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*Research Article*

# Tool Wear in GGG50 Cast Iron Milling Environments

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## ABSTRACT

In the present study, the impression of manufacturing parameters on cutting tool tip wear in the milling operation of GGG50 cast iron material with carbide coated cutting tool inserts was investigated. Taguchi orthogonal L18 experimental sequence was applied as the experimental design. As processing parameters; cutting speed, coolant and feed rate were chosen. In the test results, the amount of wear on the cutting tool tips was examined. Optimum processing multiparameters were determined by the Taguchi. Analysis of variance (ANOVA) was used to analyses the effect of input parameters on the cutting tool tip. Consequently, it has been determined that the wear is high in the working environment where the coolant is open and the cutting speed is high. In order to keep the cutting tool tip wear at a minimum level, the most suitable machining parameters are; coolant = closed, cutting speed = 160 mm/min, feed rate = 0.3 mm/rev. It was determined that the tip feed rate had little impression on tool wear.

***Keywords:*** *Milling, cast iron, tool wear, optimization, Taguchi, ANOVA*

# GGG50 Dökme Demir Frezeleme Ortamlarında Takım Aşınması

## Öz

Bu çalışmada GGG50 dökme demir malzemesinin karbür kaplanmış kesici takım uçlarla frezeleme işlemindeki imalat parametrelerinin takım aşınması üzerine etkisi incelenmiştir. Deney tasarımı olarak Taguchi ortogonal L18 deney dizisi uygulanmıştır. İşleme parametreleri olarak; soğutma sıvısı, kesme hızı ve ağız başı ilerleme seçilmiştir. Yapılan deney sonuçlarında kesici takım uçlarındaki aşınma miktarları incelenmiştir. Optimum işleme parametrelerinin belirlenmesi için Taguchi yöntemi kullanılmıştır. Giriş parametrelerinin kesici takım ucuna olan etkisini incelemek için varyans analizi (ANOVA) yapılmıştır. Sonuç olarak soğutma sıvısının açık ve kesme hızının yüksek olduğu çalışma ortamında kesici takım ucu aşınmasının yüksek olduğu belirlenmiştir. Kesici takım ucu aşınmasını en az seviyede tutmak için en uygun işleme parametrelerin; soğutma sıvısı = kapalı, kesme hızı = 160 mm/min, ağız başı ilerleme = 0.3 mm/rev olduğu saptanmıştır. Ağız başı ilerlemenin takım aşınmasına etkisinin çok az olduğu belirlenmiştir.

***Anahtar Kelimeler:*** *Frezeleme, dökme demir, takım aşınması, optimizasyon, Taguchi, ANOVA*

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# I. INTRODUCTION

Cast iron; It is the type of material that has the highest production percentage among the materials produced in the casting industry. These types of materials are used quite frequently in the machinery and automotive industry. The most preferred cast irons are; austempered ductile cast iron, cast iron with spheroidal graphite, cast iron with spheroidal graphite [1]. In addition to the difficult cutting process of cast iron, the chemical composition and the amount of alloy also affect the machinability feature. [2]. Cast iron materials have mechanical properties that provide advantages such as high resistance to abrasion and deformation, easy machinability and low melting point [3].

Machining is a preferred manufacturing method for preparing machine parts for final use in the industrial field. Materials produced by production methods such as casting, rolling or pressing are processed by machining and turned into end-use [4]. In the machining process; The workpiece is shaped by removing chips by methods such as turning, milling and drilling. Milling is a shaping method that involves removing chips from the workpiece by rotating the cutting tool tip and moving the workpiece in the X, Y, and Z axes while held in a vise. [5]. Obtaining the parameters affecting the process in the machining method and then performing the optimization process with these parameters greatly increases the efficiency of the manufacturing process. Parameters as per shear velocity, feed rate, cutting angle and coolant are the main factors affecting cutting tool tip wear. During the processing of the material, high temperatures due to friction occur and this can cause deformations in both the material and the cutting tool tip [6]. The machinability of cast iron materials may also depend on their internal structure properties. Among the graphite cast iron types, the properties of the material such as the hardness and the matrix type of its internal structure are indicative of the machinability of that material. In terms of machinability of graphite cast irons; The shape of the graphite in the material is seen as the most important factor among all the machinability parameters [7].

