



## Optimization of Cutting Parameters in Drilling AISI P20 Die Mold Steel with Taguchi and GRA Methods

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### Abstract

AISI P20 mold steels are widely used to manufacture die molding for plastic parts. In this article, AISI P20 steel was drilled by using uncoated HSS twist drills. In drilling process,  $\varnothing 8$  mm drill bit, three cutting speed ( $v$ : 10, 13 and 17 m/min) and three feed rate ( $f$ : 0.1, 0.2 and 0.3 mm/rev), and pecking drilling method were used. Taguchi L9 model was performed to design the drilling tests. Cutting forces and torque were measured by a dynamometer in during the experiments. The surface roughness and diameter of drilled holes were checked. Taguchi and ANOVA analyses were done to determine effects of cutting parameters on the experimental results. Grey Relation Analysis (GRA) was used to optimize results of the tests. The results showed that the feed rate was the main effective factor on test results. Moreover, maximum cutting speed (17 m/min) and minimum feed rate (0.1 mm/rev) were optimum cutting parameters.

## 1. INTRODUCTION

Plastics that are very important materials are widely used in many industries. Generally, plastics materials have good properties such as isolate for thermal and electric, high rate of strength/weight, high resistance for chemical erosion, lower cost for forming. So, many products that are made from plastics materials are used in life for many requirements for example bag sector, airplane industries, medical equipment, and kitchen accessories [1]. The plastic products are mostly manufactured by die molding technics. Moreover, a molding die consists of many parts. Those parts are made from alloy steels that are called mold steels. The mold steels, shown in the Table 1, widely used over the world. In addition, these standardized steels are called impax and holdax steels [2].

**Table 1.** The standardized die mold steels

Queue	AISI	DIN
1	P20+Ni	1.2738
2	P20+S	1.2312
3	P20	1.2311
4	420SS	1.2083
5	420	1.2316

To select an optimum steel for manufacturing a die mold is very important. Hence, to know a few properties of the mold steel are not enough. Many features, such as chemical resistance, ability of hardening surface and machinability, must be taken into attention to select mold steels. Also, dimension of the die and polishability always should not be missed. Moreover, hardening operations for these material are very important. So, deformation problems, such as warping, cracking, can be occurred by the heat treatment processes. To avoid such problems, pre-hardened mold steels are driven into the market. Generally, polishability of the mold steels' surfaces is a significant feature. For specials products such as

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glasses, lenses, need to be polish the surface of molding very well. Polishability prevent sticking molten plastics material on the die surface during injection process [3].

AISI P20 that is a pre-hardened mold steel has an average fabrication hardness of 30-35 HRc. In spite of pre-hardened, AISI P20 steel, chemical composition is shown in Table 2, is good machinability material because of including sulphur. Also weldability of these materials is pretty good. At the end of welding operation, any deformation on surfaces does not emerge [4]. The weldability feature provides a significant gain in terms of mold repair possibilities. And, the welded zone does not affect the polishing [5,6]. In addition, AISI P20 is a preferred steel in some ways –polishability, high toughness and good wear resistance, etc. Physical specification of the steel were given in Table 3. If desired to increase resistance of the surface extra processes, such as nitration etching and coating with nickel and chromium, can be done easily. For these properties reason, AISI P20 is a good material to use of manufacturing plastic dies [7,8].

**Table 2.** Chemical composition of AISI P20 steel

%					
Cr	Mn	Ni	Mo	C	Si
1.90	1.50	0.0	0.20	0.40	0.20

**Table 3.** Physical features of AISI P20 steel

Physical features	Room Temperature (20 <sup>0</sup> )
Elasticity module (kN/mm <sup>2</sup> )	210
Thermal conductivity (W/mK))	34.0
Hardness (HRc)	35

Some studies about AISI P20 steel were done all of the world. When the studies were examined, it was determined that milling surface operations were mainly used. Generally, common problems were investigated in the milling operations for instance wearing of cutting tools, cutting forces, surface roughness, and temperature in cutting region.

Chemical properties of the materials and cutting parameters affect machinability easily or hardly. There are many studies in this direction. Generally, AISI P20, AISI P20+S and SP300 materials were preferred for finish operation in milling processes [7]. These experimental works uncovered that used of cutting parameters for machining the mold steels are very important. The parameters influenced tool life for long or short period. So, optimisation of cutting parameters put forward. Researchers expressed that optimisation reduce costs of machining mold steels to 25-40% [8].

Normally, it is known that wearing of cutting tools affect surface roughness badly. But, many results of an experimental works that hardened AISI P20 mold steels were machined with CBN cutting tools put the exact opposite that situation. One of the using two different CBN cutting tools including low ceramic binder, worn off faster. Moreover, in spite of increasing tool wear, surface roughness did not appear badly [9]. It was put forward that PCBN cutting tools were most suitable cutters for high speed machining (HSM) the AISI P20 mold steels. If PCBN cutting tools is used instead of the coated carbide cutting tools in HSM, the gain will be increased by 30% [10].

