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Araştırma Makalesi / Research Article

An In-Depth Analysis on The Surface Roughness Variations During Turning of GGG50 Ductile Cast Iron

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Abstract

Spherical graphite materials are a type of material that can compete with steel, thanks to their durability and mechanical properties. GGG50 ductile cast iron finds application area in automotive industry primarily especially for production of the part of tracks and tractors, and its production rate is increasing. Machinability of these special materials is of great importance since the cast iron requires final forming to achieve better surface quality. Surface roughness is accepted as a performance criterion among surface quality indicators as per it reflects the variations with peaks and valleys according to the machining parameters. Therefore, this study focuses on the influence of basic turning parameters on the average surface roughness during dry machining of the GGG50 material. The evaluation was carried out based on statistical analysis, graphical presentation and optimization approach. The analysis results showed that feed rate plays a key role on the surface roughness variations with the contribution rate about 70.8 %. To obtain the best surface quality, cutting parameters should be selected as 0.16 mm for cutting depth, 0.2 mm/rev for feed and 60 m/min for cutting speed respectively. This study aims to find the best turning conditions for an industrial material by discussing the importance of fundamental turning parameters. Thus, it will be a guide for those working on this material.

Keywords: GGG50, Cast iron, Machinability, Surface roughness.

INTRODUCTION

Machining is the process of removing waste materials, expressed as chip, from the raw material to obtain the desired final product. It is important to choose the most suitable machine tool and processing method for the product to be produced in the production sector (Rüstem, Halil, Süleyman, & Süleyman, 2020; Şeker & Hasirci, 2006). Machining methods include machining operations such as turning, milling and drilling (Rüstem Binali, Yaldız, & Neşeli, 2021; Coşkun, Çiftçi, & Demir, 2021). Among these methods, turning is widely used. Turning process gives faster and better results in machined surface quality compared to other machining processes (Harun, Akkuş, & Levent, 2016). The reason for this can be said that the geometry of the cutting tool used is simpler. We can express the turning process as the removal of chips from the workpiece material, parallel to the axis of the workpiece, with the cutting tool parallel to the workpiece axis at each turn of the workpiece. In short, it is the process of removing chips from the material that makes rotational motion (Akkuş, Harun, & Levent, 2017). In machining processes, it is aimed to produce quality products with low processing time and cost. Therefore, the selection of the machinability parameters used during the process is important. Input parameters such as cutting depth, cutting speed,

feed rate machining conditions (dry, coolant, etc.) are used to determine output parameters (surface roughness, tool wear, temperature and cutting force etc.) in the turning process (Rüstem Binali, Coşkun, & Neşeli, 2022; Günay, Yaşar, Sekmen, & Korkmaz, 2016; Salur, Aslan, Kuntoglu, Gunes, & Sahin, 2019). Since the surface roughness value is also related to the output parameters, it is one of the most important parameters used by investigating the machinability levels of the materials. Ideal selection of cutting parameters is necessary for optimum machining and stock removal.
Due to the ease of production, low cost, controllable structural changes and good mechanical properties of spheroidal graphite cast irons, usage areas are quite high. Such materials are approximately 10% lighter than steels. In addition, the energy used in its production is approximately 50% less than in steel production (Kayalı & Yalçın, 2006). In addition, when spheroidal graphite cast irons are compared with other cast irons and steel castings, they have superior properties such as low melting point, excellent castability, suitability for heat treatment, higher wear resistance, better surface quality and strength to weight ratio. In addition to these features, due to the presence of graphite particles in its structure, it affects the surface roughness and cutting force and facilitates machinability (Kaçal, Gülesin, & Melek, 2008; Şahinoğlu, Güllü, & Dönertaş, 2017). The machinability studies on cast irons are given below.