There is a sectoral pressure to reduce costs and save energy in the machining method. New studies are constantly being carried out to enhance the cutting tool life used and to ensure the high productivity of the workpiece. Optimization of cutting parameters, coating processes on cutting tools and heat treatments are examples of these studies [8]. The life and reliability of the tools used in the machining method is one of the issues to be considered in terms of the manufacturing method. Tool life and reliability depend on the resistance to abrasion of the cutting tool, its toughness level and mechanical properties such as adhesion resistance [9]. Cutting tools; Even though it covers 4% of the production cost, it constitutes 10-40% of the downtime of the machine tool due to the malfunctions that occur. In this context, the cost of cutting tools affects the manufacturing cost up to 30%. For this reason, the life and reliability of cutting tools can directly affect the cost of the manufacturing method [10].

Kıvak [11] studied the optimization of the surface finish and abrasion of cutting tool tips used in milling by using the Taguchi method. He used ANOVA to reveal the impression of processing parameters on the results. As cutting tool parameters; cutting speed parameter was determined as 90-120-150 m/min and feed parameter was determined as 0.09-0.12-0.15 mm/rev. As a result of the experiments, While the feed rate affected the surface roughness the most, the shear velocity also affected the flank wear. The values estimated as a result of the regression analysis and the experimental results are very similar to each other. George et al. [12] studied the optimization of the cutting parameters of cutting tools in the milling operation of AISI 410 and 420 stainless steel materials. In the study, they designed the L9 orthogonal array experimental system. The results were revealed by using the ANOVA method. They preferred the spindle speed parameter as 500-1500-2500 rpm and the cutting speed parameter as 30-60-90 m/min. As per the experimental results, it was determined that the most contributing parameter to the surface finish was the spindle speed. As per the analyzes made, it was revealed that the predicted test results and the test results obtained from the experiments were compatible with a low margin of error. Lakshmi et al. [13,14] studied the optimization of the parameters determined for end milling of hardened steel material. They used the ANOVA method to show the accuracy of the determined experimental model. In the experiment, they determined the cutting speed parameter as 100-150-200 m/min, the feed rate parameter as 0.20-0.25-0.30 mm/rev and the cutting depth parameter as 0.2-0.3-0.4 mm. The feed rate had the most impression on the chip removal rate. As the feed rate decreased, the chip removal rate decreased. Singh et al. [15] studied the optimization of the parameters used in the milling process of Incoloy 800 material with a cutting carbide tool. Surface roughness and tool wear were also determined as output parameters. In this study, they preferred cutting speed parameters as 2000-2250-2500 rpm, feed speed parameters as 350-425-500 mm/rev and cutting depth parameters as 0.2-0.4-0.6 mm. In conclusion, they showed that the depth of cut parameter had the greatest effect on tool wear. In addition, they stated that the effect of the progress parameter was quite low.

In the present study, the impact of manufacturing parameters on cutting tool tip wear in the milling operation of GGG50 cast iron material with carbide coated cutting tool inserts was investigated. In the experiments, it was aimed to reduce the abrasion on the cutting tool tips used in the machining process of GGG50 cast iron material. Taguchi orthogonal L18 experimental sequence was applied as the experimental design. The signal-to-noise (S/N) ratio over Taguchi was used to determine the machining parameters (coolant, cutting speed and feed rate) to achieve minimal tool wear. ANOVA was applied to specify the impact of input parameters on the cutting tool tip. Since the rough milling method was applied the surface finish values were not measured.

# II. MATERIALS AND METHODS

## A. MACHİNİNG EXPERIMENTS

Experiments were conducted on a three-axis Mazak HCN 8800 horizontal machining machine. GGG50 cast iron material was used as the workpiece. The chemical properties of the experimental material used in the experiments are given in Table 1. The input parameters determined in this study were chosen in line with literature research and cutting tool tip catalog information [16-17]. Cutting speed and feed rate were determined as test parameters in the experimental system, based on the data taken from the catalog information of the cutting tool used for the milling process. In addition, two different working environments were preferred due to the material having different production processes. Experiments were conducted at three different shear velocities (160-220-280 m/min), feed rate (0.2-0.25-0.3 mm/rev) and two different environments (coolant on and coolant off). The workpiece, cutting tools, tool holder and spindle used in this study are shown in Figure 1.

