

Dry Cutting Performance of M300 Maraging Steel: Effects of Machining Parameter Variations

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Abstract – The manufacturing industry continuously faces the demand for new materials with enhanced performance characteristics. In response, innovative work materials are being developed, tailored to possess specific mechanical properties for their intended applications. Among these, 300M steel has emerged as a high strength maraging steel with potential applications across various sectors, including aerospace and defense. Despite its promising properties, no comprehensive machinability studies on 300M steel have been reported in the literature. In this study, the machinability of 300M steel was investigated through dry turning experiments, using feed rates of 0.05–0.10 mm/rev, depths of 0.10–0.20 mm, and cutting speeds of 45–90 m/min. The analysis focused on the influence of these parameters on two critical machinability measures: cutting force and surface roughness. Graphical evaluations were performed to establish the correlations between machining parameters and the measured outputs. The study demonstrates that lower cutting forces are associated with smaller depths of cut and lower feed rates, while higher values of cutting speed are required. To achieve minimum surface roughness, lower feed rates and depths of cut are necessary, whereas higher cutting speeds should be employed. These findings not only provide a baseline for machining 300M steel but also offer valuable insights for optimizing cutting parameters in the manufacturing of maraging steels.

Keywords – 300M, Maraging Steel, Machinability, Turning, Cutting Force, Surface Roughness.

I. INTRODUCTION

In contemporary manufacturing, achieving optimal material processing while ensuring sustainability in accordance with green production principles is closely linked to the machinability of the material. Machinability, in general terms, describes the ease with which a workpiece can be machined and is typically assessed through four fundamental criteria: power consumption and cutting force, tool wear, surface integrity, and surface quality [1]. Materials exhibiting high machinability are characterized by low cutting forces and energy usage, minimal tool wear, and superior surface finish [2].

Alongside the inherent machinability of a material, the selected manufacturing method plays an equally critical role in process efficiency. Greater control over machining operations enables more precise, efficient, and high-quality production. Among manufacturing techniques, machining processes remain essential for shaping components to their final geometry [3]. Examples include milling, drilling, grinding, and turning [4]. Turning, in particular, operates on the principle of chip removal from a rotating workpiece by means

of a stationary cutting tool and is one of the most fundamental operations in metal cutting [5]. Numerous studies have demonstrated that optimizing turning parameters can yield enhanced surface finish, lowered cutting forces, and prolonged tool life [6]. Consequently, the impacts of key cutting parameters (such as feed, cutting speed and depth) on performance metrics like cutting force and surface roughness have become a significant focus in recent research.

During cutting, mechanical contact between the tool and the work material generates forces at the tool–workpiece interface. Controlling these forces is vital not only for extending tool life but also for improving process efficiency [7, 8]. Achieving minimal cutting forces is therefore a desirable condition in machinability. In addition to cutting forces, the surface quality and integrity of the machined component (both influenced by the machining conditions) are critical assessment factors [9]. Surface quality is most often quantified by the surface roughness (Ra) value, with lower values indicating superior finish. A considerable body of literature has investigated machinability across various workpiece materials, and the findings of these studies can be summarized as follows.

