

Araştırma Makalesi / Research Article

The Effects of Coating Materials on Machinability Characteristics of AA7075-T6 Alloys under Different Turning Conditions

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ABSTRACT: Machining is essentially a process of creating and breaking chips, during which it is desired to clean the surface of the workpiece and create a new surface to obtain a smoother and mechanically long-lasting structure. Machining involves many processes; each specialized for a specific purpose. One of the most important machining processes is turning. Turning is performed using a variety of machine tools with different machining parameters, cutting tools, and fixtures. This paper focuses on the machinability study of AA7075-T6 alloy considering the factors such as cutting speed, feed rate and coating materials on the cutting tool. The response parameters evaluated in this study is the cutting forces, cutting temperatures, energy consumption. According to the findings, feed rate, cutting speed and coating materials were found as the dominant parameters on cutting forces, energy consumption and cutting temperatures respectively. This situation is seen in the ANOVA tables that feed is the most effective parameter for cutting force with 33.05%, coating is the most effective parameter for temperature with 3.45% and cutting speed is the most effective parameter for energy consumption with 45.54%. The frame developed for this paper aims to contribute to the current literature by comparing modern coating materials considering popular and valid machinability indicators.

Keywords: AA7075-T6 alloys, Coating material, Cutting forces, Cutting temperatures

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1. INTRODUCTION

The manufacturing sector encompasses many different fields, each working in harmony within and among them. Chief among these are technologies such as machining, casting, welding, plastic forming, and sheet metal working. Each of these areas requires expertise in its own right, as well as a blend of experience-based practical knowledge and theoretical knowledge. Furthermore, when considering the manufacturing of a product, it's not customary to use only one of the options mentioned above. Shaping a metal generally requires more than one manufacturing process. For example, casting is a manufacturing process in which a product is first poured into molds as molten metal, which is then shaped by the mold. Generally, the part's dimensions are obtained in rough form. The dimensions of a machine element or part must be achieved within a certain level of precision, which is called tolerance. Each measurement must have its own tolerance value, which is a symbol of the aforementioned precision. Therefore, when a part is produced to rough dimensions, it is not yet within these precision limits, and additional processes must be utilized to achieve this. This is precisely where finishing processes, led by machining, come into play. The aim here is to ensure that the final shape is given to the parts produced in sizes much larger than their actual dimensions (Hamid et al., 2025; Korkmaz and Gupta, 2023; Kul and Yamaner; Kuntoğlu et al., 2020).

Chip formation is the fundamental purpose of machining. In processes such as cutting a material to a diameter smaller than a specified size or shortening a cylindrical material, excess material is removed by removing material from the surface. During this process, very high temperatures and pressures occur in the deformation zones between the cutting tool and the workpiece. Therefore, the heat generated during this process is distributed between the cutting tool, the workpiece, and the chip. During this distribution, the goal is to transfer as much heat as possible to the chip to achieve optimal machining results. This is precisely what is achieved through the geometry and chip-breaking surfaces created on cutting tools. The primary goal of cutting geometry is to minimize chip contact with the tool and to remove it from the environment as quickly as possible before it becomes entangled in the workpiece (Demirpolat, 2024; Kaya et al., 2025; Korkmaz et al., 2023; Kuntoğlu et al., 2025; Makhesana et al., 2022; Yamaner and Kul, 2025). Figure 1 shows some machinability criteria including the ones within this paper.