***Table 1.*** *Chemical components of experimental material.*

| Elements | Fe (%) | C (%) | Si (%) | Mn (%) | P (%) | S (%) | Mg (%) |
|---|---|---|---|---|---|---|---|
| % wt. | 93.4 | 3.71 | 2.44 | 0.18 | 0.034 | 0.001 | 0.037 |

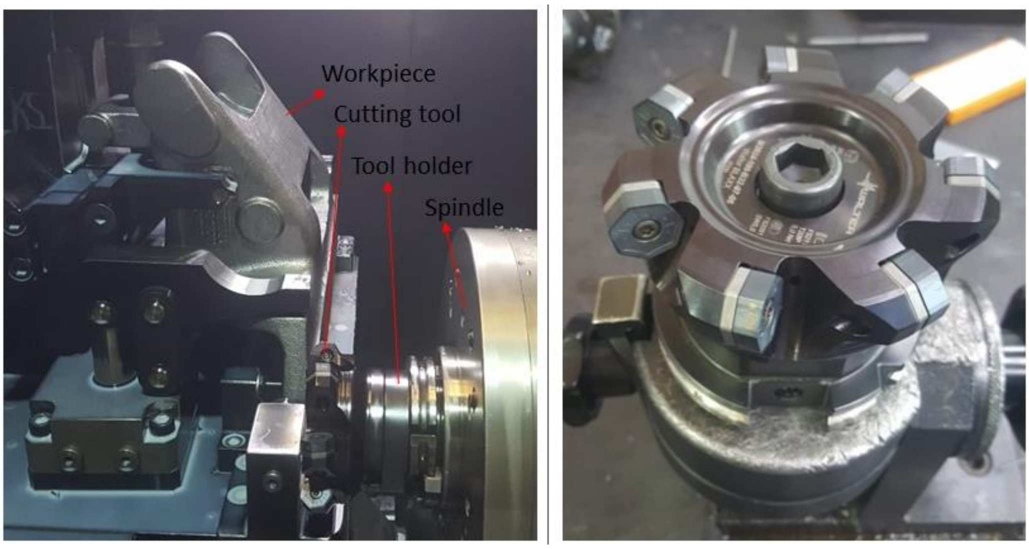



***Figure 1.*** *Experimental working setup.*

## B. WEAR MEASUREMENT

Flank wear values of the cutting tool tips used in the experiments were determined with the BestScope BS-3020T stereo microscope device. The system in which the wear values are measured is shown in Figure 2. After the milling operations were conducted, the dimensions of the wear on the edge and tip regions of the tool tips were obtained with the software used. At least 3 measurements were taken from the worn parts of the samples, from lowest, the middle and highest level of wear.


***Figure 2.*** *Imaging experiment setup.*

The average values of the obtained measurement results were determined, and the wear values of the samples were placed in the table. Input parameters and output values in the table are optimized. The experimental methodology is shown in Figure 3.

