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Research Article

REGRESSION MODELING OF THE HOLE QUALITIES DURING COLD WORK TOOL STEELS DRILLING, WITH DIFFERENT CHARACTERISTICS DRILL BITS

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ABSTRACT In this study, drill operations have been tested on Sleipner cold work tool steel by various machining parameters and drill bits. Solid Carbide Uncoated drill bits and TiAlN Coated reamed drill bits were used in experiments. Both drill bits were machined on Sleipner steel with four different cutting speeds. After machining, thrust forces and moments values generated during cutting, consisting surface and the hole qualities have been measured. Drilled by reamed drill bit's hole gave better results quality as a result of the studies. It was reached as conclusion that the optimum values parameters of the cutting speeds are between 40 to 42 m/min for both the drill bits.

Keywords: *Machinability, Drilling cutting forces, Surface roughness, cold work tool steel*

1. INTRODUCTION

As a result of further customization of industrial manufacturing types, special alloy steels are now being used more frequently. The use of alloyed steels has increased, leading to much more successful results than conventional steel. Tool steels are more valuable than standard steels because they are specially produced and produced according to the work type. In order to use these steels in the most efficient way, the manufacturing steel processing parameters in general quality need to be updated to the level of qualified tool steel. That's why it's so important to choose the right steel for the job, as well as having knowledge of how to machining it. Sleipner from cold work tool steel grades are commonly used as sheet forming molds in places where wear is observed (www.uddeholm.com). This steel is also used in industry for sheet metal forming where generally in sheet metal cutting and tearing applications up to 3 mm in high-durability materials requiring low maintenance, in cuts of hard and thin sheets (such as lamination molds), and in iron and steel plants. It is used in places where high abrasion resistance is required, high toughness, high compression strength, good tempering resistance and compatibility with surface treatment

At the same time, that alloy is suitable for surface coating techniques like nitruration, Tin and CrN coated by PVD. As well as it can be used in plastic molds, hard and additive plastics and injection molds which are expected to have very high molding life (www.uddeholm.com). Material shaping technique is as important as material selection. Achieving the desired quality at the lowest time and costs is one of the factors affecting the productivity of the work. Material shaping is often encountered in the form of holes.

Though drilling can be achieved in many different ways in manufacturing technology, drilling is the most popular method in machining, which is the conventional machining method. This method gradually renews itself in the fields of material, coating and tool geometry technology. Technological advances in providing tool components usually focuses increasing the surface processing speed and precession on the correction quality.

When the studies done in the literature are examined; Ohzeki et al. (Ohzeki, Hoshi et al. 2012) predicted that the shear forces generated during drilling on the carbon fiber reinforced plastic composite are related to delamination during drilling. They have developed a machining system that changes the cutting forces which vary with the predetermined feedrate according to the axial shear force values obtained by the piezoelectric dynamometer. The performance of the developed system has been confirmed by test running.

In addition, the drilling tests were carried out by considering the possibility of drilling errors in the CFRP composites with cutting force feedback. No significant deformation has been observed in the tests made by taking feedback under specific conditions. Tash et al. (Tash, Samuel et al. 2012) have studied the machining and computation of force and moment which result from the machinability of 356 and 319 aluminum alloys subjected to heat treatment. As a result of the experiments, a long tool life was obtained at the processing of low Mg-content 319 alloys (0,1%). Salimi et al. (Salimi, Abbasgholizadeh et al. 2011), used artificial neural networks to study the abrasions that occurred on the drill during drilling. They reported that the results of the experimental studies and artificial neural network models were very similar. Farid et al. (Farid, Sharif et al. 2011) examined chip morphology for high-speed drilling of Al-Si alloys. They observed that cutting parameters were a major influence on chip morphology. Zitoune and et al. (Zitoune, Krishnaraj et al. 2012) examined the performance of a nano-plated drill on carbon fiber reinforced plastic / aluminum sandwiches.

As a result of the experiments, it is seen that the progression rate is a significant influence on the formation of the chip size and pattern. They found that the axial cutting forces on the composite plate were less than 10-15% of that of the uncoated drill and about 50% on the aluminum.