Also, hardenability of AISI P20 steels is better than some material. For example, AISI 1040 that widely used for manufacturing mechanic parts. In some publications, it was suggested that AISI P20 is better than AISI 1040 [11,12].

Many devices and methods were handled to measure these results. Optical microscopes and SEM were used to identify wearing of cutting tools. Dynamometers were run to measure cutting forces. Thermocouples were utilized to find out temperature in cutting regions. Various type measurement

devices were driven to gauge roughness of surfaces. Moreover, many methods and techniques were used to evaluate results from the experiments [13,14].

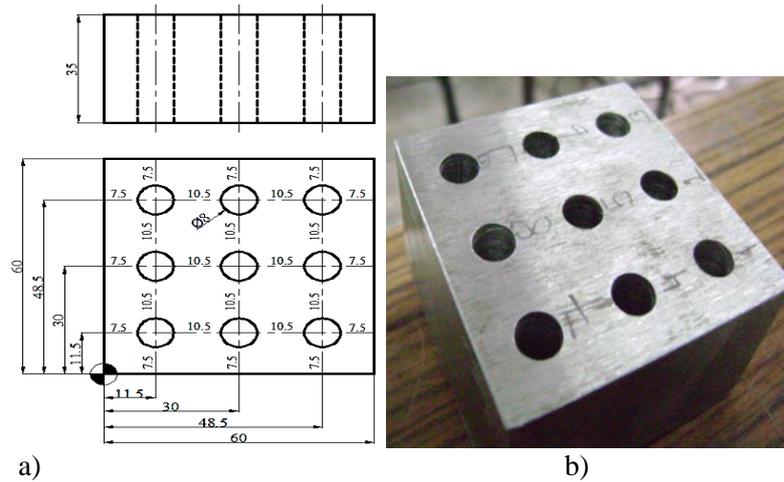
Some findings were investigated with SEM and micro structures data. Many graphs were plotted for many factors, surface roughness, cutting forces, wear of cutting tools, to interpret of relation with machining parameters such as feed rate, cutting speed, cutting tools, material [15,16]. In some studies, results of experimental works were analysed with statistical methods and techniques [17]. Taguchi and ANOVA widely preferred to disclose relation of experimental results with cutting parameters [18,19]. Moreover, FEM methods were applied to solve mechanical problems between cutting tool and machined material.

Examined studies have shown that experimental works on drilling AISI P20 steels are limited. However, drilling is an essential process in the structural frames of an aircraft and contributes to 40 to 60% of the total material removal operations [20,21]. Moreover, drilling is not a simple and easy operation. This process is commonly divided into short hole or deep hole drilling. It is known that depth hole affects quality of drilling process. The flow of the chips out of the hole is not easy for drilling deeper hole. So, two method that are conventional and pecking drilling are widely used for drilling processes. And, selection of drill bits is not very easy. Normally, drill bits are grouped according to ratio of L/D (L: length of hole and D: Diameter of cutting tool) [22]. Because, length of drill bits modify the drilling precision. Also, temperature, drilling forces and torque change the accuracy of the holes. In addition, the cutting parameters directly affects temperature, drilling forces and torques [23]. Having increased torque ( $M_z$ ) and force ( $F_z$ ) causes breaking the drill bits down and rapidly wearing out.

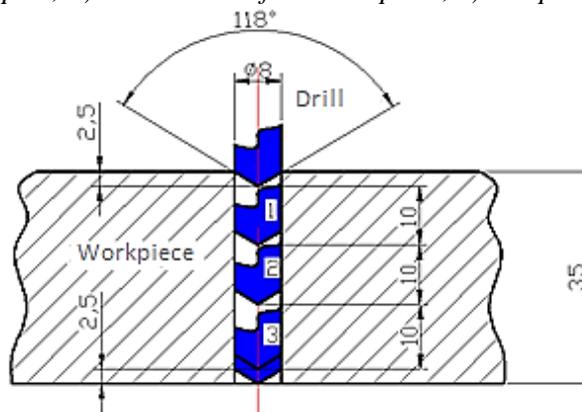
Therefore, it has been decided to drill holes. In this article, we have attempted to determine the cutting parameters that increase quality of the hole in drilling AISI P20 die steels with uncoated HSS twist drills. Hence, Taguchi and Gray relationship analysis (GRA) was performed to determine optimum results for experiments.