Şahinoğlu et al. evaluated the machinability of GGG50 material, the sound intensity, vibration and surface roughness in the course of the turning process by using four different feed, cutting speeds and depth in the turning process. As a result of the study, they stated that the vibration, sound intensity and surface roughness values increased with the increase in the rate of feed (Şahinoğlu et al., 2017). Uzun and Çakıroğlu evaluated the cutting force generated during chip removal from vermicular graphite cast iron material and the surface roughness of the material surface after processing (Uzun & Cakıroglu, 2020). Del Val et al. studied the wear mechanisms of TiN coated tools in the course of high speed tapping of GGG50 ductile cast iron (Del Val, Alonso, Veiga, & Arizmendi, 2023). Şeker and Hasırcı evaluated the machinability of austempered cast irons on the basis of surface quality and cutting forces (Şeker & Hasirci, 2006). In his study, Binali studied the temperature change that occurs during the turning of the GGG50 material (Rüstem Binali, 2022). Yazman et al. investigated the relationship between machinability and chip morphology of GGG50 material (Yazman et al., 2017). Ucun et al. studied turning of austempered spheroidal graphite cast iron. In their study, surface roughness, tool wear and cutting forces were evaluated (Ucun, Aslantaş, Taşgetiren, & Gök, 2007).

In the literature search, it was seen that there are studies on the machinability of spheroidal graphite materials, but it is not sufficient for the GGG50 material. In this study, machinability on the surface roughness formed after turning of the GGG50 material, which is among the spheroid graphite cast irons, which is increasing in usage area and competing with steels, is discussed. This study discussed the machinability of GGG50 material on the surface roughness in turning. In this context, the surface roughness of the material was measured on the machined surface. The main purpose here is to obtain the minimum surface roughness value on the workpiece surface during the chip removal of the cutting tool. For this reason, Taguchi optimization, graphical evaluation and ANOVA analysis were used to determine the effects of machining parameters on surface roughness.

MATERIALS AND METHODS

In this section, the characteristics of the workpiece and cutting tool materials used in the experimental study and the details of the turning process are discussed. In addition, the experimental design will be explained in detail.

Machine Tool and Material Properties

In experimental studies, GGG50 spheroidal graphite casting material was used. Spheroidal graphite cast irons are structurally differentiated from other cast iron materials due to their color and graphite shapes. The chemical composition of the material (GGG50) used is given in Table 1. The dimensions of the material used in the turning experiments are 30 mm in diameter and 100 mm in size. The cutting tool used has the code of TiC coated CCMT 09T308-304. The cutting tool and workpiece material were selected in line with the recommendations received from the manufacturing companies. Specifications about the cutting tool are given in Table 2.

Table 1. Chemical composition of GGG50 cast iron (matmatch.com, 2022).

Material	C	Mg	Mn	P	Si	S
GGG50	3.5-3.8	0.06-0.12	0.4	0.1	2-3	0.01

Table 2. The cutting tool used and its properties.

Cutting tool code	Cutting Edge Length	Thicknes	Corner Radius	Cutting tool
CCMT 09T308-304	9.7 mm	3.97 mm	0.8 mm	

Experimental studies were carried out on a conventional lathe (De Lorenzo, Italy). The lathe used and the experimental setup are given in Figure 1.

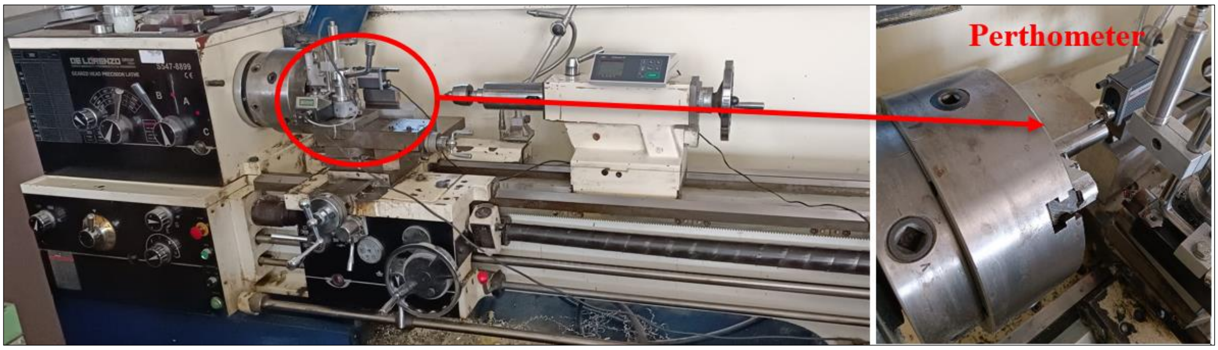


Figure 1. Experimental setup.