When examining both drills, it has been found that the nano-plated drills are considerably successful in terms of surface roughness and axial forces. Çiçek and kıvak al. (Çiçek, Kıvak et al. 2012) studied the performance of cryonically machined M35 HSS drills on austenitic stainless steels. The machined exposed cutting tool shows better results in terms of axial forces, surface roughness, tool life and wear at 304 and 316 stainless steel at different cutting and feed speeds compared to the non-machined insert.

As a result of the tests it was understood that it is more difficult to process 304 stainless steel to 316 stainless steel. İsbilir and Ghassemieh (Isbilir and Ghassemieh 2012) have worked on the analysis of carbon fiber reinforced composite drilling by the finite element method. In the study, the experimental results were modeled with 3D finite element and the results were compared.

Our study has been carried out on Sleipner cold work tool steel by a new product a self-reamed TiAlN coated carbide drill and uncoated carbide drill. End of the experiments, the cutting forces, surface roughness, dimensional accuracy and deviation from circularity obtained and the results were investigated.

2. EXPERIMENTAL

2.1 Material and Method

The chemical composition of the cold work tool steel Sleipner alloy used in the experimental work is given in Table 1.

The Sleipner steel industry has been chosen for its multi-purpose use, which is often used in metal sheet forming and construction such as long-life plastic injection molds. The materials used in the work are cut by sawing in the dimensions given in Fig. 1 and then the surface is machined in the CNC vertical machining to ensure surface cleanliness and parallelism. Pre-drilling is not carried out before drilling in CNC vertical machining.

Table 1. Chemical composition of Sleipner cold work tool steel (Özkul 2012)

C	Mn	Cr	Mo	V
0,90	0,5	7,8	2,5	0,5

Sleipner cold work tool steel delivery is 235 HB. Physical properties of the product are shown in Table 2.

Table 2. Sleipner cold work tool steel physical properties (www.uddeholm.com)

Temperature °C	20	200	400
Density (g/cm^3)	7,73	7,68	7,60
Thermal Expansion Coefficient	-	11,6*10^{-6}	12,4*10^{-6}
Thermal conductivity (W/M˚C)	-	20	25
Modulus of Elasticity (MPa)	205000	190000	180000
Specific Heat (j/Kg ˚C)	460	-	-

The test specimens are shown in Figure 1 prepared in dimensions of 24x60x240mm.

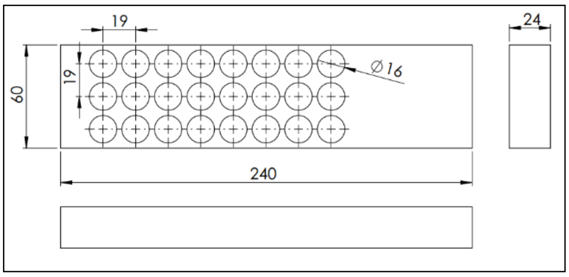

Fig. 1. Test sample (Özkul 2012)

Fig. 2 shows the workpiece and the holes through which the dynamometer is mounted.

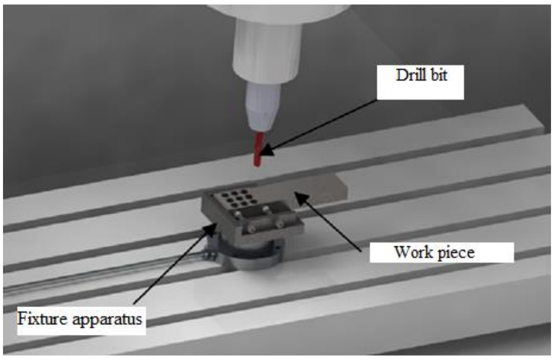

Fig. 2. Fixture apparatus

Two different types of carbide drills with a diameter of 16 mm were used in the holes to be made by vertical machining in the CNC machine. The forms of the self-tapping carbide drill and the carbide drill as tool geometries are shown in Fig. 3.