## 2. MATERIAL AND METHOD

In this study, drilling tests were performed for AISI P20 mold steel. Many test specimens were prepared for AISI P20 alloy steel by size in 60x60 x35 mm (Figure 1). HSS twist drill bits were preferred as a cutting tool. The drill bits are manufactured according to DIN 338 standard. The cutting tool has Ø8 mm diameter and two-flute, and 30-degree helical and 118-degree tip angle. The holes that are in a 3x3 grid (Figure 1) were drilled on a CNC Milling machine. The holes are thoroughly the part. That is, depth of hole is equal to high of the test part (35mm). The pecking drilling method and dry cutting conditions were used in the tests. In the pecking drilling process, the drill goes the part out at every step and comes back and continues to process. HSS uncoated twist drills, and 3 feed rate and 3 cutting speed were used (Table 4) in the experiments. The  $M_z$  (torque) and  $F_z$  (force) were measured in drilling tests. But,  $M_z$  and  $F_z$  of the beginning and ending of drilling process were excluded for evaluation of the test results. Because, it is considered that countersink of drill bit affects  $F_z$  and  $M_z$ . Approximately, 2.5 mm was determined for countersink of the drill. The remaining (35-5 = 30 mm) size was divided into 3 (3x10) steps for pecking drilling method (Figure 2).



**Figure 1.** Test part; a) Dimensions of the workpiece, b) Samples of drilled holes



**Figure 2.** Pecking drilling method

In the experiments, Kistler 9272 dynamometer and equipment (Figure 3) were used for measurement the  $F_z$  drilling force and  $M_z$  drilling torque. An example (Figure 4) was given for the  $F_z$  and  $M_z$  plots that generated with the dynamometer. In the graphs, separated curves (numbered on the graph) indicate for each step in pecking drilling. In the graph, the top curves show the  $F_z$  values and the other curves indicate the  $M_z$  values. The values in three regions of the graph (marked as 1, 2 and 3) were considered for evaluation of the results.  $F_z$  and  $M_z$  values were calculated by averaging in these three region. Beginning and ending values of the graph were excluded from evaluation test results. These values are countersink of the drill bit. Moreover, after that the drilling processes were finished many measurements were performed on the holes. The holes' diameter ( $Dia$ ) and surface roughness ( $Ra$ ) were checked one by one. The measurement device for surface roughness was set 0.8x5 (cut of length) up range.  $Ra$  (average roughness) value were used to measure surface roughness.

**Table 4.** Conditions of the experimental works

Machine tools	Johnford VMC-550 Fanuc Serial O-M CNC Milling Machine
Cutting tools	Uncoated HSS twist drill bit: $\varnothing$ 8mm, Edge angle $120^\circ$ , Helical angle $30^\circ$ , 2 flute
Material	AISI P20
Cutting parameters	Cutting speed (V): 10 13 17 m/min. Feed rate (f): 0.1 0.2 0.3 mm/rev.