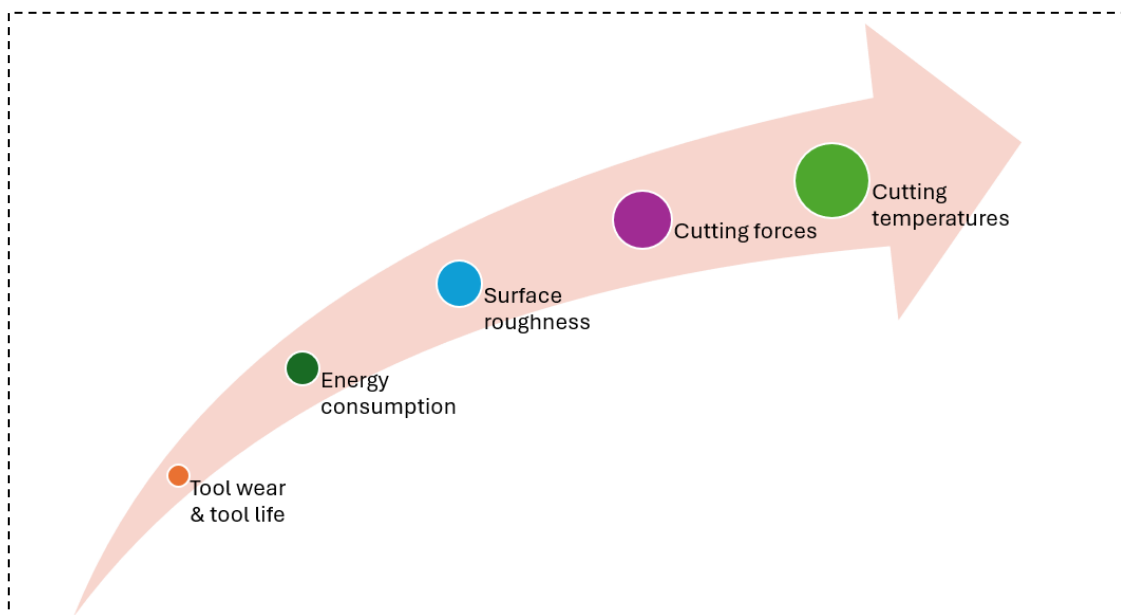


Figure 1. Some of the machinability characteristics

One of the prominent machinability criteria is the cutting temperatures as they serve an indicator of the stable machining with reduced risks such as excessive tool wear. The easiest way to avoid high temperatures is to inject lubricants and coolants into the environment (Binali et al., 2025; Coşkun et al., 2021; Demir et al., 2018; Kumar et al., 2019). Therefore, the dry cutting process used in the past was highly susceptible to both tool stages and surface deterioration. On the other hand, cutting fluids, such as boron oil, improve surface quality and extend tool life to a certain extent. Another technology developed in recent years is minimum quantity lubrication. This technology involves spraying oil into the cutting environment at a certain pressure. This allows the finely divided oil droplets to easily penetrate the cutting tool and workpiece contact areas. Furthermore, the greatest advantage of this method is the use of significantly less oil compared to traditional lubrication. This also presents a sustainable and economical solution. A review of some of the literature reveals a study conducted by Çakır et al. Using the MQL method, the effects of four different cutting speeds, cutting fluid flow rates, and two different feed rates on surface finish during the turning of two different aluminum alloys, AA7075 and AA2024, were investigated. The study concluded that increasing feed and cutting speed negatively impacted surface finish, while increasing flow rates improved it (Çakır et al., 2016). Another study by Binali and Kuntoğlu investigated the optimization and investigation of cutting forces in the turning of GGG50 cast iron. The results showed that feed rate had the strongest effect on cutting forces, and the most effective cutting parameters were determined as 0.16 mm depth of cut, 0.2 mm/rev feed, and 80 m/min cutting speed (Binali and Kuntoğlu, 2023). A study by Gupta and colleagues analyzed the cutting properties of PVD-coated turning tools. The test involved turning C45 steel using TiN, AlCrN, and TiAlN-coated solid tools. Cutting forces were measured, while cutting speed and feed rate were varied throughout the test. The TiAlN coating proved to be the most effective coating in terms of tool life due to its hardness and self-lubricating properties, virtually preventing the workpiece material from adhering to the tool surface, thus increasing tool life (Gupta et al., 2018). Another study comparing the properties of CVD- and PVD-coated carbide tools is a study presented by Ginting, which examined the productivity of hard turning AISI 4340 using multilayer CVD and single-layer PVD coatings (TiCN). Productivity was characterized by material removal rate and material removal volume (Ginting et al., 2018). As can be seen in the literature, parameters such as tool coating, machining environment, and material diversity have been used in machinability tests of various materials.

This study handles the machinability study of AA7075-T6 alloy under different cutting conditions and coating materials such as TiC and TiNi. Responses are energy consumption, cutting temperatures and cutting forces which measured by several sensors adapted to machine tool. This paper includes the insights of the clues about treated alloys under different cutting/cutter conditions which will lighten the industrial needs and academic perspectives.