Experiments Plan and Taguchi Design

Three different feeds, cutting speed and cutting depth parameters were used in experimental studies. The processing parameters used are given in Table 3. These parameters were determined according to the company recommendation and the machinability parameters of other cast iron materials in the literature, and then the cutting speed ranges and feed rates were determined. In case of production problems of the material before the experiments, approximately 1 mm of chip removal was carried out on the test material.

Table 3. Machining parameters and levels.

Machining parameters	Levels
Cutting speed	60-80-130 m/min
Feed speed	0.2-0.4-0.6 mm/rev
Cutting depth	0.12-0.16-0.2 mm

In experimental studies, Taguchi experimental design approach is used in order to reach the desired final goal by reducing the number of experiments and to obtain maximum efficiency by reducing the cost (Asiltürk & Neşeli, 2012; Şap, Usca, & Uzun, 2022; Usca et al., 2022). Taguchi is a systematic and efficient approach to determining optimum conditions. In order to measure and evaluate the quality characteristics in Taguchi experimental design, the smallest best objective function was evaluated using the S/N ratio. Taguchi L_9 orthogonal index used in experimental design is given in Table 4.

Table 4. Taguchi-based orthogonal experimental design.

Exp. No	**f (mm/rev)**	**d (mm)**	**Vc (m/min)**
1	0.2	0.12	60
2	0.2	0.16	80
3	0.2	0.2	130
4	0.4	0.12	80
5	0.4	0.16	130
6	0.4	0.2	60
7	0.6	0.12	130
8	0.6	0.16	60
9	0.6	0.2	80

Measurement of Surface Roughness

Surface roughness is defined as a response parameter in machinability tests. While measuring the roughness index, the average roughness values were chosen. In order to evaluate the roughness values to be used as a result of the experimental studies, five different measurements were made from the material surface after each treatment, and the average of three different measurements was taken by eliminating the maximum and minimum values. Measurements were taken without removing the chuck after chip removal. The roughness measurement was made with a Mahr brand perthometer. The calibrated setup for measurement on the machine tool can be seen in Figure 1.

