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Evaluation of Machining Parameters Affecting Cutting Forces in Dry Turning of GGG50 Ductile Cast Iron

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Abstract: Cutting forces in turning have dramatic impact on the cutting stability, tool wear index and surface quality. Machinability of cast iron is important as per this material is served as the main source in manufacturing specific parts of automotive industry. Also, this special material may require final operation to eliminate the manufacturing related defects and residuals. In this context, this study focuses on the optimization and analysis of cutting forces during dry turning of GGG50 material. Thus, Taguchi based experimental design was applied using three levels of cutting speed, feed rate and cutting depth and totally 9 experiments were performed. The discussions on the cutting forces were made based on statistical analysis, optimization approach and graphical presentations. Accordingly, feed rate is the most influentive parameter on cutting forces with the contribution rate about 71.2 %. Cutting speed and cutting depth follows it with the contributions of 21.7 % and 1.5 %. To achieve the minimized cutting forces the parameter group should be; 0.16 mm, 0.2 mm/rev, 80 m/min. This study is expected to be an auxiliary resource for designers and manufacturers in the field to improve the machinability aspects of casted materials.

GGG50 Sfero Döküm Demirin Kuru Tornalanmasında Kesme Kuvvetlerini Etkileyen İşleme Parametrelerinin Değerlendirilmesi

Anahtar Kelimeler
Kesme kuvvetleri,
Dökme demir,
Optimizasyon,
Tornalama

Öz: Tornalamadaki kesme kuvvetlerinin kesme stabilitesi, takım aşınma indeksi ve yüzey kalitesi üzerinde önemli etkisi vardır. Dökme demirin işlenebilirliği önemlidir, çünkü bu malzeme otomotiv endüstrisinin belirli parçalarının imalatında ana kaynak olarak hizmet eder. Ayrıca bu özel malzeme, imalattan kaynaklanan kusurları ve artıkları ortadan kaldırmak için son işlem gerektirebilir. Bu bağlamda, bu çalışma GGG50 malzemesinin kuru tornalanması sırasında kesme kuvvetlerinin optimizasyonu ve analizine odaklanmaktadır. Bu nedenle, kesme hızı, ilerleme hızı ve kesme derinliği olmak üzere üç seviye kullanılarak Taguchi tabanlı deney tasarımı uygulanmış ve toplam 9 deney gerçekleştirilmiştir. Kesme kuvvetleri ile ilgili tartışmalar, istatistiksel analiz, optimizasyon yaklaşımı ve grafiksel sunumlara dayalı olarak yapılmıştır. Buna göre ilerleme hızı, yaklaşık %71,2'lik katkı oranı ile kesme kuvvetleri üzerinde en etkili parametredir. Bunu %21,7 ve %1,5'lik katkılarla kesme hızı ve talaş derinliği takip etmektedir. En aza indirilmiş kesme kuvvetlerini elde etmek için parametre grubu şöyle olmalıdır; 0,16 mm, 0,2 mm/dev, 80 m/dak. Bu çalışmanın, döküm malzemelerin işlenebilirlik yönlerinin iyileştirilmesi konusunda tasarımcı ve üreticilere yardımcı bir kaynak olması beklenmektedir.

1. INTRODUCTION

Machinability studies are very important in the machining industry to determine the interactions between the workpiece and the cutting tool material before production. Although machinability studies are widely carried out today, its popularity is maintained. The reason for this is developing technology and increasing material need. New materials and cutting tools are produced every day. The need for new types of tools and materials is to achieve maximum efficiency with lower costs. Among the machinability studies, various machining methods are used. The most widely used method among them is turning with a single-edged cutting edge [1-5]. Among the machinability output parameters, although all parameters are important, the cutting force, which directly and indirectly affects other parameters, is very important. Changes in cutting force can cause oscillations on the part, resulting in poor machined surface quality, tool wear, temperature rise and vibration following wear, and an increase in the amount of energy consumed for machining with increased force [6-8]. Between the commonly used cast iron materials is the spheroidal graphite cast iron material. Although the mechanical properties of spheroidal graphite cast iron materials are closer to steels, they have high strength and ductility. Among the usage areas of this type of cast iron, there are materials such as gears, press machines, flywheels, tractor parts and cylinders [9-11]. The literature review of the machinability studies on cast irons is given below.