2. MATERIALS AND METHODS

2.1 Work Material, Cutting Tools and Machine Tool

AA7075 is a high-strength aluminum alloy widely used in the aerospace, automotive and defense sectors due to its outstanding mechanical properties such as high strength-to-weight ratio, good corrosion resistance and high fatigue resistance. In this study, cutting tools coded CCMT-09T308-304 was selected for the experiments. As said before, two certain coating materials namely TiC and TiNi were used to make a comparison about the cutting performances. A new cutting tool was used in each experiment to obtain more accurate data and eliminate wear-related problems. The lathe was

adjusted and aligned before the experiments. It was also serviced and made suitable for the experiments.

2.2 Experiments and Sensors

The experiments were conducted at a constant depth of cut (0.4 mm) using three different feed rates (0.1 mm/rev, 0.2 mm/rev, and 0.3 mm/rev) and three different cutting speeds (120 m/min, 180 m/min, and 240 m/min) while varying the basic turning parameters. To avoid any problems during the experiments, preliminary experiments were conducted to remove residual slag. Furthermore, preliminary experiments were conducted to determine the range of cutting parameters. The primary objective here was to prevent uncontrolled chip formation or excessive vibration. Force, temperature and power consumption sensors were used in the experiments. Experimental setup as shown in the figure 2 below. One of these sensors is a dynamometer (TeLC DKM 2000-Germany) and also serves as a tool holder for the cutting tool. This way, the cutting tool moves with the carriage, both performing the cutting action and measuring the force values. Another sensor, a temperature sensor (TeLC-Germany), views the cutting environment from above and uses radiation to measure the cutting environment. Both sensors provide real-time measurements and transmit data to a computer via a cable. The sensor used for energy consumption is a KAELE Multiser 02 PC TFT Network Analyzer (Istanbul, Turkey). The transmitted data was analyzed and graphed using Excel software.



Figure 2. Experimental setup

2.3 Data Evaluation

The data collected from the experiments will be evaluated by graphical demonstrations and variance analysis. The variance analysis will provide influential parameter and contribution ratios for each parameter according to the responses such as cutting temperature, energy consume and cutting forces. Variance analysis was chosen because it is reported in the literature to ensure consistency between parameters and reduce the number of experiments (Asiltürk and Neşeli, 2012; Korkmaz and Günay, 2018; Kuntoğlu and Aslan, 2021; Turan et al., 2025).

3. RESULTS AND DISCUSSION

3.1 Cutting Forces

The change in cutting forces can be considered a direct indicator of tool-material interaction during metal removal (Kuntoğlu et al., 2021; Sahoo et al., 2020). The results show that the coating type has a decisive effect on the forces. The fact that the TiC coating produced lower forces in all cases suggests that the coating offers more tribologically suitable surface properties. This provides a significant advantage in terms of tool life and energy efficiency, especially in industrial applications requiring high metal removal rates. Furthermore, the increase in cutting forces with increasing feed rate indicates that the tool encounters greater cutting resistance. Conversely, increasing cutting speed reduces forces up to a certain point, after which it tends to increase again. This curve highlights the importance of maintaining a balance between speed and feed parameters. The fact that the effect of coating type becomes particularly pronounced at higher feed rates suggests that the coating type can be a strategic criterion in tool selection. Therefore, the findings provide critical insights that affect not only coating performance but also production economics.

The change in cutting force in Figure 3 is noticeable depending on the type of tool coating, with TiC-coated tools generating less force than TiNi-coated tools under all conditions without exception. This suggests that TiC coatings are more suitable for use at higher cutting speeds and feed rates, i.e., when metal removal rates are high. Additionally, increases in cutting speed are initially positive at 120-180 m/min, but end negatively at 180-240 m/min. This suggests that 180 m/min is the ideal cutting speed. Conversely, increases in feed rate increase cutting forces under almost all conditions. Therefore, when common intersection settings are evaluated, it is clear that 180 m/min cutting speed and 0.1 mm/rev feed parameters are optimal. The ideal turning conditions for 7075 aluminum alloy are 180 m/min cutting speed, 0.1 mm/rev feed, and a TiC-coated tool. It has also been reported in the literature that different coating types have an effect on machining performance (Gupta et al., 2018).