RESULTS

Anova Based Evaluation

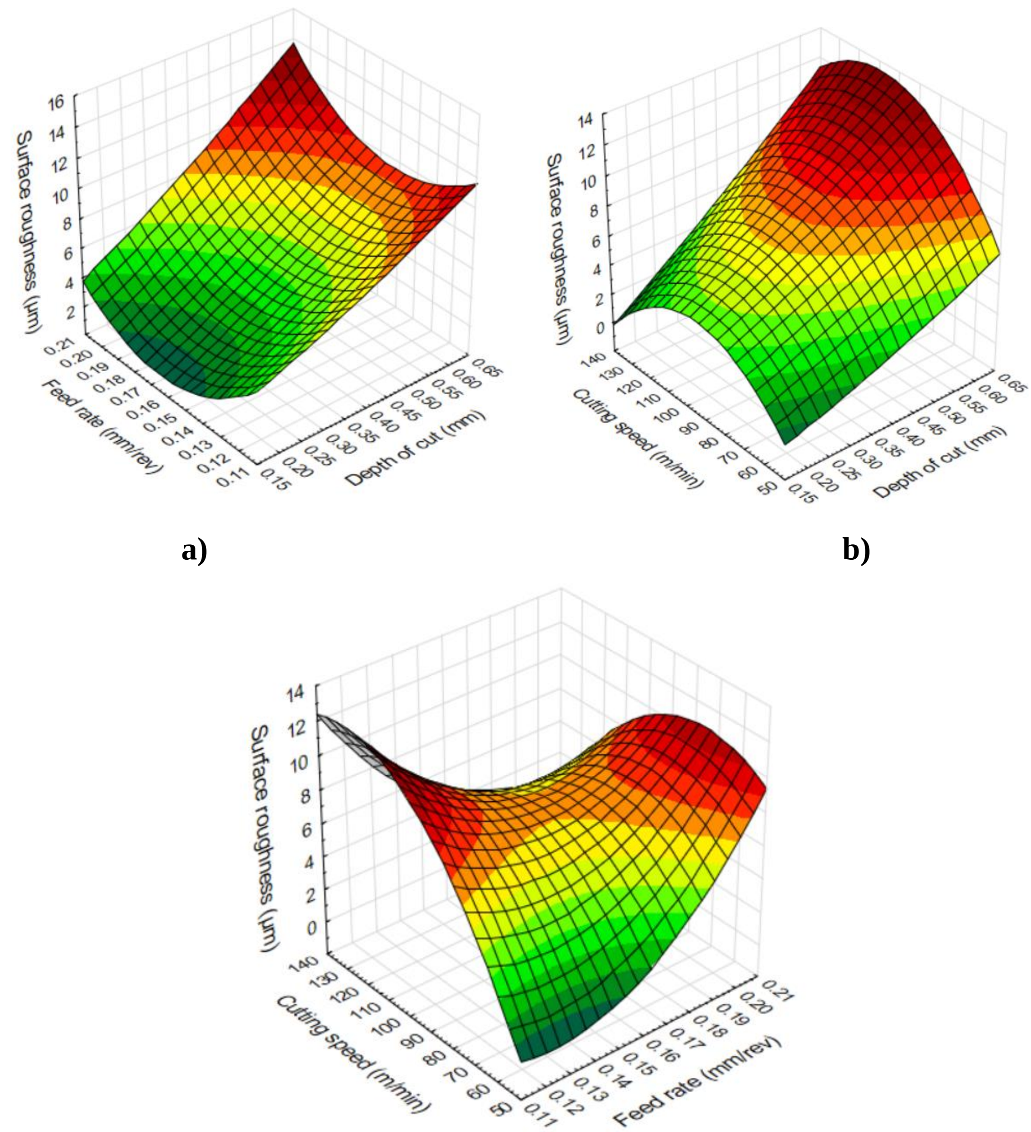
ANOVA is widely applied method for statistical analysis of the experimental parameters in order to obtain the percent contributions to the response parameter. In addition to that, this approach allows for determination of the different statistical indicators to confirm the most and least effective parameters such as F value and P value. When looking at the ANOVA based evaluations in the machining studies, general trend says that this kind of approach provides reliable and fast possibility of discussion (Asiltürk & Neşeli, 2012; Neşeli, Yaldız, & Türkeş, 2011). In this direction, table 5 represents the ANOVA results of the turning parameters belong to GGG50 material for surface roughness. As can be seen, feed rate has the most influence on the surface roughness as expected with the contribution rate about 70.8 %. The reason is that the influence of the speed of the cutting tool in the feed direction determines the waviness of the surface and effect the formation of the peaks and valleys (Coşkun et al., 2021; Kuntoğlu et al., 2020; Kuntoğlu, Gupta, Aslan, Salur, & Garcia-Collado, 2022). Through the cutting time, this has influence on all surface deformations. After feed rate, cutting speed comes the second place with the contribution rate about 11.8 %. Lastly, depth of cut is the last parameter has influence with 8.9 %. Total percent contribution without residual error is about 91.5 % which shows the accuracy of the model can be used in the future works for surface roughness. Other statistical parameters such as P and F values support the percent contribution results.

Table 5. ANOVA results for the turning parameters.

Source	DF	Seq SS	Adj MS	F value	P value	PC (%)
Feed rate	2	66.437	33.218	8.36	0.107	70.8
Depth of cut	2	8.380	4.190	1.05	0.487	8.9
Cutting speed	2	11.094	5.547	1.40	0.417	11.8
Residual Error	2	7.945	3.972	-	-	8.5
Total	8	93.855	-	-	-	100

3D Graphical Evaluation

3d graphs permits for the observation of the how the design parameters act at the certain values and intermediates on the response parameter. In this direction it can be valuable in machinability studies because such operations are open for the momentary alterations as they are the function of many input parameters (Rüstem Binali, 2022; Kuntoğlu et al., 2020; Kuntoğlu & Sağlam, 2021). That's why the outcomes of these approaches can be useful to determine how change the responses according to several combinations of modelling parameters. Therefore, this study appoints 3d graphs for inspection of the surface roughness variations by discussing the influence of cutting speed, feed and cutting depth. Figure 2 shows the impacts of the cutting parameters respectively for the combinations of cutting speed, depth and feed. Seemingly, increasing depth of cut increases the roughness irrespective of other parameter changes. Increasing cutting speed also have negative effect on the roughness however this trend changes at certain value. The depth of cut increasing with the feed rate maximizes the roughness value compared to other interactive parameters. This situation can be seen in Figure 2.a. After some point roughness shows decreasing behavior which should be considered to regulate surface quality. Lastly, higher levels of feed rate increase the surface roughness with no exception according to the different values of cutting speed and depth. Such observations will be helpful for the identification of exact values in obtaining minimum surface roughness during machining.



a) b)

c)

Figure 2. 3d evaluation of surface roughness by combining turning parameters.