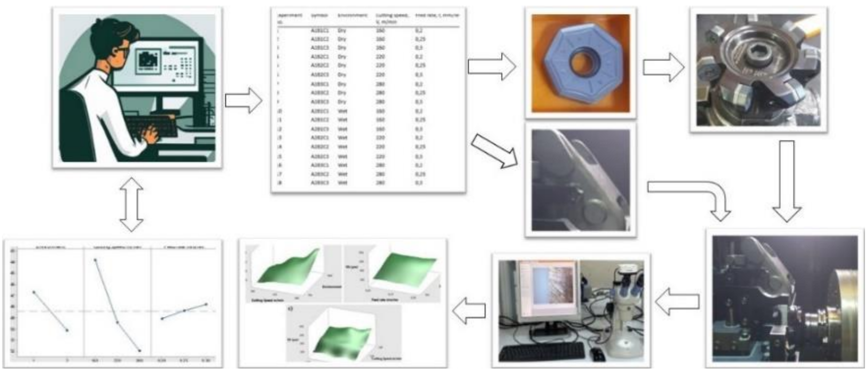


***Figure 3.*** *Experimental methodology.*

# III. EXPERIMENT DESIGN AND OPTIMIZATION

The Taguchi method allows to reduce the set of tests to be used in a study. In this way, a reliable and powerful experimental design can be revealed in engineering studies. Orthogonal arrays designed using the Taguchi method can perform a minimum number of tests with many variable parameters, while reducing the effects of factors other than these parameters [18]. The fundamental parameter of the analysis performed with this method is the loss function. With this function, deviations between the targeted results and experimentally obtained results are calculated. The resulting loss function: It reinstall the S/N ratio that has the ratio of the targeted signal value to the non-targeted random noise. There are three basic S/N ratios in the optimization study with the Taguchi method; lowest is best, highest is best, and most normal is best. In addition, determining the optimum levels of machining parameters used in machining ensures a regular and reliable operation. [19]. This method allows the deflection between the experimentally obtained results and the predicted results to be determined using the loss function. This function is then converted to the S/N ratio. Thanks to the analysis of these S/N ratios; the lowest values are better, nominal values are better, and the highest values are better [20]. In this study, it is aimed to reduce the abrasion on the cutting tool tips used in the milling process. Therefore, the lowest value better characteristic is preferred, as shown in the S/N ratio analysis. S/N ratio analysis is shown in Equation 1.

The lowest is the better characteristic:

$$\eta = S/N_s = -10log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \tag{1}$$

As a result, with the help of the Taguchi method, the difference between the targeted value (τ) of a process and the loss function value (y) can be found with the formula in Equation 2 given below. In line with this formula, it is aimed to reduce the costs of the work done and transaction inconsistencies [18].

$$L(y) = kc(y - \tau)^2 \tag{2}$$

When τ = 0, the performance characteristic of the test process is minimized. This situation is shown in the formula in Equation 3.

$$L(y) = kc(y)^2 \tag{3}$$

When the performance characteristic level of the test process is desired at the highest level, the formula in Equation 4 is applied.

$$L(y) = \frac{kc}{(y)^2} \tag{4}$$

Input parameters and levels used in the experimental system were determined as in Table 2.

***Table 2.*** *Milling process parameters and levels.*

| Parameters | Symbol | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Environment | A | Dry | Wet | - |
| Cutting speed,V, m/min | B | 160 | 220 | 280 |
| Feed rate,f,mm/rev | C | 0.2 | 0.25 | 0.3 |

# IV. RESULTS AND DISCUSSION

## A. OPTIMIZATION OF MACHINING PARAMETERS

In this study, different combinations were created for the input parameters by using Taguchi methods for the wear of the cutting tool tips and each combination was measured by experimental method. Optimization studies of experimental parameters and wear values were made on Minitab application. Optimization of these parameters was done with S/N ratios. Due to the cost of cutting tool bits used in machining, the less these tool bits wear, the better in terms of cost in the industry. For this reason, the "lowest value is better" equation is preferred in calculating the S/N ratio. The results and wear values of the cutting tool tips are given in Table 3.

***Table 3.*** *Experimental results and wear values.*

| **Experiment no.** | **Symbol** | **Environment** | **Cutting speed,V, m/min** | **Feed rate,f,mm/rev** | **Vb (µm)** |
|---|---|---|---|---|---|
| 1 | A1B1C1 | Dry | 160 | 0.2 | 136.41 |
| 2 | A1B1C2 | Dry | 160 | 0.25 | 113.48 |
| 3 | A1B1C3 | Dry | 160 | 0.3 | 102.25 |
| 4 | A1B2C1 | Dry | 220 | 0.2 | 255.85 |
| 5 | A1B2C2 | Dry | 220 | 0.25 | 237.42 |
| 6 | A1B2C3 | Dry | 220 | 0.3 | 230.71 |
| 7 | A1B3C1 | Dry | 280 | 0.2 | 323.77 |
| 8 | A1B3C2 | Dry | 280 | 0.25 | 305.12 |
| 9 | A1B3C3 | Dry | 280 | 0.3 | 294.21 |
| 10 | A2B1C1 | Wet | 160 | 0.2 | 312.28 |
| 11 | A2B1C2 | Wet | 160 | 0.25 | 303.91 |
| 12 | A2B1C3 | Wet | 160 | 0.3 | 296.74 |
| 13 | A2B2C1 | Wet | 220 | 0.2 | 477.98 |
| 14 | A2B2C2 | Wet | 220 | 0.25 | 458.62 |
| 15 | A2B2C3 | Wet | 220 | 0.3 | 391.37 |
| 16 | A2B3C1 | Wet | 280 | 0.2 | 602.13 |
| 17 | A2B3C2 | Wet | 280 | 0.25 | 509.85 |
| 18 | A2B3C3 | Wet | 280 | 0.3 | 487.52 |