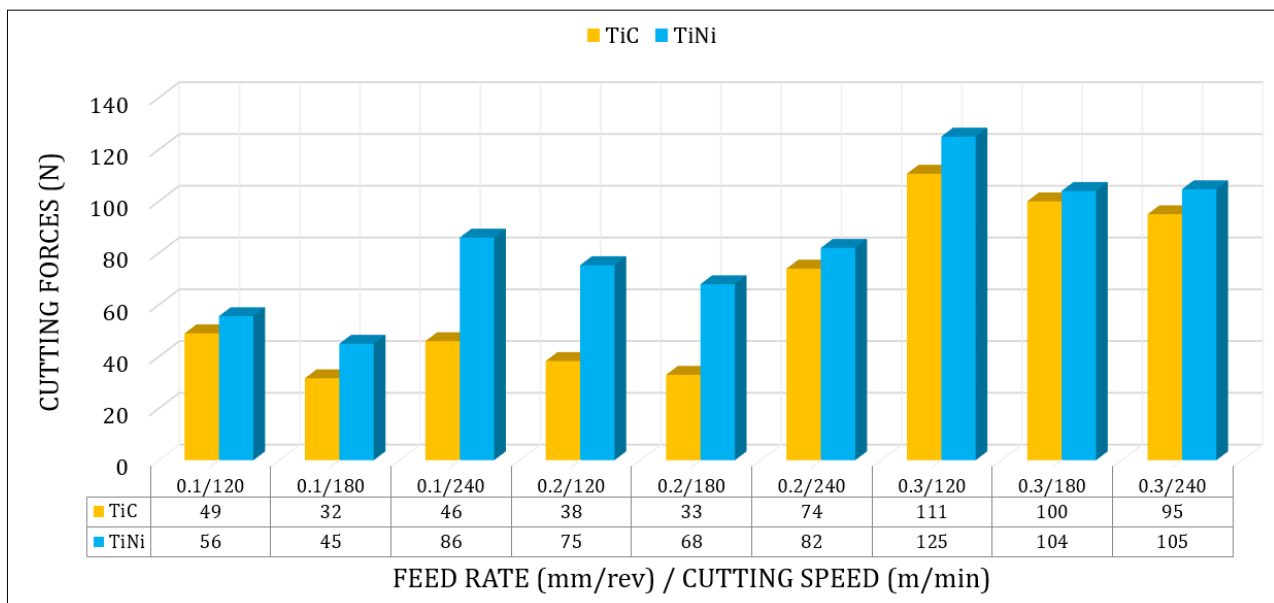


Figure 3. Cutting force change with feed, cutting speed and coatings

Table 2 demonstrates analysis of variance for means for the cutting forces results. Accordingly, feed rate is the most effective parameter on cutting forces which is followed by coating material and cutting speed lastly. Secondly, Figure 4 shows the ideal levels of the each parameter respectively to

achieve the most desired cutting force numbers. The trend upwards sign that higher cutting forces are obtained which makes the other side optimal. Therefore the optimum parameter combinations from turning experiments are 180 m/min cutting speed, 0.1 mm/rev feed, and a TiC-coated tool which are identical with the graphical results. When the ANOVA results are examined at statistical significance levels, the dominant effect of feed rate on cutting force is clearly evident, with a p value of <0.001. This supports the direct relationship between the cutting volume and the force increase during chip formation. The coating material also showed a significant effect at $p < 0.01$, highlighting the contribution of surface properties to cutting resistance. In contrast, the p-value for cutting speed remained above 0.05 and exhibited a lower statistical significance level. This result suggests that while speed affects force within certain ranges, it is not as critical as feed rate. The trends in the main effects plot reveal that forces increase sharply as feed rate increases, reaching a maximum, particularly at 0.3 mm/rev. The decrease in forces at cutting speeds around 180 m/min indicates more stable metal removal conditions. In the coating comparison, the low-force generation advantage of TiC stands out in terms of its potential to increase tool life and energy efficiency (Çiftçi, 2005; Özlü et al., 2025). These findings contribute not only to the clarification of optimal parameter combinations but also to the factors that should be prioritized during production. Furthermore, a more detailed examination of feed and coating interactions may enable the development of strategies to reduce tool wear, particularly at high feed rates.