Optimization of Machining Parameters

Optimization is used in daily life everywhere to determine the best operational conditions. Plus, it is also very important in manufacturing industries mostly due to the intend to make the process optimum in terms of time, energy, cost, and technological wellness. Therefore, optimizing the processes in these areas bring multiple benefits to the industries. In this direction, this paper handles the machining parameters in turning of GGG50 material to obtain the best conditions for surface roughness. Using minitab software, figure 3 was obtained which is main effects plot for means and gives the optimal values of parameters. According to this evaluation strategy, the value gives the minimum means is the best option for achieving the best response parameter. Therefore, minimum feed (0.2 mm/rev) nominal cutting depth (0.16 mm) and minimum cutting speed (60 m/min) should be selected for the minimum surface roughness. The reason for the feed was explained in the previous section however for the cutting speed, it is true that with the increase of movement speed of the cutters, chip removal become easier and the lower cutting forces provide better surface quality (R Binali, 2017; Kuntoğlu et al., 2022; Yurtkuran, Korkmaz, & Günay, 2016). Such a result can be useful in real life conditions to improve the surface quality of cast irons after machining.

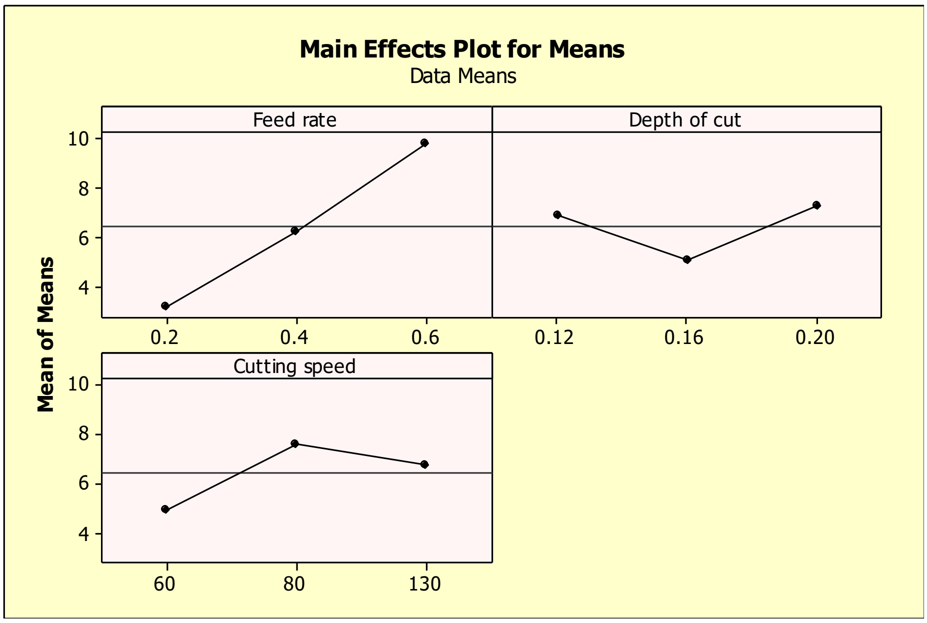


Figure 3. Optimum results for the minimum surface roughness.

Conclusions

This study aims to investigate the optimal machining conditions during turning of the GGG50 cast iron to achieve the minimum surface roughness value. As a result of the study, those working with this material in the machining industry will have learned about the processing parameters. The following deductions can be done from this paper:

- Minimum feed (0.2 mm/rev) nominal cutting depth (0.16 mm) and minimum cutting speed (60 m/min) should be selected for the minimum surface roughness.
- Higher levels of feed increase the surface roughness with no exception according to the different values of cutting speed and depth.
- Feed is the most influential factor on the surface roughness with the contribution rate about 70.8 %. Cutting speed comes the second place with the contribution rate about 11.8 % and cutting depth is the last parameter has influence with 8.9 %.

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