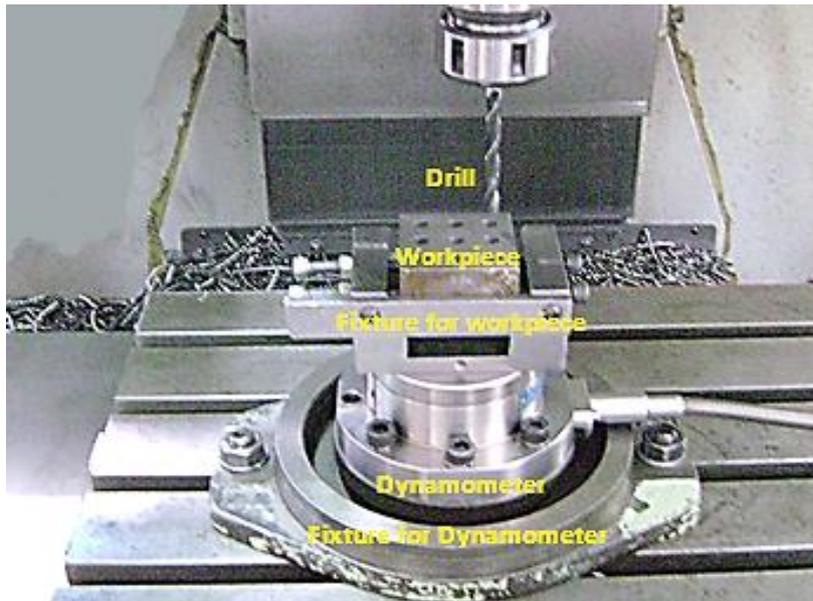


Figure 3. Experimental set-up

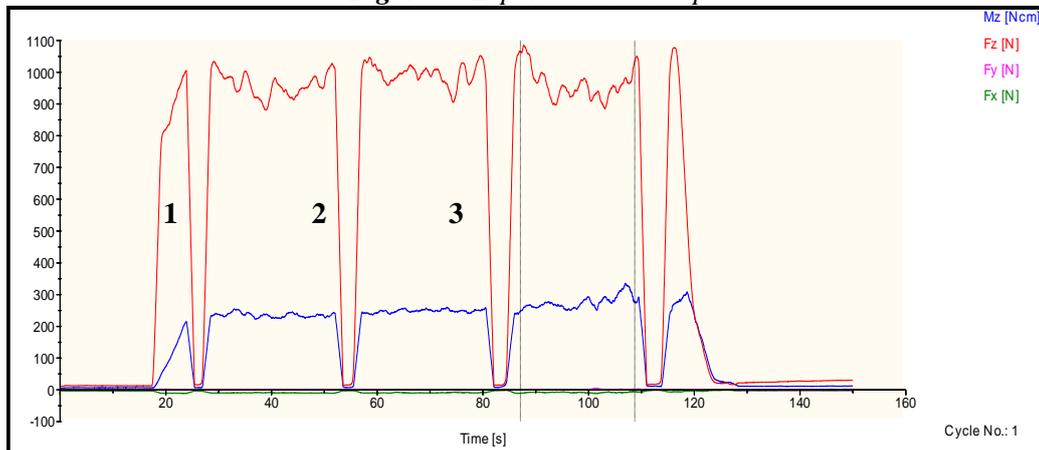


Figure 4. Graph of Cutting forces and Torque measured with the experimental set-up

### 3. OPTIMIZATION

In general, it is more preferable to make statistical analysis rather than to interpret the graphs that are simply generated for the experimental results. Therefore, the Gray Relation Analysis (*GRA*) was used in the evaluation of the experimental results. *GRA* is a statistical method that enables the effects of more than one factor on more than one result [24]. Two test factors (*V*: cutting speed, *F*: feed rate) and four test results (*Mz*: moment, *Fz*: drilling force, *Ra*: surface roughness and *Dia*: hole diameter) were used for *GRA* in this study. *GRA* analysis is a sophisticated method that requires many sub processes. The following operations are performed:

- (1) Calculation of Responses for factors (Responses table),
- (2) Standardized Experimental Results (data pre-processing),
- (3) Calculation of *GRC* (Grey Relation Coefficients),
- (4) Calculation of *GRG* (Grey Relation Grade),
- (5) Optimum Order.

#### 3.1. Calculation of Responses for factors

Taguchi analysis is used for this process. There are three (3) methods for Taguchi analysis. These are *Smaller-the-better*, *Larger-the-better* and *Nominal-the-better*. In this study, "Smaller-the-better" method was preferred in determining the effect levels of experimental factors to evaluate the lowest values for

surface roughness (*Ra*), hole’s diameter variations (*Dia*), drilling moment (*Mz*) and drilling force (*Fz*). The following equation (1) is used for *Smaller-the-better* [25].

$$\eta = -10 \log_{10} \left( \frac{1}{r} \sum_{i=1}^r R_{ij}^2 \right) \tag{1}$$

Generally, a lot of models for experimental design were used in Taguchi method [26,27]. The *L9* model (3\*\*2) was preferred for *Smaller-the-better* in this study. The *L9* model (3\*\*2) include two factors (*V* and *F*), and each of them has 3 levels (listed in Table 5). The Taguchi *L9* model needs to do 9 experiments. Four experimental results (*Mz*, *Fz*, *Ra* and *Dia*) were obtained from each of test. All of the experimental results are shown in Table 6.

**Table 5.** Taguchi *L9* model

Cutting Parameter	Factor	Unit	Level		
			1	2	3
Cutting Speed ( <i>V</i> )	A	(m/min)	10	13	17
Feed rate ( <i>F</i> )	B	(mm/rev)	0.06	0.08	0.1

**Table 6.** Experimental results for Taguchi *L9* model

Taguchi <i>L9</i>		Exp. Parameter		Exp. Result			
A	B	V(m/min)	F(mm/rev)	Mz(Ncm)	Fz(N)	Ra(μm)	Dia(mm)
1	1	10	0.06	252.6	968.0	4.23	8.08
1	2	10	0.08	296.5	1186.8	4.12	8.03
1	3	10	0.1	399.0	1451.2	5.30	8.12
2	1	13	0.06	238.9	955.9	4.13	8.04
2	2	13	0.08	300.0	1075.6	3.90	8.06
2	3	13	0.1	444.5	1397.3	4.25	8.08
3	1	17	0.06	259.5	874.9	4.03	8.02
3	2	17	0.08	283.6	1161.3	4.14	8.10
3	3	17	0.1	345.4	1321.3	4.74	8.04