The analysis of the effect of the input parameters used in the experiment was made with the S/N table. This S/N response chart is shown in Table 4. This table, obtained by the Taguchi method, specifies the most appropriate input parameters to minimize the wear on the cutting tool tips. In this table, the values that have the least effect on the abrasion of the cutting tool tip are shown in bold. The level values of the cutting tool wear parameters given in Table 4 are shown graphically in Figure 2. Optimum values of the determined input parameters can be specified with these graphs. The optimal level of each parameter was determined as the highest level of the S/N ratio in the graphs. Accordingly, A1B1C3 was found to be the most suitable test set for cutting tool tip wear. This set of experiments; It represents the optimum parameters as coolant closed as working environment, 160 m/min as shear velocity and 0.30 mm/rev as feed rate. The experimental set with the highest tool tip wear was determined as A2B3C1. The parameters of this experimental set were specified as working medium with coolant open, cutting speed as 280 m/min and feed rate as 0.3 mm/rev.

***Table 4.*** *S/N results for tool wear.*

| Levels | Environment | Cutting speed,V, m/min | Feed rate,f,mm/rev |
|---|---|---|---|
| Level 1 | **-46.24** | **-45.50** | -50.02 |
| Level 2 | -52.35 | -50.27 | -49.22 |
| Level 3 | | -52.13 | **-48.65** |
| Delta | 6.11 | 6.63 | 1.37 |