Mavi and Korkut investigated the change in surface roughness on the material surface after machining on vermicular graphite cast iron. They stated that the cast iron material gave the best surface roughness value in processing at the highest speed [12]. Binali, in his study, studied the temperature change in the machining of GGG50 spheroidal graphite cast iron material by turning. As a result of his study, he stated that the most effective parameter on the temperature was the cutting speed [13]. Karabulut and Güllü investigated the milling of vermicular graphite cast iron with cutting tools with different approach angles. In their study, they stated that it is the most important factor in the increase of cutting forces in the direction of feed, as the amount of feed increases with the decrease in the value of the approach angle [14]. Düzce and Samtaş investigated the face milling process of GG25 casting material. In their study, they evaluated the temperature formations during machining with cutting tools with three different coatings (TiAlN coated, TiN-TiCN-Al2O3 coated and ALTiN coated). They determined that the most effective machining parameter affecting the temperature is the cutting tool with the most suitable coating type for the cutting depth and the minimum temperature, the cutting tool with TiN-TiCN-Al2O3 coating [15]. Ucun et al. carried out machinability tests of austempered ductile cast iron material by turning tests. In their study, surface roughness, tool wear and cutting forces were evaluated. As a result of their studies, they stated that the surface roughness decreased with increasing cutting speed. They also stated that austempering at low temperatures had a positive effect on the workpiece surface [16].

As can be seen in the literature research, there are machinability studies of spheroid graphite casting materials, but GGG50 is not at a sufficient level for spheroid graphite casting materials. For this reason, in our study, the machinability of the GGG50 material on the conventional lathe was determined according to the cutting force values that occur during the process. In this context, the cutting force generated during chip removal was measured with the help of a dynamometer. The main purpose here is to obtain the minimum cutting force value and to ensure that other machinability output parameters are obtained at an ideal level. Taguchi based S/N ratio, 3D graphical evaluation and ANOVA statistical analysis were used to determine the effects of machining parameters on cutting force values in order to obtain optimum values.

2. MATERIAL AND METHOD

The details of the cutting tool and material used in the experimental studies and the turning tests performed to determine the properties and cutting force values are given in this section. In addition, the details of the experimental design used are included.

2.1. Cutting Tool and Workpiece Material

In the machinability experiments, the cutting force values were compared for the optimization of the machining parameters of the GGG50 casting material. This material is brittle and short chips are formed during machining. Machinability is better than other cast iron materials. Tensile Strength is 500 N/mm2 and hardness is approximately 170-220HB. The chemical composition of the elements in the GGG50 spheroidal graphite casting material used in the studies are given in Table 1 as a percentage. The material used in the experimental studies has a cylindrical geometry and its dimensions are 30 mm in diameter and 100 mm in length. A new cutting tool material was used for each experiment and the cutting tool has a TiC coating and CCMT 09T308-304 code. The cutting tool was selected according to the workpiece material in line with the recommendations received from the manufacturers. Cutting tool specifications are given in Table 2.

Table 1. Chemical composition of GGG50 cast iron [17]

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 tool quality	Cutting Edge Length	Thickness	Corner Radius
CCMT 09T308-304	P25	9.7 mm	3.97 mm	0.8 mm

2.2. Machine Tool Test Procedure

Experiments were made on De Lorenzo S547-8899 lathe. Machine specifications are given in Table 3. In the experimental studies, the processed materials were connected between the chuck and the tailstock, and the connection of the test bench and the workpiece and the tool holder-cutting tool connections are given in Figure 1.

Table 3. Machine tool properties

Technical Specifications	Value	Unit
Maximum workpiece diameter	460	mm
Distance between chuck and tailstock	1500	mm
Spindle speed range	25-1800	rev/min
Spindle speed number	12	piece
Feed range	0.04-2.46	mm
Number of feeds	122	piece
Maximum tool holder size	25x25	mm
Motor power	5.5	kW

Figure 1. The clamping system of the lathe, workpiece and cutting tool

2.3. Taguchi Based Experimental Design

When it is desired to get the highest efficiency from the work done in physical experiments, it is necessary to try the interaction of all values of the processing parameters with each other. However, these increases both processing time and cost [18-20]. For this reason, Taguchi-based experimental approaches are used to achieve the desired process outputs with minimum cost and time. Three different cutting speed, feed rate and cutting depth parameters were used in the study, and the Taguchi L9 orthogonal array of the parameters used are given in Table 4.

Table 4. Machining parameters and Taguchi-based orthogonal experimental design

Experimental No	Feed (f) (mm/rev)	Cutting depth (d) (mm)	Cutting Speed (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

2.4. Measurement of Cutting Forces

The dynamometer used for force measurement in the experimental study is a TelC DKM2000 turning dynamometer. The dynamometer can measure the forces occurring during the operation in the three axes direction and with the help of the strain gage. The dynamometer body is mounted with a clamp and successfully measures the shear forces occurring in the cutting zone. The device can be directly connected to the computer and data tracking, processing and recording can be done with its own XKM2000 software. The body of the dynamometer and the appearance of the signal screen followed by the computer are given in Figure 2.