Table 2. Analysis of variance results of cutting forces

Source	DF	SS	MS	F	p	PCR%
Feed Rate	2	10096.9	5048.5	33.05	0.000	69.75
Cutting Speed	2	977.9	488.9	3.20	0.077	6.75
Coating Material	1	1568.0	1568.0	10.27	0.008	10.83
Residual Error	12	1833.0	152.8			
Total	17	14475.8				

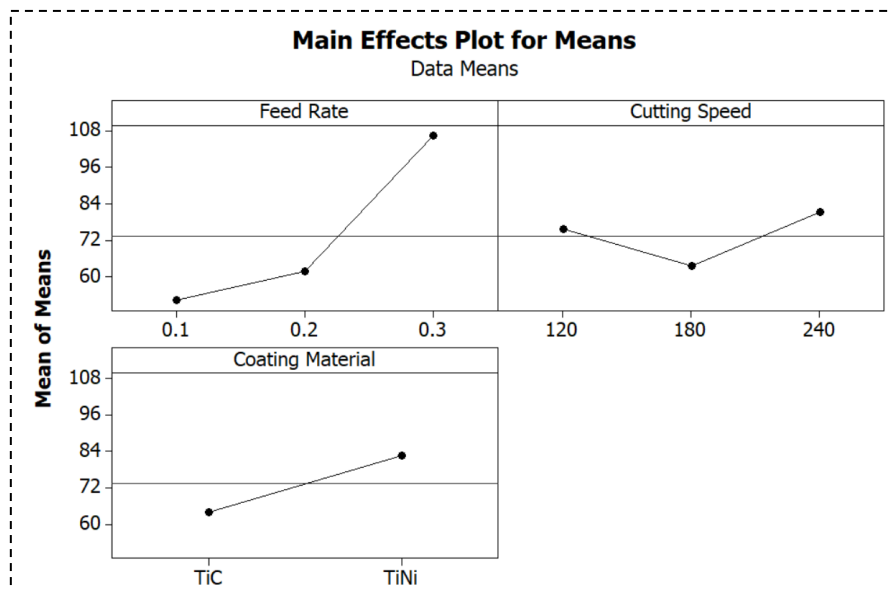


Figure 4. Main effects plot for means for the cutting forces

3.2 Cutting Temperatures

The temperature generated during cutting has a direct impact on tool life, surface finish, and energy efficiency (Binali, 2023; Kuntoğlu et al., 2025; Makhesana et al., 2023; Özdemir et al., 2024).

Experimental results revealed that TiC coatings generally produce lower temperatures compared to TiNi. This can be explained by TiC's better thermal conductivity and friction-reducing effect. Controlling temperature, particularly under high speed and feed conditions, ensures consistent material removal performance. The fact that temperature values behave differently than expected for some parameter combinations is a reflection of the complex thermal-mechanical interactions that occur during cutting (Hao et al., 2019; Karagöz et al., 2025; Zhang et al., 2022). For example, when the feed rate increases significantly, the temperature does not always increase linearly, suggesting that the material deformation and chip formation mechanisms differ. It is also noteworthy that the effect of the speed parameter is more limited compared to the feed rate. This confirms that coating selection is the key variable in temperature control. Generally, lower temperature levels reduce tool wear, increase machining efficiency, and provide a more stable metal removal process.

The graph below shows the temperature variation under different cutting conditions. As can be seen, the TiC coating produces lower cutting temperatures than the TiNi coating. Overall, with only one exception (0.1 mm/rev and 180 m/min), the TiC coating produced lower temperatures. It's worth noting that the results are very similar under this condition. The lowest cutting temperature occurs at the feed and cutting speed parameters of 0.2 mm/rev and 240 m/min. This parameter combination is an interesting result in this graph, where the cutting temperature normally increases with increasing cutting speed. It's also noteworthy that the feed rate increase has a different effect than the other variables.