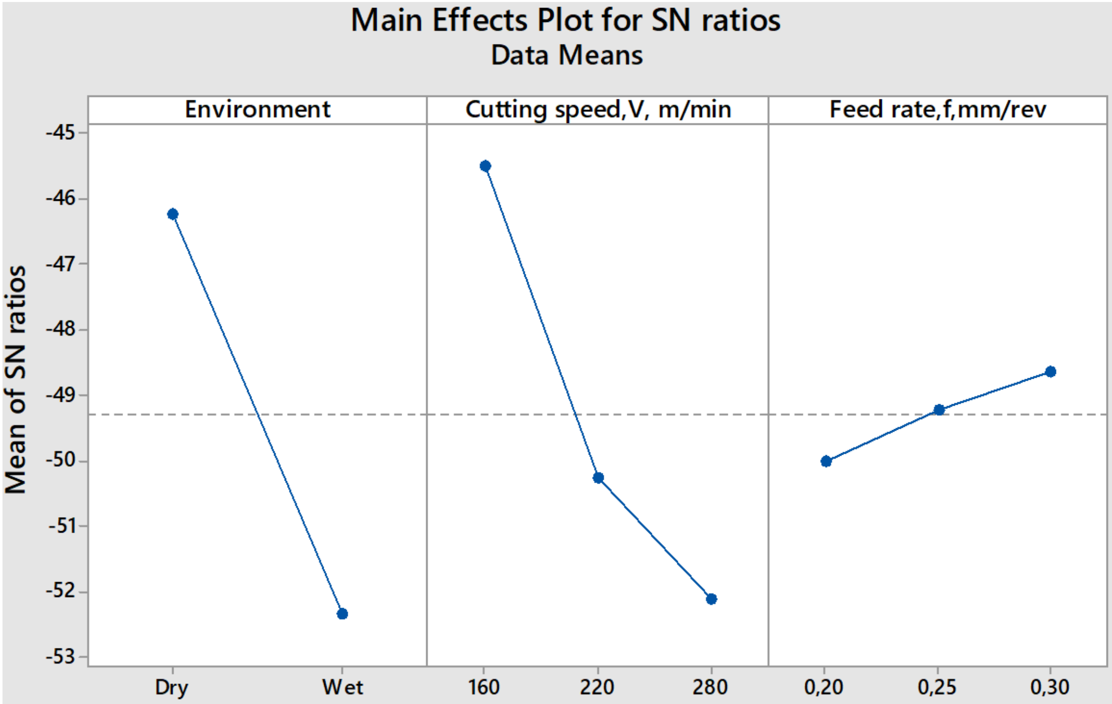



***Figure 2.*** *S/N ratios of parameters in the milling process.*

Figure 3.a shows the effects of shear velocity and working environment on average cutting tool tip wear. Looking at the graph, it is seen that the increase in cutting speed causes abrasion on the cutting tool tip. Looking at the literature, it is emphasized that as the shear velocity in the milling process increases, the abrasion on the cutting tool tip also increases [21-23]. When processing is carried out within the working parameters specified for GGG50 nodular cast iron material, the coolant may have a negative effect and corrode the tool tip [24]. However, it is seen that the shear velocity parameter does not affect the cutting tool tip wear as much as the ambient conditions. It is also seen that the working environment has a great effect on the abrasion on the cutting tool tip. It can be said that the open cooling liquid in the working environment also increases the average wear value. The reason for this is that thermal fatigue occurs with the use of coolant and as a result, more wear occurs compared to a