The objective of this paper is to investigate the effect of cutting parameters on cutting forces during turning of CPM 10V steel with coated cutting tool. Machining of CPM 10V steel and finding a suitable tool is very challenging due to its physical and mechanical properties, especially since the machining of this material has not been extensively researched. The experiments were carried out using an Index GU -600 CNC lathe and the cutting forces were measured in process. A three-factorial three-level experimental design was used for the experiments. Statistical method analysis of variance (ANOVA) is applied to study the effects of cutting speed, feed rate, and depth of cut on cutting forces. The results of this study show that depth of cut has the most significant effect on main force and radial force, while feed rate and cutting speed have the most significant effect on feed force. The developed model can be used in the machining industry to predict and analyze cutting parameters for optimal cutting forces.

**Key words:** CPM-10V steel, powder metallurgy, cutting parameters, ANOVA.

**EFFECT OF CUTTING PARAMETERS ON CUTTING FORCES IN TURNING OF CPM 10V STEEL**

Received: 02 May 2021 / Accepted: 12 August 2021

Abstract: The objective of this paper is to investigate the effect of cutting parameters on cutting forces during turning of CPM 10V steel with coated cutting tool. Machining of CPM 10V steel and finding a suitable tool is very challenging due to its physical and mechanical properties, especially since the machining of this material has not been extensively researched. The experiments were carried out using an Index GU -600 CNC lathe and the cutting forces were measured in process. A three-factorial three-level experimental design was used for the experiments. Statistical method analysis of variance (ANOVA) is applied to study the effects of cutting speed, feed rate, and depth of cut on cutting forces. The results of this study show that depth of cut has the most significant effect on main force and radial force, while feed rate and cutting speed have the most significant effect on feed force. The developed model can be used in the machining industry to predict and analyze cutting parameters for optimal cutting forces.

**Key words:** CPM-10V steel, powder metallurgy, cutting parameters, ANOVA.

1. INTRODUCTION

In the recent past, considerable improvements have been made in turning, making it easier to machine materials that are difficult to cut and resulting in better machinability (better surface finish and lower cutting forces). The forces acting on the tool are an important aspect of machining. Knowledge of cutting forces is necessary for estimating power requirements and designing machine tool elements and fixtures that are sufficiently rigid and free from vibration. Most of the energy consumed in metal cutting is converted to heat near the cutting edge of the tool, and many of the economic and technical problems in machining are caused by this heating. Therefore, proper selection of cutting tools and process parameters to achieve high cutting performance in a turning operation is a critical task [1].

Steels with high vanadium content in the tooling industry are used, such as cutting blades, paper cutters, drilling tools, cold forming tools, etc. The main problem with this type of steel is reduced toughness, which is an undesirable consequence of increasing the vanadium content. Powder metallurgy is a technology developed to obtain a fine carbide structure, even when a high content of alloying additions is made. Soon, crucible metallurgists discovered that much higher alloy steels, especially high vanadium steels, were possible with powder metallurgy. In 1978, the "Powder Metallurgy" method was used to develop CPM 10V steel with a high vanadium content (about 10%), which has both good wear resistance and high toughness. Since then, CPM 10V has been widely used in tools that require high wear resistance and have a toughness problem [2].

Figure 2 shows the difference in the microstructure of steels produced by conventional methods and powder metallurgy. The difference in the homogeneity of the microstructure is visible.

**Fig. 1. Microstructure of CPM 10V steel and conventional steel [2]**

This paper aims to analyze the parameters of the processing mode (cutting depth, feed rate, and cutting speed) on the cutting forces (The main cutting force - \( F_c \), radial force - \( F_p \), and feed force \( F_f \)), as well as to develop a mathematical model. Minitab 17 software was used to analyze the results.

Note: The manuscript was presented at the 14. International Scientific Conference MMA held in Novi Sad, Serbia, 23.-25. September, 2021.
2. MATERIALS AND METHODS

2.1 Experimental setup

Experimental work was carried out at the Faculty of Technical Sciences, in the Laboratory for Conventional Machining.

The conditions for experimental testing are given in this chapter. Conditions apply to: The workpiece material, machine tool, cutting tool and, cutting conditions, measuring technique.

The workpiece material: Experimental tests were performed on CPM 10V steel produced by powder metallurgy. Powder metallurgy is a technology developed to obtain a fine carbide structure even when a large amount of alloying additions are used. 10V is the evolution of the earlier 4÷5% vanadium steel. Its combination of toughness, wear resistance, and cutting edge stability predestines it to replace tool steels that are prone to chipping at the tool cutting edge during cold working [3]. The chemical structure is shown in Table 1. The workpiece had a length of 80 mm (cutting length) and a diameter of 40 mm.

| Steel | C | Mn | Si  | Cr | V   | Mo | S   |
|-------|---|----|-----|----|-----|----|-----|
| 10V   | 2.45 | 0.5  | 0.9 | 5.25 | 9.75 | 1.30 | 0.07 |

Table 1. Chemical structure of CPM 10V steel [4]

Machine tool: The experimental work was carried out at the Department of Production Engineering, the Faculty of Technical Sciences in Novi Sad. The machining was conducted on a Index GU-600 CNC lathe in dry condition.