**3.2. Standardized Experimental Results**

Gray Relationship Coefficients (*GRC*) have to be calculated for *GRA*. But, the experimental results are subjected to pre-processing instead of direct use for the evaluation. This process is also called standardization. The goal is to extract the numerical differences from the units of measurement used for the test results. As a result of the standardization process, the test results are expressed between 0 and 1 [24]. Different equations are used in the process, for example, *Larger-the-better* and *Smaller-the-better*. In this study, it was aimed to determine the optimum experimental results. Therefore, standardization ( $x_i(k)$ ) for the process *Smaller-the-better* equation (Eqn. 2) were used [25]. The values obtained from the calculation are shown in Table 7.

$$x_i(k) = \frac{\max|x_i^0(k)| - x_i^0(k)}{\max|x_i^0(k)| - \min|x_i^0(k)|} \tag{2}$$

**3.3. Calculation of GRC (Gray Relation Coefficients)**

*GRC* must be evaluated for the Gray Relation Analysis. The standardized values for *Ra*, *Dia*, *Mz* and *Fz* were used to calculate *GRC*. Equation 3 is used for gray relation coefficients,  $\epsilon(k)$ .

$$\varepsilon(k) = \frac{\min_j \min_k |x_0(k) - x_j(k)| + \xi \max_j \max_k |x_0(k) - x_j(k)|}{|x_0(k) - x_j(k)| + \xi \max_j \max_k |x_0(k) - x_j(k)|} \tag{3}$$

The value range for  $\xi$  in the equation is  $0 \leq \xi \leq 1$ . In practice 0.5 value is used for  $\xi$  [23,24].

### 3.4. Calculation of GRG (Grey Relation Grade)

Gray Correlation Grades (*GRG*) are necessary to know in determining the most suitable test parameters for optimal test results. *GRG* ( $\gamma_i$ ), is calculated by using the *GRC* values. Equation 4 is used for the calculation process.

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \varepsilon_i(k) \tag{4}$$

Following the *GRG* calculation, the obtained grades are sorted from largest to smallest. The greatest grade indicates the experimental parameters that should be used for optimum test results [27]. The greatest grade are at painted line in Table 7. In other words, the *GRA* solution is this line. The line indicates the 3rd level of the cutting speed factor and the 1st level of the feed rate factor for optimum test results. However, the result is not enough to determine easily optimum test parameter. Evaluation of the results of experiments with Taguchi and ANOVA is also important for *GRA* [24, 30].

**Table 7.** Evaluation *GRA* for Taguchi  $L_9$  experimental design

Exp. Order Exp.	Fact.		Exp. Results				Standardized Exp. Results $x_i(k)$				GRC ( $\varepsilon(k)$ )				GRG ( $\gamma_i$ )	Opt. Order
	A	B	Mz	Fz	Ra	Dia	Mz	Fz	Ra	Dia	Mz	Fz	Ra	Dia		
1	1	1	252.60	968.00	4.23	8.08	0.933	0.838	0.764	0.400	0.882	0.756	0.680	0.455	0.693	3
2	1	2	296.50	1186.80	4.12	8.03	0.720	0.459	0.843	0.900	0.641	0.480	0.761	0.833	0.679	5
3	1	3	399.00	1451.20	5.30	8.12	0.221	0.000	0.000	0.000	0.391	0.333	0.333	0.333	0.348	8
4	2	1	238.90	955.90	4.13	8.04	1.000	0.859	0.836	0.800	1.000	0.781	0.753	0.714	0.812	2
5	2	2	300.00	1075.60	3.90	8.06	0.703	0.652	1.000	0.600	0.627	0.589	1.000	0.556	0.693	4
6	2	3	444.50	1397.30	4.25	8.08	0.000	0.094	0.750	0.400	0.333	0.355	0.667	0.455	0.453	6
7	3	1	259.50	874.90	4.03	8.02	0.900	1.000	0.907	1.000	0.833	1.000	0.843	1.000	0.919	1
8	3	2	283.60	1161.30	4.14	8.10	0.783	0.503	0.829	0.200	0.697	0.502	0.745	0.385	0.582	6
9	3	3	345.40	1321.30	4.74	8.04	0.482	0.225	0.400	0.800	0.491	0.392	0.455	0.714	0.513	7

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

In this section, Taguchi and ANOVA analysis were performed for the test results [28]. *Main effects* of the test parameters on the test results were determined by the Taguchi analysis. *Smaller-the-better* method were applied for the Taguchi  $L_9$  model. Taguchi main effects graphs for three levels of the two factors (*V*, *F*) on the test results (*Mz*, *Fz*, *Ra* and *Dia*) were given in Figure 5. The graphs are shown that each factor’s levels make the test data minimum. The minimum test results are determined at below of the horizontal line in the graphs. The line represents average for factors. Moreover, the response values of the factors obtained by Taguchi analysis on the experimental results were given in Table 8. The order of the factors that most influence the test results are specified *Rank* line in the table.