dry working environment [25,26]. If the coolant used in milling operations is flooded, it causes wear on the cutting tool tip due to the effect of chips breaking off from the material. In addition, the high temperature caused by cutting forces and the coolant flowing in flood form create a thermal fatigue effect on the cutting tool tip [25,27]. Figure 3.b shows the effects of feed rate and working environment on cutting tool tip wear. As seen in the graph, the head feed rate parameter has little effect on the cutting tool tip wear. Figure 3.c shows the effects of feed rate and cutting speed on cutting tool tip wear. According to Figure 3.a and Figure 3.b graphics, when Figure 3.c is examined, it can be said that the feed rate parameter has no effect on the cutting tool tip wear. Studies in the literature show that the feed rate has little effect on the cutting tool tip wear [28-30]. When the working environment and cutting speed parameters are compared with the feed rate parameter, it is seen that they are effective in cutting tool tip wear.

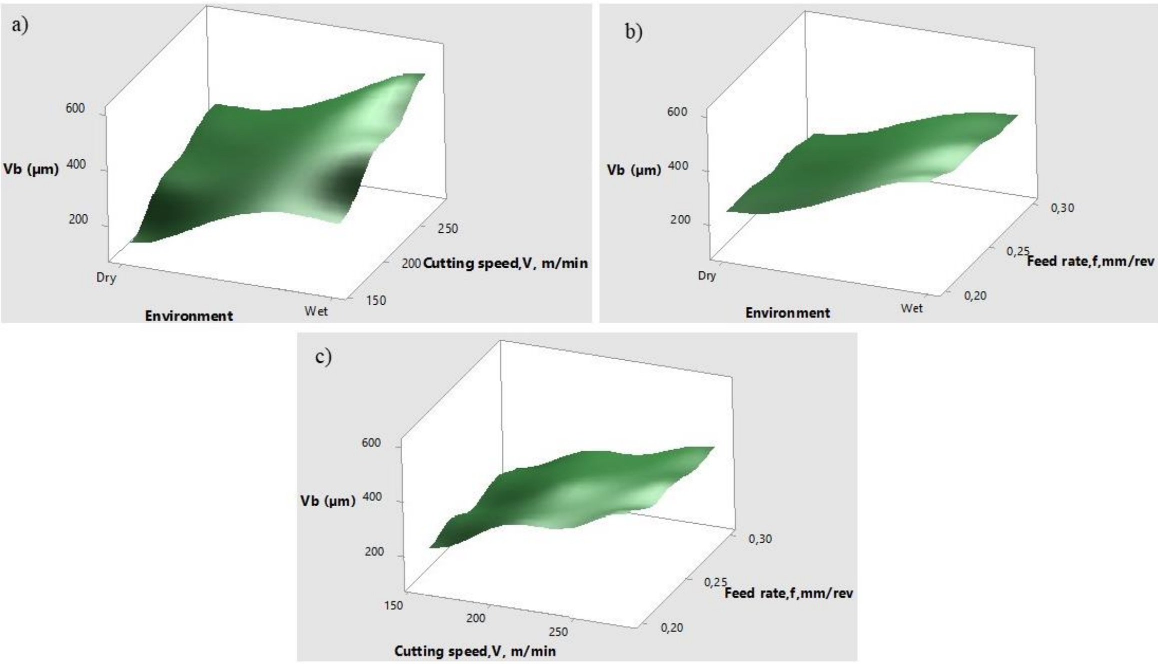
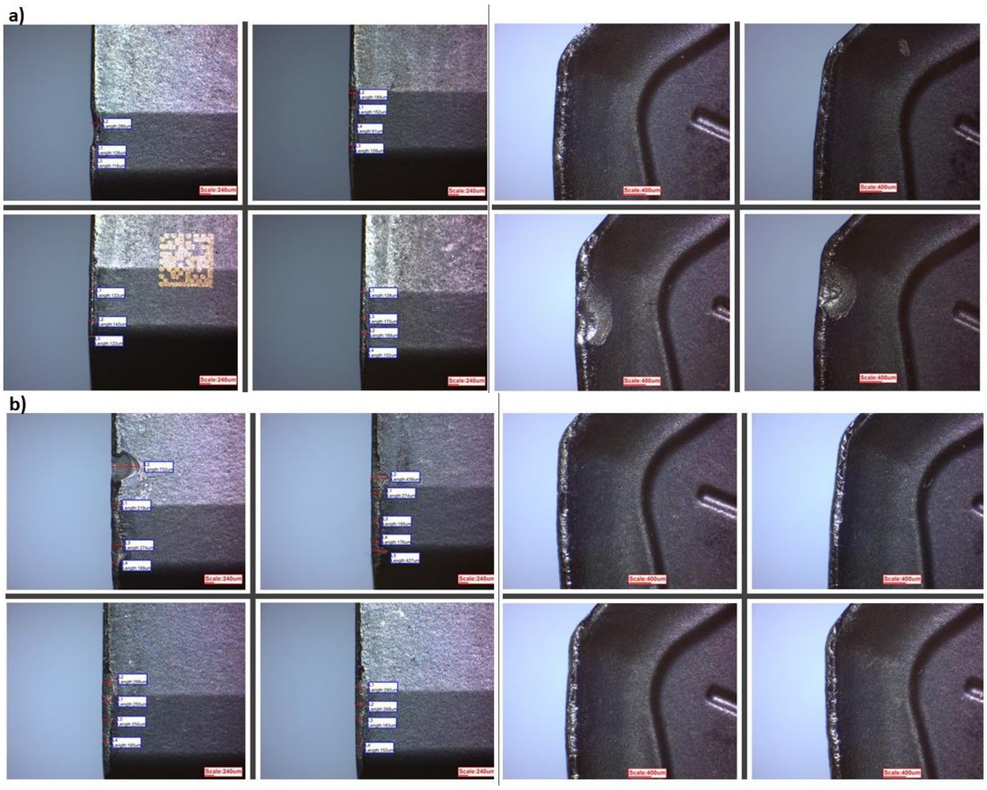