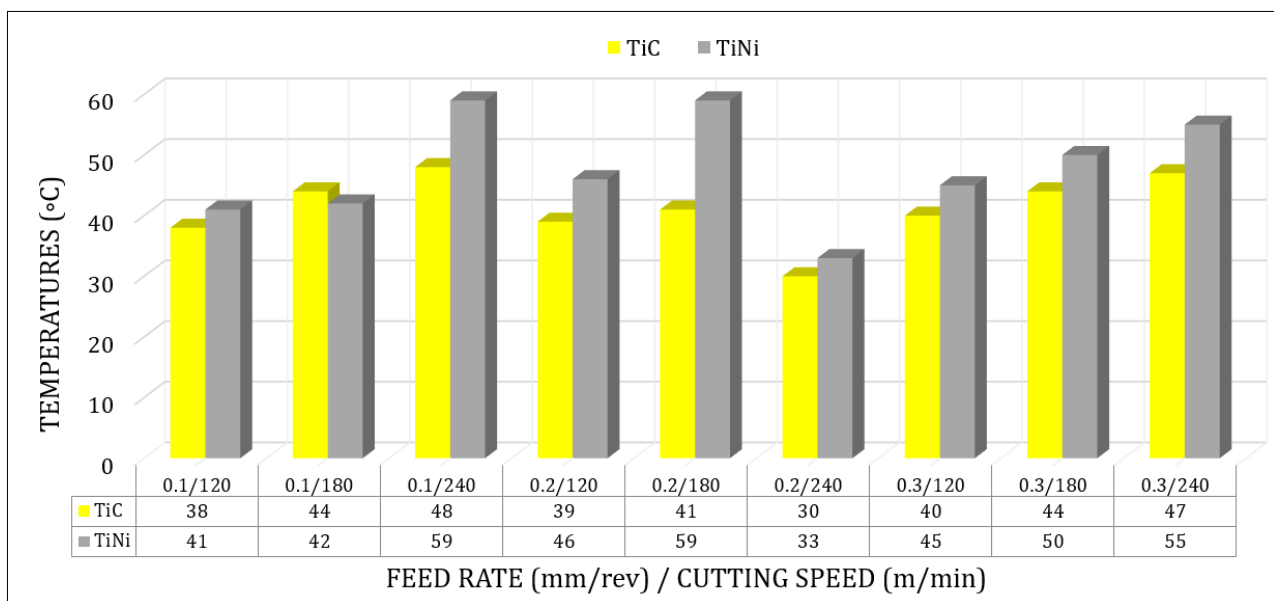
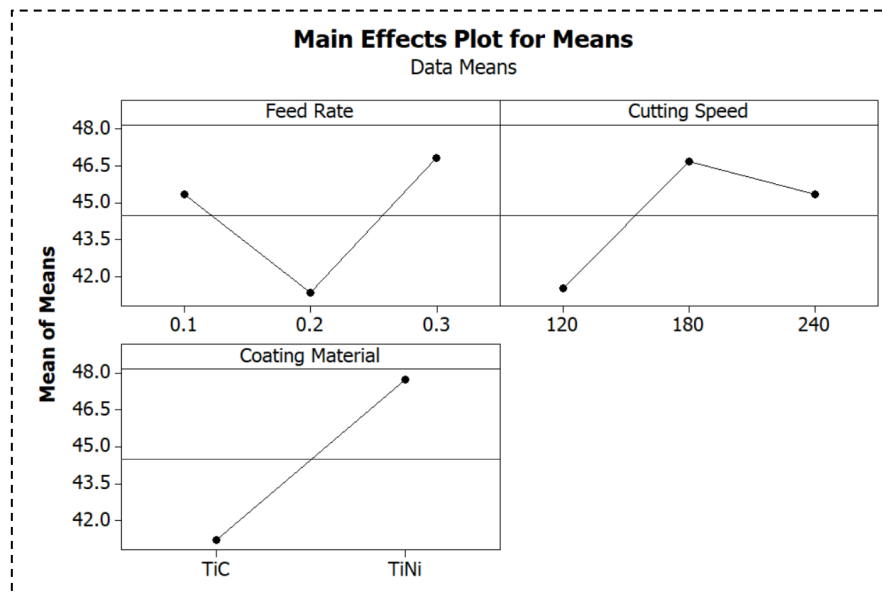


Figure 5. Cutting temperature change with feed, cutting speed and coatings

Table 3 indicates variance analysis with means for the cutting temperatures. Accordingly, coating material is the most effective parameter on cutting temperatures which is followed by feed rate and cutting speed. It's important to say that feed rate and cutting speed are close each other and ineffective, can be neglected. Figure 6 indicates the desired levels of the each parameter respectively to achieve the best cutting temperatures. The trend upwards sign that higher cutting temperatures are achieved which makes the other side optimal. Therefore the optimum parameter combinations from turning experiments are 120 m/min cutting speed, 0.2 mm/rev feed, and a TiC-coated tool.