Cutting tool: A turning cutter SVLRL2525M16, with cemented carbide inserts (“SECO” type VBMT160408-M5, TP1501) with coated Ti(C,N) + Al2O3+ Cr (Used edge detection) [5]. Table 2 illustrates the geometrical characteristics of the cutting tool positioned on its tool holder.

| Geometrical Characteristics of VBMT160408-M5 insert | Value |
|---------------------------------------------------|-------|
| Clearance angle major                             | 5°    |
| Insert included angle                             | 35°   |
| Theoretical cutting edge length                   | 16.61 mm |
| Corner radius                                     | 0.80 mm |
| Insert thickness                                  | 4.76 mm |

Table 2. Geometrical specifications of VBMT160408-M5 insert [5]

Cutting conditions:

- Cutting speed \( v \),
- Feed rate \( f \),
- Depth of cut \( a \).

Table 3 is shown machining parameters and their levels based on the material of the workpiece and the recommendations of the tool manufacturer.

| Levels | Depth of cut \( a \) [mm] | Feed rate \( f \) [mm/rev] | Cutting speed \( v \) [m/min] |
|--------|---------------------------|-----------------------------|----------------------------|
| Max. +1 | 1.6                       | 0.26                        | 600                        |
| Mid. 0  | 1.13                      | 0.22                        | 424                        |
| Min. -1 | 0.8                       | 0.18                        | 300                        |

Table 3. Machining parameters and their levels

Measuring technique: For the cutting force measurements a Kistler® three-axis piezoelectric type 9257A is used (Figure 2a). The dynamometer is mounted on the machine via a specially designed holder, as shown in Figure 2b.

![Fig. 2. a) The 3-axis Kistler 9257A dynamometer, b) specially designed holder of dynamometer](image)

The piezoelectric dynamometer is connected to a charge amplifier through 3 coaxial cables shielded, grounded, and waterproof. Further on, the amplifier communicates with a PC across an A/D card, which converts the analogy signal to digital. The signal processing is performed by the LabView program. Figure 3 illustrates the layout diagram for the data processing.

![Fig. 3. Layout diagram for signal processing](image)

3. RESULTS AND DISCUSSION

In table 4 is shown the setup of experiments and results of cutting forces. All of the experiments were conducted with one insert without coolant.

| S. No. | \( a \) [mm] | \( f \) [mm/rev] | \( v \) [m/min] | \( F_v \) | \( F_p \) | \( F_f \) |
|--------|--------------|----------------|---------------|--------|--------|--------|
| 1      | 0.8          | 0.18           | 300           | 880.53 | 84.02  | 379.74 |
| 2      | 1.6          | 0.18           | 300           | 1594.42| 177.13 | 339.89 |
| 3      | 0.8          | 0.26           | 300           | 1140.57| 86.24  | 420.45 |
| 4      | 1.6          | 0.26           | 300           | 2154.48| 187.84 | 421.54 |
| 5      | 0.8          | 0.18           | 600           | 784.58 | 69.42  | 397.23 |
| 6      | 1.6          | 0.18           | 600           | 1495.42| 176.43 | 419.22 |
| 7      | 0.8          | 0.26           | 600           | 990.89 | 68.88  | 422.01 |
| 8      | 1.6          | 0.26           | 600           | 1971.29| 175.00 | 455.99 |
| 9      | 1.13         | 0.22           | 424           | 1250.11| 115.37 | 413.66 |
| 10     | 1.13         | 0.22           | 424           | 1260.04| 112.31 | 397.19 |
| 11     | 1.13         | 0.22           | 424           | 1284.36| 115.46 | 395.42 |
| 12     | 1.13         | 0.22           | 424           | 1287.87| 115.28 | 396.24 |

Table 4. The setup of experiments and results of cutting forces
3.1 Response surface regression: \( F_v \)

For regression analysis, analysis of variance (ANOVA), as well as the response surfaces commercially available statistical analysis software, was used. The analysis determined the significance of the model and the flow of the processing parameters on the cutting forces. Based on Table 4, an analysis of variance was performed. The results of the analysis are shown in Table 5.

Table 5. Response Surface Regression: \( F_v \) versus \( a, f, v \)

Based on the value of \( P \), a decision is made on the significance of the parameters. If the value of \( P < 0.05 \), the parameter is significant [6]. By reviewing Table 5, it can be concluded that all parameters are significant, except for \( a \) and \( v \).

The adequacy of the model is reflected in the value of "Lack-of-fit" the value of \( \text{Lack-of-fit} \) is 0.600, which means that the model is adequate (Equation 1).

\[
F_v = 335 - 300 \times a + 648 \times f + 0.284 \times v + 176.6 \times a^2 + 4450 \times a \times f - 2,873 \times f \times v
\]

The significance of parameters can be determined based on ANOVA analysis. Figure 4 shows the strength of the processing parameters for the force \( F_v \), where it can be seen that the largest and only influence on the force \( F_v \) has the depth of cut, followed by a feed rate, and the least important is the cutting speed.