The slope of the curves in Figure 5 shows effective of factors. For example, the most effective factor on *Mz* is the *F* in figure 5a. However, *V* at the less effective factor is for *Mz*. It is clearly stated the *Rank* values given for *Mz* in table 8 [29]. The most effective first factor for *Mz* is *F* (*Rank*: 1) and the second

factor is *V* (*Rank*: 2). In addition, the effects of the factors on *Fz* are examined (Figure 5.b), it is seen that *F* is the most effective factor. Because, the slope of the graph increase rapidly. This information is proved by the *Rank* values given for *Fz* in Table 8. With respect to *Rank*, the most effective factor for *Fz* is *F* (*Rank*: 1) and *V* is the second factor (*Rank*: 2). And, the graph in Figure 5.c express that the effect of *F* and *V* factors on the *Ra* test results is high. Because there is a rapidly rise in both curves. Which is the most effective factor on *Ra*? The *Rank* values (Table 8) give exactly. The *I* value given in the rank row is the declaration that *F* is the first factor. In the end graph for *Dia* (Figure 5.d), the effects of *F* and *V* are high. *F* is the most effective factor, due to *Rank*: 1 (Table 8).

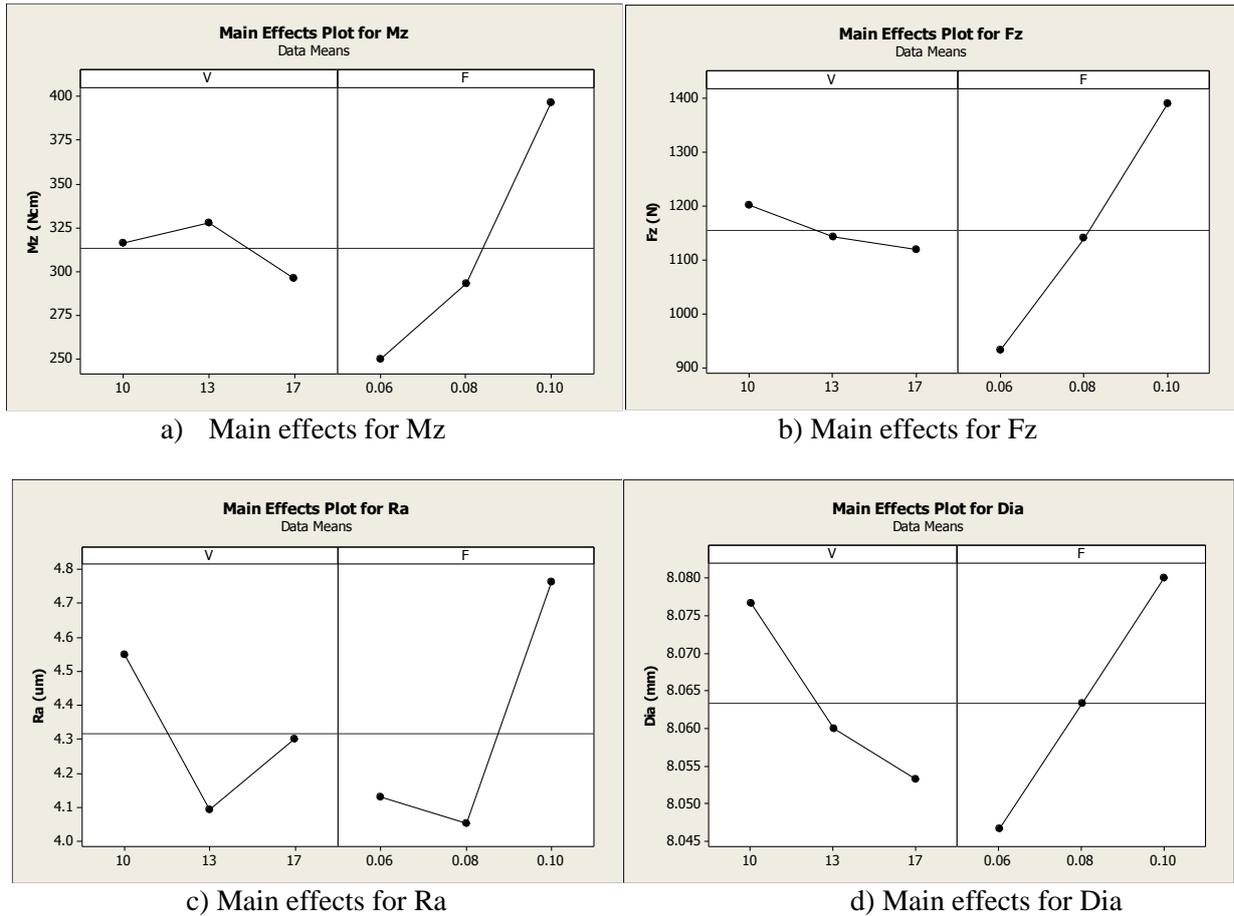


Figure 5. Effects of Factors for experimental results (Taguchi Smaller-the-better method)