Table 3. Analysis of variance results of cutting temperature

Source	DF	SS	MS	F	p	PCR%
Feed Rate	2	97.00	48.50	0.87	0.445	9.25
Cutting Speed	2	86.33	43.17	0.77	0.484	8.23
Coating Material	1	193.39	193.39	3.45	0.088	18.44
Residual Error	12	671.78	55.98			
Total	17	1048.50				

**Figure 6.** Main effects plot for means for the cutting temperature

3.3 Energy Consumption

Energy consumption is a critical indicator for both cost and sustainability in manufacturing processes (Binali et al., 2022; Binali et al., 2024; Gupta et al., 2024; Pehlivan, 2022; Sarıkaya et al., 2022; Uğur et al., 2022). The findings indicate that the coating type has a limited effect on energy consumption, while speed and feed parameters play a decisive role. The increase in energy consumption, particularly at higher feed and speed values, is directly related to the increased mechanical work involved in machining. However, the fact that TiC coatings consistently lead to lower energy consumption suggests that the coating creates less friction during cutting. The rapid increase in energy consumption with feed demonstrates that the feed parameter is a critical element in production planning. Furthermore, the minimal consumption observed at low speeds and medium feed values suggests that process parameters can be more efficient in certain combinations for energy optimization. This result reduces manufacturing costs and contributes to a reduced carbon footprint. It should be noted that even small differences can translate into large-scale energy savings, especially under mass production conditions. Therefore, when appropriate coating selection and parameter optimization are considered together, a sustainable machining process can be achieved from both an environmental and economic perspective.

The lowest energy consumption is observed for TiC at feed and cutting speed parameters of 0.2 mm/rev and 120 m/min. The highest energy consumption is observed for TiNi at feed and cutting speed parameters of 0.3 mm/rev and 240 m/min. It is noticeable that increases in cutting speed and feed gradually increase energy consumption. This is clearly evident as we move to the right of the graph. The TiC coating consumes less energy than the TiNi tool under all conditions, without exception.

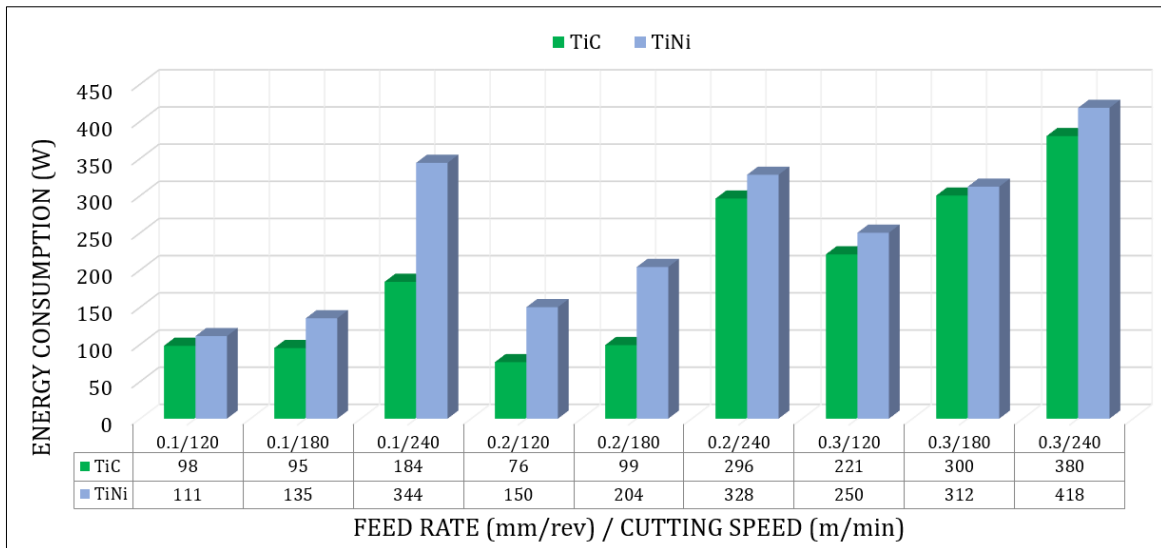


Figure 7. Energy consumption change with feed, cutting speed and coatings

Table 4 demonstrates ANOVA for means for the energy consumption. Accordingly, cutting speed is the most influential contributor on energy consumption which is followed by feed rate and cutting speed lastly. Coating material is highly ineffective which can be eliminated. Figure 8 shows the ideal levels of the each parameter to reach the most desired energy consumption values. The trend upwards sign that higher energy consumption are obtained which makes the other side optimal. Therefore the optimum parameter combinations from turning experiments are 120 m/min cutting speed, 0.1 mm/rev feed, and a TiC-coated tool.