![Main Effects Plot for \( F_v \)](image)

Fig. 4. Effect of cutting parameters on cutting force \( F_v \)

3.2 Response surface regression: \( F_p \)

In the same way, as for the force \( F_v \), an analysis of the force \( F_p \) was performed. The results of the analysis are shown in Table 6.

Table 6. Response Surface Regression: \( F_p \) versus \( a, f, v \)

The value of \( P \) for the "Lack of fit" function is 0.119, which means that the model is adequate (Equation 2). The feed rate is not significant for the penetration force \( F_p \), as well as all iterations with it \( (a \times f, \text{ and } f \times v) \).

The reduced mathematical model is shown by Equation 2.

\[
F_p = 37 + 9.7 \times a - 0.0157 \times v + 36.42 \\
\times a^2 + 0.0384 \times a \times v
\]

(2)

Figure 5 shows the strength of the processing parameters for the force \( F_p \), where it can be seen that the largest and only influence on the force \( F_p \) has the depth of cut, while the feed rate and cutting speed have almost no effect.

![Main Effects Plot for \( F_p \)](image)

Fig. 5. Effect of cutting parameters on penetration force \( F_p \)

3.3 Response surface regression: \( F_I \)

As in previous times, an analysis for the force \( F_I \) was performed. The results of the analysis are shown in Table 7.

The value of \( P \) for the "Lack of fit" function is 0.325, which means that the model is adequate (Equation 3). The depth of cut is not significant for the force \( F_I \), as well iterations \( a \times a, a \times f, \text{ and } f \times v \) in this case, a reduced mathematical model will not be used, because the value of R-sq(adj) is <90%, so the original
mathematical model was used, whose accuracy is R-sq = 96.24%.

Table 7. Response Surface Regression: \( F_f \) versus \( a, f, v \)

\[
F_f = 343.4 - 228 \cdot a + 649 \cdot f + 0.153 \cdot v + 22.5 \cdot a^2 + 414 \cdot a \cdot f + 0.1974 \cdot a \cdot v - 1.267 \cdot f \cdot v
\]

(3)

Figure 6 shows the strength of the processing parameters for the force \( F_f \), where it can be seen that the largest influence on the force \( F_f \) has the feed rate and cutting speed, while the depth of cut has no effect.

![Main Effects Plot for \( F_f \)](image)

Fig. 6. Effect of cutting parameters on cutting force \( F_f \)

4. CONCLUSION

Based on the theoretical and experimental studies carried out and the analyzes performed, the following conclusions can be drawn:

- Collecting data on forces in the cutting zone is a complicated process and depends on a variety of factors as well as on the accuracy of the measurement and acquisition system. A properly tuned measurement and acquisition system is a prerequisite for a good experiment.
- Design of experiments and analysis of variance contributes greatly to accurately represent the adequacy and significance of models and parameters, thus facilitating the work of researchers.
- The machinability of CPM 10V tool steel in terms of cutting forces is better with increasing cutting speed (as cutting speed values increase, forces decrease).
- The major influence on the main cutting force is the depth of cut followed by feed rate and the least important is cutting speed.
- Radial cutting force: depth of cut has the greatest influence, while feed rate and cutting speed have no influence.
- Feed rate and cutting speed have a similar influence on feed force while the depth of cut has no influence.

Continuing research in the field of machining CPM 10V tool steel with carbide inserts can go in the direction of expanding the factors influencing the cutting forces in turning. Optimization of the process is also the way to be followed in further research.

5. REFERENCES

[1] Vaxevanidis, N.M., Kechagias, J.D., Fountas, N., Manolakos D.E.: Influence of cutting parameters on the machinability of AISI D6 tool steel in turning, Chapter 9 in: J.P. Davim (ed.) Machining: Operations, technology and management, Nova Publishers, USA, 2013.
[2] Haswell, T.W., Kasak, A.L: Powder metallurgy steel article with high vanadium-carbide content, Crucible Inc., Pittsburgh, Pa, 1978.
[3] Haswell, W. T., Kasak, A: Powder-Metallurgy steel article with high vanadium-carbide content, US Patent US4249945A, 1981.
[4] Larrin, T.: CPM 10V Steel – History, properties, and how to heat treat, Knife engineering, Pittsburgh, Pa, 2020.
[5] “Secotools.com”
https://www.secotools.com/article/p_02959792.
[6] Montgomery, C.D.: Design and analysis of experiments, Library of congress, Hoboken NJ, 2017.

ACKNOWLEDGEMENT

This paper has been supported by the Ministry of Education, Science and Technological Development through the project no. 451-03-68/2020-14/200156: “Innovative scientific and artistic research from the FTS (activity) domain”.

Authors: M.Sc. Anđelko Aleksić, Full Prof. Milenko Sekulić, Full Prof. Marin Gostimirović, Assist. Prof. Dragan Rodić, Assoc. Prof. Borislav Savković, Full Prof. Aco Antić, University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485-23-24, Fax: +381 21 454-495.
E-mail: andjelkoar94@uns.ac.rs; milenkos@uns.ac.rs; maring@uns.ac.rs; rodicdr@uns.ac.rs; savkovic@uns.ac.rs; antica@uns.ac.rs;