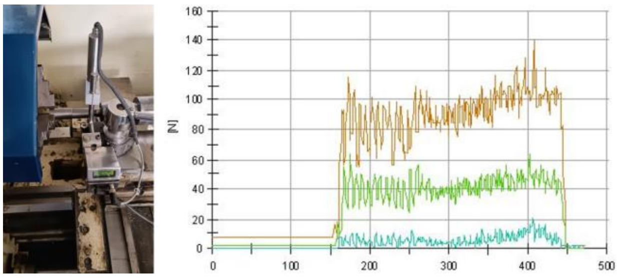

Figure 2. Connecting the dynamometer to the bench and the monitored signal display

3. RESULTS

3.1. Graphical Evaluation

Graphical representation is an effective technique to observe the impacts of input parameters not only with the certain values applied in the experiments but also for the intermediate values. This kind of approach provides to understand how two design parameters affect the output parameter simultaneously. The combined different levels of inputs give the final surface by merging the different overlap points as can be seen in Figure 3. First, increase in feed rate increases the cutting forces with no exception when looking at its combination between cutting speed and cutting depth. This can be explained with the influence of the elevated load comes to the cutting tool with higher feed values [21, 22]. Also, higher feed rate values make the cutting tool faster and material removal rate increases [3]. Increase in cutting depth has complex impact on the cutting forces as can be seen in two graphs. At high cutting speeds, high levels of cutting depth can be applied which can be explained by the elevated cutting speed make easier chip formation [23, 24]. A similar situation was stated in the study conducted by Karabulut and Güllü [14]. Also in other scenario, at low cutting speed, cutting the material become harder and with the increase of cutting depth, cutting forces become higher. Such studies and results are available in the literature [25, 26]. For short, it is true that feed rate has a determined effect on cutting forces, but the other two parameters have controversial influences. In practice, it would be better to apply the parameter levels which give the lowest cutting forces.