Herrera Fernández et al. [10] examined the effects of various cutting parameters on cutting temperature, energy consumption and forces, during the dry turning of Ti6Al4V alloy. Their findings indicated that depth of cut had the most notable influence on temperature and cutting forces, whereas feed was the dominant factor in energy consumption. Multi-criteria optimization, supported by the developed models, contributed to the formulation of sustainable and efficient machining strategies. Kónya et al. [11] evaluated the impacts of different emulsion concentrations and tool coatings on the machinability of austenitic stainless steels. The results showed that coated tools combined with emulsion usage reduced cutting forces and tool wear; however, oil concentrations above 9% increased cutting forces. While dry machining provided the best surface roughness results, concentrations exceeding 9% were not recommended when considering tribological performance and tool life. Marcelino et al. [12] studied the influence of cutting speed on surface roughness during the turning of AISI 1018 steel. Cutting speeds of 42, 66, and 105 m/min were tested, with the best surface finish obtained at the highest speed. It was concluded that greater cutting speeds improve surface quality by reducing vibration and cutting forces. Singh et al. [13] optimized cutting parameters and machining conditions (including minimum quantity lubrication (MQL), rotary heat-assisted turning (RHVT), compressed air, and dry cutting) during the turning of Al7075-T6 aerospace alloy. Using Taguchi L16 experimental design and ANOVA, machining condition was identified as the most influential factor affecting surface roughness and tool wear. Results revealed that MQL at low cutting speeds minimized friction, thereby reducing both tool wear and surface roughness. Fountas et al. [14] evaluated the dry hard-turning machinability of 0CrMoV18-5 cold-work tool steel using CBN cutting inserts. The impacts of cutting speed, feed rate, and depth on main cutting force and surface roughness (Ra) were analyzed through ANOVA and regression modeling. The study found that surface roughness was primarily affected by feed and cutting speed, while main cutting force was mainly determined by feed and depth. Furthermore, multi-objective optimization was performed using the NSGA-III algorithm. Mohanta et al. [15] concentrated on optimizing cutting speed, feed rate, and depth to mitigate surface roughness and cutting forces during the turning of CuAl10Fe5Ni5-C alloy. Employing PVD AlTiN-coated cutting tools and Taguchi L27 experimental design, they reported a positive effect of coated tools on both surface quality and cutting forces, with feed rate identified as the most significant parameter. The integration of Principal Component Analysis (PCA) with the Taguchi method was highlighted as a robust approach for experimental design. Korkmaz et al. [16] investigated cutting forces during the turning of Nimonic 80A superalloy experimentally and through finite element modeling (FEM). Three cutting parameters (depth, cutting speed, and feed) were varied in the experiments, and the effects on cutting forces were analyzed using ANOVA. FEM simulations employed previously determined Johnson-Cook material model parameters, and an average deviation of 6.45% between experimental and simulation results validated the model accuracy. In a subsequent study, Korkmaz et al. [17] modeled cutting forces and energy consumption during the turning of AISI 420 martensitic stainless steel using FEM. Depth was identified as the main determinant for energy consumption, accounting for 49.55%. The average differences between experimental and simulation results were 7% for cutting forces and 4.5% for energy consumption, demonstrating that FEM can reliably predict cutting parameters for difficult-to-machine materials. Kumar et al. [18] studied the effects of feed, depth, and cutting speed on surface roughness and cutting force during dry turning of an Al-4Mg/MgAl2O4

nanocomposite with high-speed steel tools. Cutting force increased up to 100 m/min and decreased at elevated speeds, while built-up edge formation was more pronounced at low speeds. The composite containing 1 wt% MgAl₂O₄ achieved the best surface quality, with a surface roughness of 2.4 μ m at a feed of 0.14 mm/rev.

Extensive literature review revealed that no systematic studies have investigated the interactive effects of cutting speed, feed, and depth specifically for M300 maraging steel. In this context, the present study experimentally examines the influence of these key machining parameters on cutting force and surface roughness during turning of M300 steel. By addressing this knowledge gap, the study aims to provide valuable machinability data and practical guidance for processing M300 maraging steel, thereby contributing to both the scientific literature and industrial applications.

II. MATERIALS AND METHOD

This section outlines the properties of the machine tool, cutting tool, and work material used in the experiments. Experimental conditions (including machining parameters, cutting environment, and preliminary tests) are briefly described. Finally, the sensors and devices employed for measuring output parameters are presented. A schematic representation of the study methodology is provided in Figure 1.

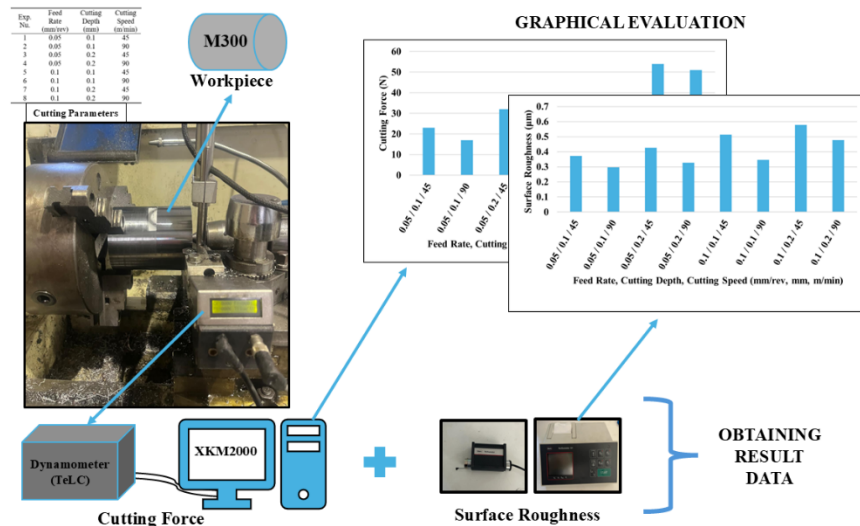


Fig. 1 Graphical abstract of the realized study

A. Workpiece Material and Cutting Tool

M300 maraging steel was adopted as the workpiece material for this research. The workpiece had a diameter of 110 mm and a machining length of 100 mm. This material is widely used in industry, particularly for critical components in the defense sector, which motivated its selection. A CCMT-09T308-304 insert was used as the cutting tool, and to ensure consistent and accurate results, the tool was replaced with a new one after each experimental run. The chemical composition of M300 steel is summarized in Table 1.