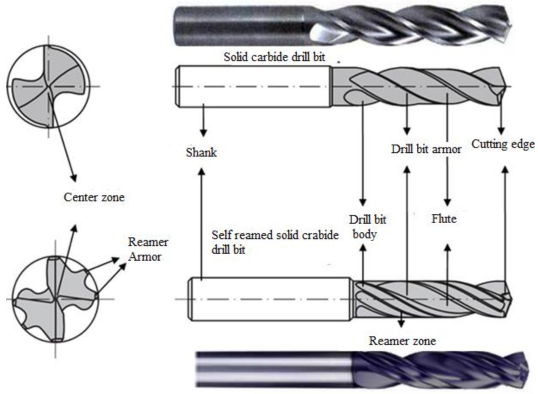

Fig. 3. Tool geometry of carbide drills (Özkul 2012)

The tool has an end angle (Ψ) of 140° and a helix angle (γ) of 30°. Coating of self-encrusted carbide drill is TiAlN (Titanium Aluminium nitrile) and the other carbide drill is uncoated.

2. Drilling Operations

Vertical machining experiments were carried out at the Johnford VMC-550 CNC vertical machining centre. The technical characteristics of vertical processing are given in Table 3.

Table 3. Technical specifications of the vertical machining centre used in the experiments

Power	5,5 kW
Max. rpm	8000 rpm
x, y, z axis length	600, 500, 600 mm
Precession	0,001 mm
Operating system	Fanuc

The cutting parameters used for both cutting tools are given in Table 4 below. Cooling fluid was used during drilling.

Table 4. Cutting parameters used in experiments

Feed rate (mm/rpm)	Cutting speed (m/min)
0,16	36-40-44-48

Experiments were carried out at 4 different cutting speeds. The applied cutting speed parameters are 3 holes processed on the sample with the same cutting tool. The mean values of the data generated during the machining and the surface are used in the graphs. The thrust forces and moment values generated during the cutting process are measured with a dynamometer. In the experiment, quantities of deviation and circularity of the hole geometry were determined by the coordinate measuring machine CMM (Coordinate Measuring Machine) on the holes and surfaces formed after the machining operation was finished. The roughness amounts of the holes formed on the surface of the hole are measured by the surface roughness device, the measured parameters are given in Table 5 below.

Table 5. Cutting parameters used in experiments (Özkul 2012)

Experiment Code	Feed rate (mm/rpm)	Cutting speed (m/min)	Thrust force (N)	Moment (Ncm)	Diameter Deviation (mm)	Circularity Deviation (mm)	Average Surface Roughness (µm)
RM-1-1	0,16	36	2641	1720	0,008	0,044	1,315
RM-1-2		36	2734	2120	0,003	0,034	1,264
RM-1-3		36	2874	2175	0,01	0,045	0,957
RM-2-1		40	2537	1646	0,009	0,009	1,11
RM-2-2		40	2518	1722	0,011	0,045	1,003
RM-2-3		40	2531	1814	0,007	0,012	1,271
RM-3-1		44	2519	1622	0,022	0,022	0,923
RM-3-2		44	2517	1702	0,017	0,008	0,674
RM-3-3		44	2537	1777	0,021	0,002	1,023
RM-4-1		48	2517	1648	0,021	0,009	0,836
RM-4-2		48	2521	1657	0,021	0,011	0,785
RM-4-3		48	2486	1669	0,024	0,004	0,815
KM-1-1	0,16	36	3775	2121	0,006	0,095	2,771
KM-1-2		36	3978	1856	0,003	0,021	0,948
KM-1-3		36	3861	1651	0,008	0,012	1,555
KM-2-1		40	3830	1797	0,007	0,022	2,621
KM-2-2		40	3685	1754	0,004	0,012	0,886
KM-2-3		40	3866	1650	0,007	0,021	1,629
KM-3-1		44	3950	1745	0,01	0,025	2,735
KM-3-2		44	3607	1658	0,008	0,012	0,995
KM-3-3		44	3301	1735	0,014	0,013	1,327
KM-4-1		48	3598	1718	0,015	0,014	1,482
KM-4-2		48	3441	1695	0,018	0,009	1,681
KM-4-3		48	3685	1689	0,009	0,016	1,697