Table 8. Response Values of factors for experimental results (Taguchi Smaller-the-better method)

Level	Mz		Fz		Ra		Dia	
	A	B	A	B	A	B	A	B
1	316.0	240.3	1202.0	932.9	4.550	4.130	8.077	8.047
2	327.8	293.4	1142.9	1141.2	4.093	4.053	8.060	8.063
3	296.2	396.3	1119.2	1389.9	4.303	4.763	8.053	8.080
Delta	31.6	146.0	82.8	457	0.457	0.710	0.023	0.033
Rank	2	1	2	1	2	1	2	1

According to Taguchi analysis, it is found that the first factor *F* and the second factor *V* are taken into account when the test results are optimized in the drilling of AISI P20 die steel with Ø8 mm uncoated drill bits by using pecking drilling method with dry cutting conditions. In fact, the most influential factor's levels that will make the test results minimum (*Smaller-the-better*) are indicated in the *Main Effects Plot* graphs (Figures 5 a, b, c, d). Actually, those factors' levels are at below of the average line in the graphs. Accordingly, these factors' levels are *F1* and *V3* for *Mz*, *F1* and *V3* for *Fz*, *F2* and *V2* for *Ra* and *F1* and *V3* for *Dia*. These levels can be expressed like an optimum parameter for the test. However, it

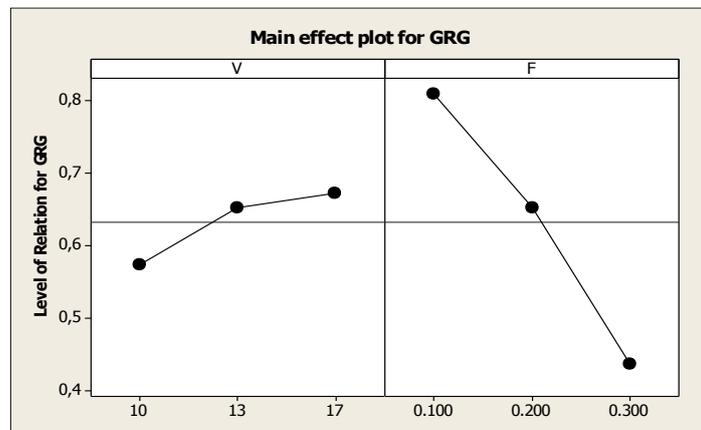
will not be realistic. So, *GRA* analysis is needed to determined exactly optimum levels of the factors [30,31].

In the *GRA* analysis, the optimum parameters are determined by the largest *GRG* values. The largest *GRG* value is 0.919 (in table 7) indicate the optimum levels of factors [32,33]. This line is organized with num. 1 for the *opt. order*. However, this order is defined by the num. 7 for *exp. order*. In other words, the 7th test parameters are optimum parameters. It appears clearly that *B1* and *A3* factors are optimum parameters. Consequently, the *GRA* result indicates that the high cutting speed (*V3*) and the lowest feed rate (*F1*) must be used to optimize the test results.

But, the result should be checked by *Taguchi* analysis to prove the truth of the *GRA* [33,34]. So, *Larger-the-better* method, which makes the *GRG* values the greatest, should be used for *Taguchi* analysis. The *Taguchi* analysis results for the *GRG* are given in Table 9 and Figure 6. The most effective factors for *GRG* are given at row *Rank* in table 9. It is seen that the most effective factors are *F* (*Rank: 1*) and *V* (*Rank: 2*). Also, Figure 6 shows that each level of the *V* and *F* factors influences on the *GRG*. The largest *GRG* results show that the first level of factor *F* (*F1*) and the third level of *V* (*V3*) should be considered. Optimal factors' levels suggested by the applied *GRA* method are also appropriate in terms of *Taguchi* analysis.