Table 1. Chemical composition of the M300 maraging steel (wt%) [19]

Work Material	Ni	Co	Mo	Ti	Si	Fe
M300	17–19	7–10	4.50–5.20	0.30–1.20	0.08	Bal.

B. Machine Tool and Preliminary Experiments

Physical machining experiments were conducted on a DE Lorenzo manual lathe. The workpiece was securely clamped in the lathe chuck, and preliminary tests were conducted to identify and mitigate potential issues before finalizing the machining conditions. Based on these preliminary tests, the machining parameters listed in Table 2 were selected for the main experiments.

Table 1. Cutting parameters used in experiments

Exp. Nu.	Feed Rate	Exp. Nu.	Feed Rate
1	0.05	0.1	45
2	0.05	0.1	90
3	0.05	0.2	45
4	0.05	0.2	90
5	0.1	0.1	45
6	0.1	0.1	90
7	0.1	0.2	45
8	0.1	0.2	90

C. Cutting Environment and Measurement of Output Parameters

All experiments were executed under dry cutting environment, with no fluids applied, in order to primarily assess the effect of cutting parameters on the output variables. Cutting forces were measured using a TeLC dynamometer installed on the machine and connected to a computer via XKM2000 software. Surface roughness measurements were obtained using a Mahr Perthometer M1. The recorded cutting force and surface roughness data were transferred to an Excel spreadsheet for tabulation. In the final evaluation phase, graphs were generated in Excel to facilitate graphical analysis of the experimental results.

III. RESULTS AND DISCUSSION

A. Cutting Force

Cutting force is a critical machining parameter that directly affects machining efficiency, power consumption, and energy usage [20]. Analyzing this parameter contributes to sustainable production, as fluctuations in cutting force account for a significant portion of energy demand during machining [21]. The cutting force values obtained from the experiments are presented graphically in Figure 2. The lowest cutting force was recorded under the conditions of 0.05 mm/rev feed rate, 0.1 mm depth, and 90 m/min cutting speed, while the maximum cutting force occurred at 0.1 mm/rev feed rate, 0.2 mm depth, and 45 m/min cutting speed. Analysis of the data shows that an rise in feed for each parameter combination results in a corresponding increase in cutting forces. Higher feed rates increase the volume of material removed per unit time, which elevates power consumption and consequently increases cutting forces. Similar findings are reported in [22]. Likewise, an growth in depth also leads to greater cutting forces due to the expansion of the cutting area and greater overall material deformation resistance [23]. [24] also shows that cutting forces increase with increasing depth. The decrease in cutting speed resulted in a positive effect on cutting forces, leading to a reduction in their magnitude. This outcome can be attributed to the fact that higher cutting speeds cause elevated cutting temperatures, which in turn reduce the strength of the workpiece material [25]. However, the observed reduction values were relatively minimal compared to the effects of feed rate and depth of cut. Similar findings have also been reported in previous studies in the literature [26, 27].