***Figure 3.*** *3d graphical representation of the effect of machining parameters on the cutting tool tip.*

The images of the wear on the cutting tool tips obtained by the stereo microscope as a result of the experimental studies are shown in Figure 4. Figure 4.a shows A1B1C3 test set, Figure 4.b shows A1B3C2 test set, Figure 4.c shows A2B1C1 test set, and Figure 4.d shows the abrasion of the cutting tool tips after applying the A2B3C1 test set.



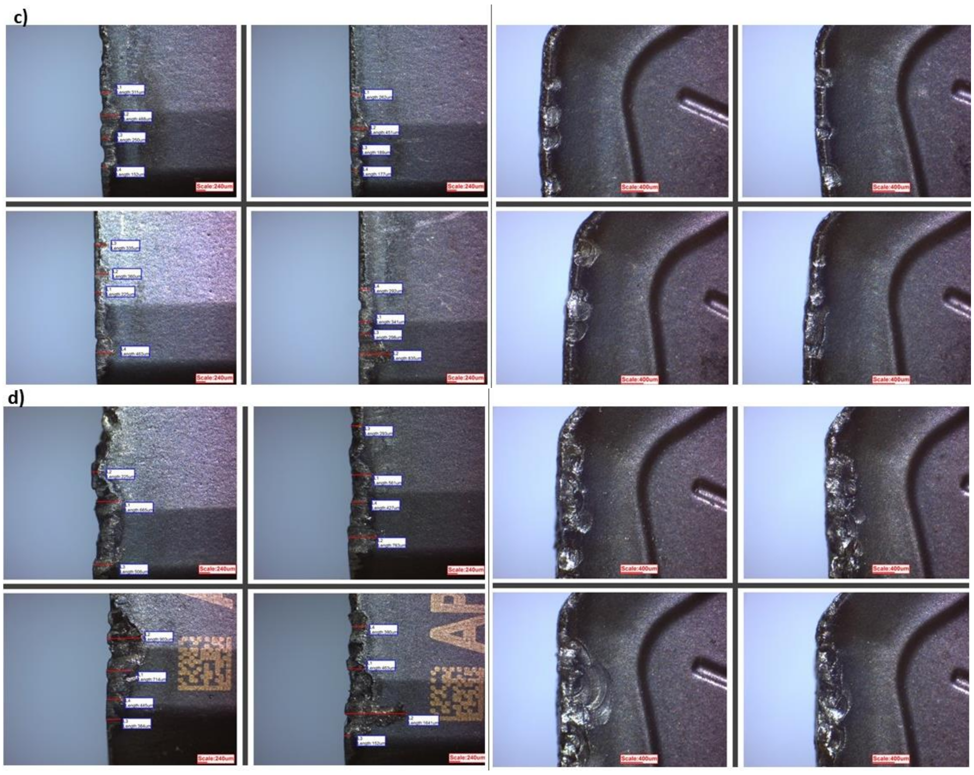



***Figure 4.*** *Imaging of the wear on the cutting tool tips with a stereo microscope. Figure 4.a. A1B1C3 experiment set. Figure 4.b. A1B3C2 experiment set. Figure 4.c. A2B1C1 experiment set. Figure 4.d. A2B3C1 experiment set.*

## B. ANALYSIS OF VARIANCE (ANOVA)

The ANOVA method is a statistical analysis method used to detect significant and insignificant interactions between independent parameters determined in the experimental design. In addition, it is used to prove the accuracy of the experimental set established by the Taguchi method [31,32]. In the study, ANOVA method was used to analyze the effects of cutting speed, feed rate and coolant on the wear of the cutting tool tips. The ANOVA analysis results of the wear on the cutting tool tips are given in Table 5.

***Table 5.*** *ANOVA results for wear of cutting tool tips.*

| Variance Source | Degree of Freedom (DoF) | Adj SS | Adj MS | F Value | P Value | PCR (%) |
|---|---|---|---|---|---|---|
| Environment | 1 | 188330 | 188330 | 358.68 | 0 | 55.875 |
| Cutting speed,V,m/min | 2 | 134560 | 67280 | 128.14 | 0 | 39.9221 |
| Feed rate,f,mm/rev | 2 | 7866 | 3933 | 7.4 | 0.008 | 2.33374 |
| Error | 12 | 6301 | 525 | | | 1.86942 |
| Total | 17 | 337056 | | | | 100 |

The fact that the P values determined in the ANOVA results for the input parameters were $P<0.05$ indicates that these parameters affect the tool wear a lot [33]. As the input parameters shown in the table above, it is seen that the effects of cooling water, cutting speed and cutting-edge feed on the cutting tool tip wear are 55.875%, 39.922%, and 2.333%, respectively As per the results, it has been determined that the effect of feed rate on the cutting tool tip is very small. In the ANOVA analysis test, it was stated that the coefficient of determination (R2) was 98.13%. Although it is seen that the feed rate parameter does not have much effect on tool wear in the milling process of GGG50 ductile iron material, when looking at the literature, it is seen that it is effective in other machining methods such as drilling, grooving and tapping [34,35].

# V. CONCLUSIONS

In this study, it was studied to determine the optimum working parameters of GGG50 ductile cast iron material in dry and coolant environments with carbide cutting tools by using Taguchi method. The reliability of the experimental results was evaluated by ANOVA analysis. The results obtained are listed as follows.

- It has been determined that the coolant being open in the working environment and the high cutting speed affect the cutting tool tip wear negatively.
- As per the analysis results obtained, the parameter that has the lowest effect on the cutting tool tip wear is the feed rate.
- It was determined that crater wear occurred at the cutting tool tip in the experimental parameters where the coolant was open, and the cutting speed was increased.
- In the study, it was observed that the flank wear mechanism occurred at the cutting tool tips.
- It has been determined that the use of coolant based on the increased temperature in the milling process causes thermal fatigue.
- As per the results of ANOVA analysis, feed rate the parameter that has the least effect on cutting tool tip wear.
- Considering the S/N ratios, it was observed that the most suitable test set to keep the cutting tool tip wear at a minimum level was A1B1C3 (Coolant = closed, cutting speed = 160 mm/min, feed rate = 0.3 mm/rev).

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