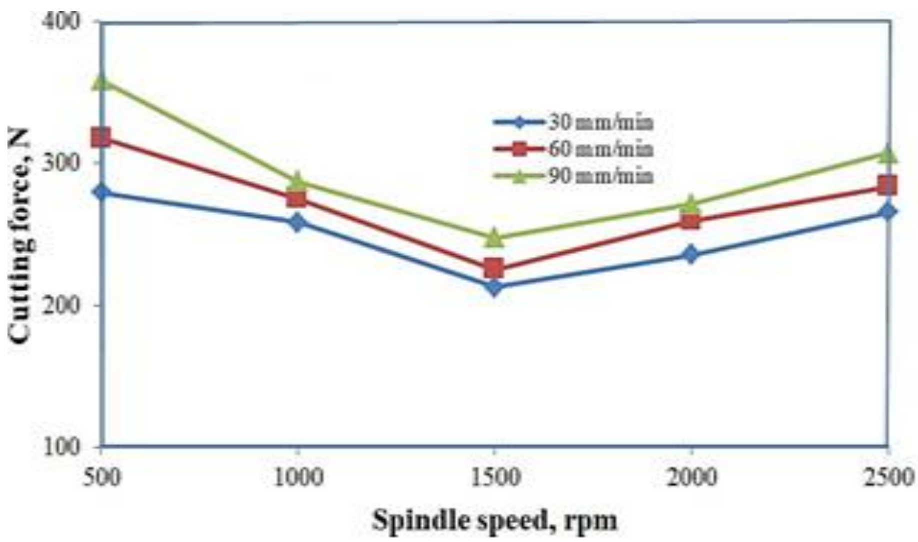

Figure 5.3 Spindle speed vs. Cutting force graph for MSS 416

VI. Conclusion

The cutting parameter optimization during the CNC dry milling of MSS 416 and MSS 420 was carried out using the L9 Taguchi Method

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The major findings are listed below.

1. From all the phases of the experiment, it is clear that depth of cut, spindle speed, and feed have a significant impact on surface roughness, cutting force, and temperature for MSS 416 and MSS 420 grades.
2. The optimum cutting parameters for cutting force and surface roughness are obtained at 1500 rpm spindle speed, 30 mm/min feed, and 0.3 mm DOC.
3. The optimum cutting parameters for temperature are obtained at 1000 rpm spindle speed, 30 mm/min feed, and 0.3 mm DOC.
4. From the experiments, it is also observed that higher values of Temperature, F_c, and R_a are obtained for MSS 420 when compared with MSS 416 because of the difference in chemical composition and the presence of a higher percentage of C and Cr in MSS 420.
5. In Phase-1 and phase-2 experiment, varying spindle speed and feed with constant DOC is considered. Results show that F_c and R_a are most affected by spindle speed and then feed for both the grades.

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