**Table 9.** Analysis of *Taguchi* for *GRG* (*Taguchi Larger-the-better method*)

Level	A	B
1	0.5733	0.8080
2	0.6525	0.6513
3	0.6714	0.4378
Delta	0.0981	0.3703
Rank	2	1



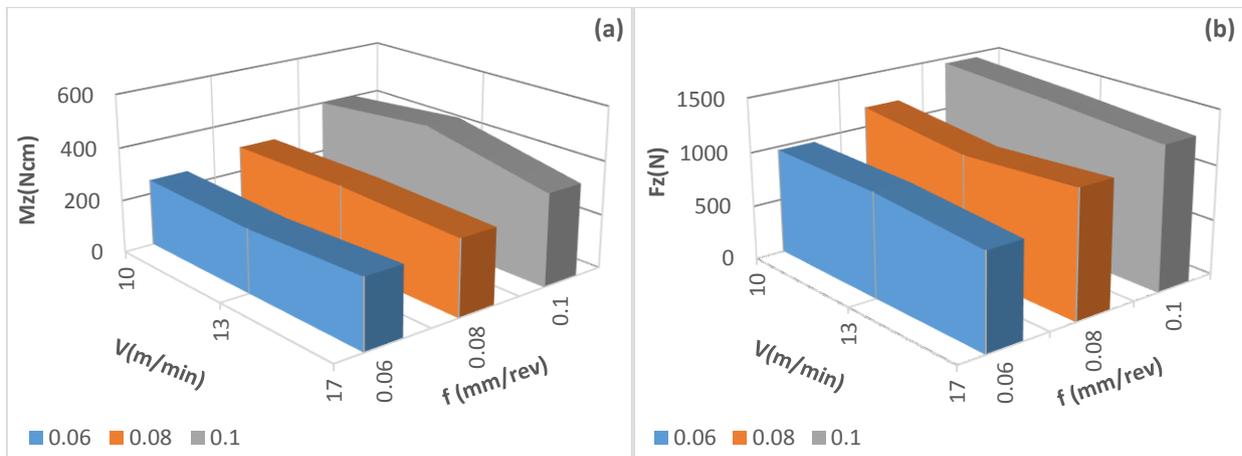
**Figure 6.** Graph of *GRG* (*Taguchi Larger-the-better method*)

After that optimum parameters are determined by *GRA*, contribution of test parameters to the experimental results should be evaluated. In this way, the accuracy of determining the optimum parameters will be supported [25,29]. *ANOVA* statistical evaluation method can be used for contribution (%) of factors on test results. So, this method was performed on *GRG* values obtained during *GRA* analysis. The *ANAVO* results for *GRG* levels are given in Table 10. In the chart, the % contribution of the *V* and *F* factors (*Source* column of the Table 10) to the results was given by the letter *P*. When the letter *P* values are examined, it is seen that the contribution of factor *A* is 6.5% and the contribution of factor *B* is 81.5%. It is found that the contribution of the *B* factor to the *Mz*, *Fz*, *Ra* and *Dia* test results is 81.5%. It is higher than *B*. In other words, *F* is the most effective parameter on the test results. So, *F* should be taken into account in order to optimize the test results [33, 34].

**Table 10.** ANOVA results for GRG

Source	DF	Sum of Sq	Mean Sq	F	P	%
A (V:m/min)	2	0.016272	0.0081436	1.06	0.426	6.5
B (F:mm/rev)	2	0.207238	0.103619	13.55	0.017	81.5
Error	4	0.030594	0.007648			12
Total	8	0.254104				100

In other hand, the drilling tests were performed without any problem occurred. Experimental works were done normally. In the experiments, force and moment didn't increase suddenly. The torque and force graphs (Figure 7) describe clearly that. Moreover, No problems were found by HSS drill bits. Problems such as broken drill, worn drill, etc. did not come into play. The drill bit picture (Figure 8) shows easily that. Hence, it can be said that drillability of AISI P20 material is generally easy with HSS drill bits in the experiments.

**Figure 7.** Graphs of the test results: a)  $M_z$  b)  $F_z$ **Figure 8.** A drill bit was used in the tests

## 5. CONCLUSION

In this article, the optimum drilling parameters were determined in the drilling of AISI P20 die steel with uncoated HSS drills by using pecking drilling method. The Taguchi analyses showed that the feed rate was more effective on  $M_z$ ,  $F_z$ ,  $R_a$  and  $Dia$  than cutting speed. In other word, the torque, the drilling force, the surface roughness and the diameter hole ( $Dia$ ) values also increased rapidly by going the  $F$  value up. However, the effect of  $V$  value on the test results is generally less. The values of  $M_z$ ,  $F_z$ ,  $R_a$  and  $Dia$  didn't climb suddenly by stepping of  $V$  value up.

The *GRA* method suggests that the optimum parameters are  $V3$  and  $F1$ . The *GRA* method stated that  $F$ : 0.1 mm/rev and  $V$ : 17 m/min should be used to optimize test results. In other words, if the minimum

torque and drilling force, and the best surface roughness and the minimum diameter change are required in drilling processes, the lowest feed rate and the highest cutting speed must be used.

Evaluation by *ANOVA* analysis of the *GRA* results, was not encountered any unconformity. Moreover, experimental works showed that drillability of AISI P20 material with HSS drill bits is generally easy.

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## CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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