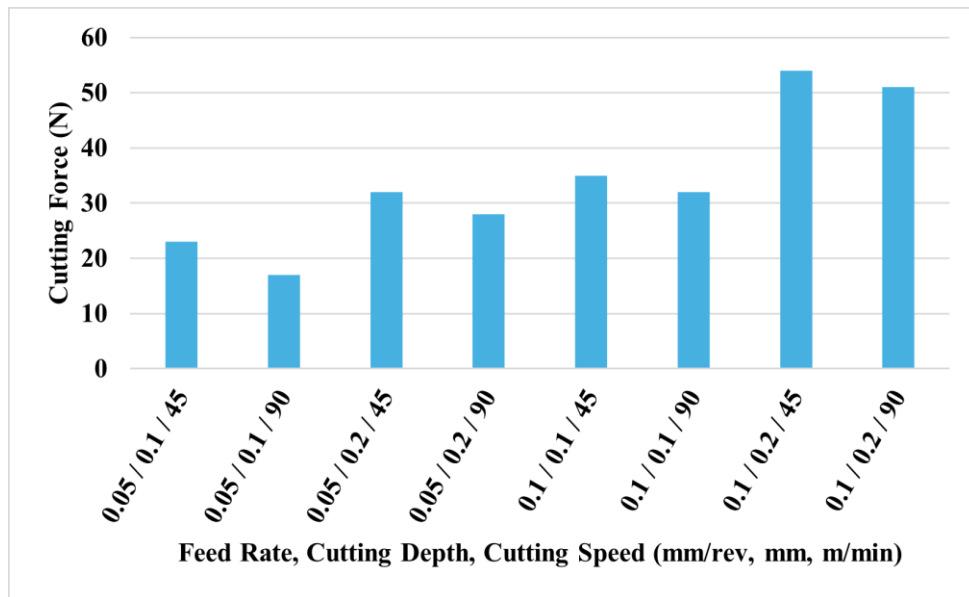


Fig. 2 Graphical representation of cutting force value

B. Surface Roughness

Surface roughness is a key indicator of product quality and is considered an essential technical requirement in most mechanical applications [28]. Moreover, it is widely used in literature as an important output parameter for evaluating material machinability. Figure 3 presents the surface roughness values achieved in this investigation. The minimum surface roughness was observed at 0.05 mm/rev feed rate, 0.1 mm depth, and 90 m/min cutting speed, whereas the maximum roughness occurred at 0.1 mm/rev feed rate, 0.2 mm depth, and 45 m/min cutting speed. Examination of the graph reveals that the increase in the feed rate parameter led to higher surface roughness values. This increase can be attributed to the fact that higher feed rates result in a greater amount of material removed per unit time [29]. This finding is consistent with the results reported in the literature [30, 31]. Similarly, the increase in cutting depth resulted in a rougher surface. This is likely due to the larger cross-section of removed material and greater contact between the cutting tool and work material, which increases tool pressure and accelerates wear, consequently raising roughness [32, 33]. Increasing cutting speed yielded improved surface quality, as higher speeds reduce cutting forces and associated vibrations, enhancing the machined surface finish [34, 35].

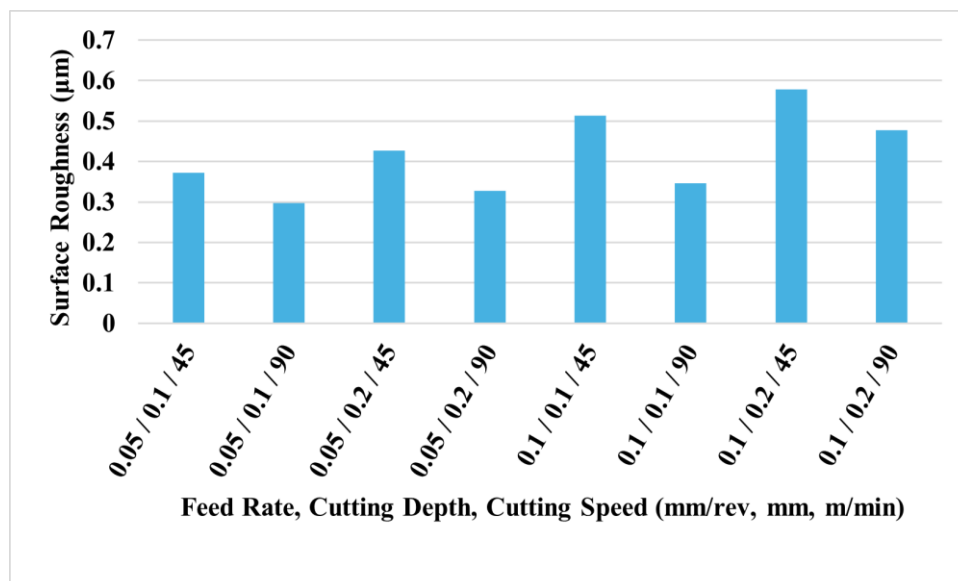


Fig. 3 Graphical representation of surface roughness values

IV. CONCLUSION

This study analyzed the impacts of varying cutting parameters on surface roughness and cutting force during the turning of M300 maraging steel on a manual lathe. The main findings can be summarized as follows:

- The optimum surface roughness was achieved at a feed of 0.1 mm/rev, a depth of 0.1 mm, and a cutting speed of 90 m/min, while the minimum cutting force was obtained at a feed of 0.05 mm/rev, a depth of 0.1 mm, and a cutting speed of 90 m/min.
- While the increase in feed rate and cutting depth led to higher cutting forces, the increase in cutting speed resulted in a slight reduction in cutting forces.
- Similar to the cutting force values, an increase in feed rate and cutting depth led to higher surface roughness values, whereas an increase in cutting speed resulted in a decrease in surface roughness.
- Future studies should address the effects of machining parameters on machinability output parameters in a more comprehensive manner compared to the existing literature, as gaining a broader perspective is expected to provide valuable insights and enhance the understanding of the machinability of M300 maraging steel.

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