Table 4. Analysis of variance results of energy consumption

Source	DF	SS	MS	F	p	PCR%
Feed Rate	2	77838	38919	35.59	0.000	38.03
Cutting Speed	2	99579	49789	45.54	0.000	48.66
Coating Material	1	14093	14093	12.89	0.004	6.88
Residual Error	12	13121	1093			
Total	17	204631				

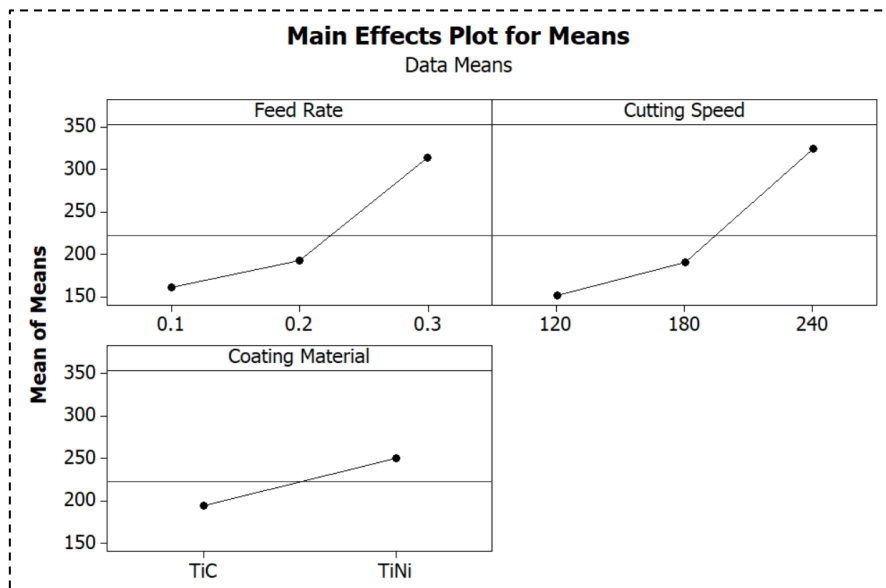


Figure 8. Main effects plot for means for the energy consumption

4. CONCLUSIONS

In this study, the machinability of the AA7075 alloy by turning was investigated. The effects of cutting tools with different coatings on cutting force, temperature, and energy consumption were investigated. The results obtained from the thesis are as follows:

- The change in cutting force is noticeable depending on the type of tool coating, with TiC-coated tools producing less force than TiNi-coated tools under all conditions without exception. This demonstrates that TiC coatings are more suitable for use at higher cutting speeds and feed rates, i.e., when metal removal rates are high.
- The ideal turning conditions for 7075 aluminum alloy are 80 m/min cutting speed and 0.1 mm/rev feed, and a TiC-coated tool.
- TiC coatings produce lower cutting temperatures than TiNi coatings.
- The lowest cutting temperature occurs at feed and cutting speed parameters of 0.2 mm/rev and 240 m/min.
- The lowest energy consumption occurs at feed and cutting speed parameters of 0.2 mm/rev and 120 m/min. When we look at the highest energy consumption, it is seen that TiNi occurs at the feed and cutting speed parameters of 0.3 mm/rev and 240 m/min.
- The study can be analyzed more comprehensively using different approaches (machine learning, artificial neural networks). Furthermore, increasing the working environment could yield more comprehensive results. Future studies could consider such approaches.

5. CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

6. AUTHOR CONTRIBUTION

Uğur FİDAN contributed to the management of the concept and/or design process of the research, data collection, data analysis and interpretation of the results, preparation of the manuscript, final approval and full responsibility. Tayfun ÇETİN contributed to the determination and management of the concept and/or design process of the research, data analysis and interpretation of the results, preparation of the manuscript, critical analysis of the intellectual content, final approval and full responsibility. Hakan GÜNDOĞMUŞ contributed to the management of the concept and/or design process of the research, data analysis and interpretation of the results, preparation of the manuscript, final approval and full responsibility.

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