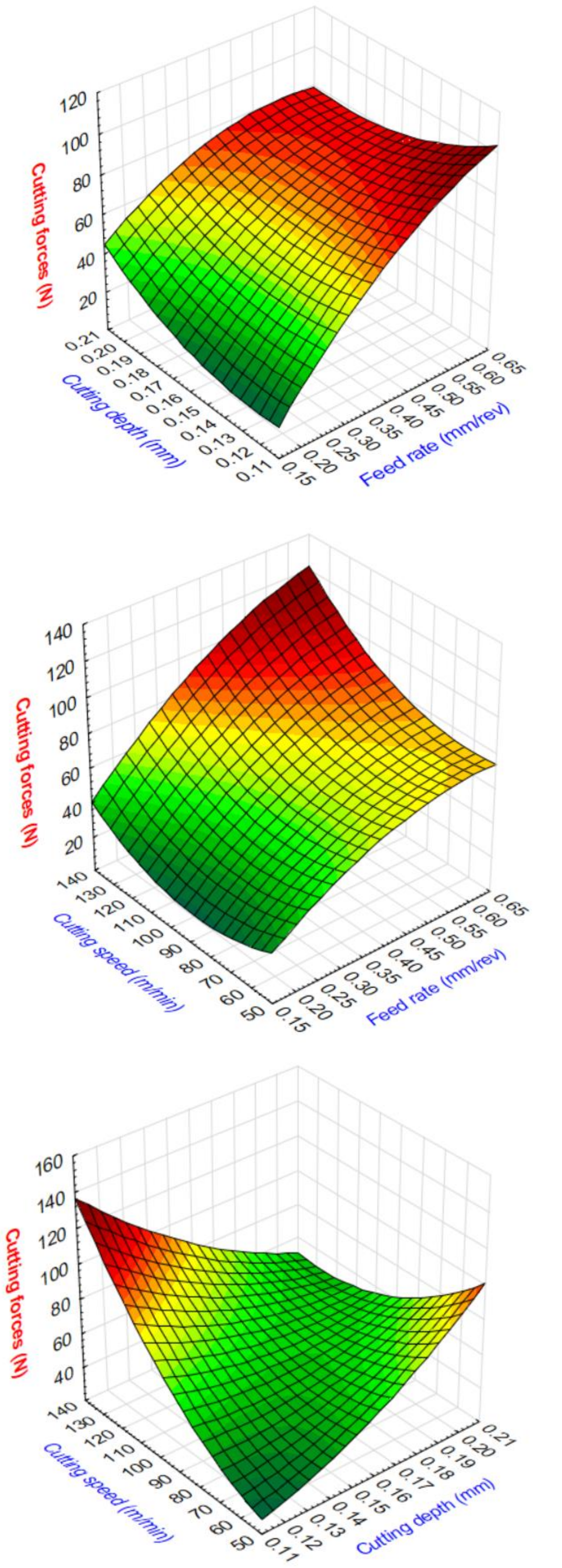

Figure 3. The combinations of turning parameters versus cutting forces

3.2. Optimization

Optimization is one of the important approaches in engineering world since it provides the best options for obtaining the desired results after an experimental work [27, 28]. There are numerous optimization methods which already have been preferred to analyze the machining data such as cutting forces [29, 30]. Since there are many input parameters that belongs to machine tool, cutting tool and work material, achieving the best conditions in any type of operation is a difficult challenge. From this point of view, it is significant to obtain a series of optimum results in terms of basic machining parameters. With this motivation, this study focused on the optimization of turning parameters during machining of cast iron. Two different approaches can be used in this direction i.e. means plot or S/N ratios. Taguchi based plot for means were utilized to reach the optimum parameter combinations as can be seen in Figure 4. Also, Table 5 gives the calculated values of the means. Mean of means plots give the points that placed from minimum to maximum for each level of turning parameters. Accordingly, nominal rate of cutting depth and cutting speed namely 0.16 mm and 80 m/min are the best options for minimum cutting forces. This explains the varying impact of these two parameters in 3d graphs demonstrated before. On the other hand, feed rate seems as the most influential factor on the cutting forces according to the difference between highest and lowest values in the graph. Plus, optimum value of the feed rate is 0.2 mm/rev which is compatible with the graphical results. There are studies in the literature that the feed rate was the most effective parameter on the cutting force [31]. In this case, it can be stated that the study is compatible with the literature.

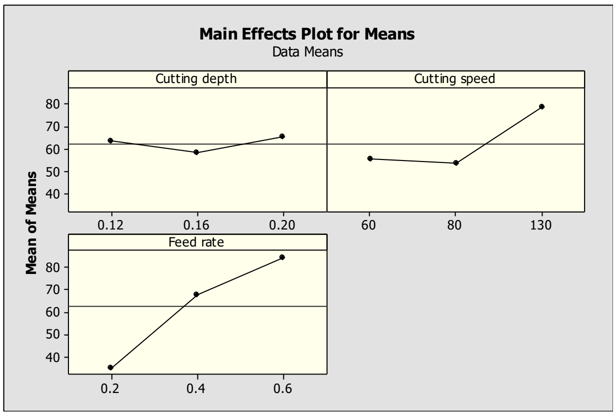

Figure 4. Optimized results of turning parameters for cutting forces

Table 5. Response table for means

Level	Cutting depth	Cutting speed	Feed rate
1	63.67	55.33	35.33
2	58.33	53.67	67.67
3	65.33	78.33	84.33
Delta	7	24.67	49.00
Rank	3	2	1

3.2. Statistical Analysis

Statistical analysis is an effective way to discover the effective parameters and ineffective parameters when looking at their influences on a response parameter [32, 33]. ANOVA is a way that broadly applied especially in machining area [31, 34-36]. That's why in here, it is aimed to use this approach to evaluate the parameter influences on cutting forces. Table 6 gives the results including turning parameters and statistical indicators. Accordingly, feed rate was found as the most effective parameter with the contribution rate about 71.2 % and it was followed by the cutting speed and cutting depth respectively with the contributions about 21.7 % and 1.5 % respectively. Other statistics such as P and F values are compatible with the percent contribution results.

Table 6. Statistical analysis of the turning parameters for cutting forces

Source	DF	Seq SS	Adj MS	F-value	P-value	PC (%)
Cutting depth	2	80.22	40.11	0.27	0.788	1.5
Cutting speed	2	1140.22	570.11	3.83	0.207	21.7
Feed rate	2	3724.22	1862.11	12.52	0.074	71.2
Residual Error	2	297.56	148.78	-	-	5.6
Total	8	5242.22	-	-	-	100

4. CONCLUSION

This study is aimed to make an analysis about the machinability characteristics of GGG50 cast iron considering the cutting forces as the response parameter. From the data analysis performed based on the statistical evaluation, graphical demonstration and optimization approaches, the following deductions can be done.

- According to the 3d graphs, feed rate has a determined effect on cutting forces, but the other two parameters have controversial influences. Increase in feed rate increases the cutting forces with no exception.
- To obtain the minimum cutting forces the parameter group should be as 0.16 mm for cutting depth, 0.2 mm/rev for feed rate, and 80 m/min for cutting speed respectively.
- In the literature, it has been stated that the most effective parameter in the study on temperature for this material is the cutting speed. In this study, feed rate was found as the most effective parameter with the contribution rate about 71.2 % and it was followed by the cutting speed and cutting depth respectively with the contributions about 21.7 % and 1.5 % respectively.
- Researchers who carry out such studies can perform operations such as milling and drilling for this type of material. They can also experiment with minimal quantity of lubrication and different types of cutting fluids, except for dry machining.

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