RM : Self-reamed TiAlN Coated drill bit
KM : Uncoated carbide drill bit

3. EXPERIMENTAL AND STATISTICAL ANALYSIS RESULTS AND DISCUSSION

3.1. Experiment and Statistical Analysis

The parameters of different cutting speeds used in the experiments have been determined the thrust force, moment, surface roughness, deviation and deviation from the circularity on the specimens of the different types of drills. The data were analysed by ANOVA (analysis of variance / variance analysis) and different methods using MS Excel software. The values used in the works are the average of the values of the same 3 holes processed with the same parameters in Table 5. Estimated values are shown in the graphs, depending on the data obtained from the experiments performed and the statistical predicted values and the 10% increase in the independent variables in the 3 levels not used in the experiments. The values used are as dummy model, with self-reamed drill bit dedicated as "1" and carbide drill bit dedicated as"0" value. The obtained regression equations are valid for the values for which the cutting speed is not "0" value.

3.2. Analysis of Thrust Force

The model summary of the thrust force with the values obtained as the results of the experiments is given in the ANOVA analysis, Table 6 and Table 7.

R^2, the number of determinants of the model, represents the rate of the independent variable, cutting rate, and the relation of the drill type to the dependent variables. The R^2 value of 0,993 indicates that the percentage of the association is around 99,3%. This value is very close to 100 percent, indicating how the bond is strong structure.

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Table 6. Thrust force model

Regression Statistics	
Multi R	0,997
R^2	0,993
arranged R^2	0,990
Standard Error	61,198
Observation	8

Table 7. ANOVA table for thrust force

ANOVA					
	SD	*KT*	*KO*	*F*	*significance F*
Regression	2	2666348	1333174	356	0,000
Difference	5	18726	3745		
Total	7	2685074			

	coefficients	*Standard Error*	*t Stat*	*P-value*
Intersection	4656	205,49	22,66	0,00
Drill type *(Mt)*	-1137	43,27	-26,28	0,00
Cutting rate *(Vc)*	-22	4,84	-4,63	0,01

When the significance coefficient of ANOVA output is less than 0,000 in 0,05, regression models are evaluated as significant. The linear regression equations for the thrust force (Cf) of the system are given in Eq (1).

$$Cf = 4656 - 1137Mt - 22Vc \quad (1)$$

Fig. 4 shows the predicted values of the thrust force and the different regression models of the cutting rate parameters, which are not experimentally realized but are increased by 10%.

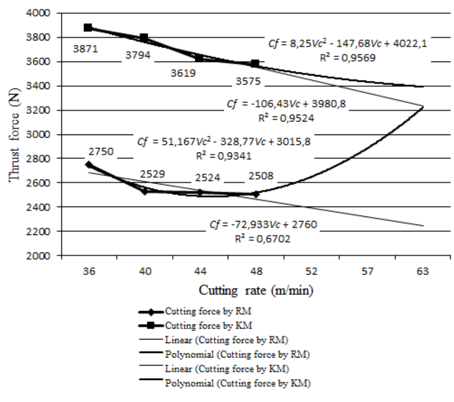

Fig. 4. Thrust force value change graph against increasing untested test parameters at 10%

As seen in Fig. 4, in the RM drill, less force is observed at increasing cutting speeds than in the MM drill. Although there is no about 0,1% force difference between 40 m / min and 44 m / min in the RM drill, the increase in the KM drill at the same cutting speed values is around 1,04%.

When the R^2 values are examined, it is seen that only the value of the self-taught drill has a value of 67,02% in the linear regression, while the others show very successful results.

Table 8. Moment values model

Regression Statistics	
Multi R	0,833
R^2	0,694
Arranged R^2	0,571
Standard Error	76,219
Observation	8

The R^2 value of the resulting model was 0,694 (69,4%). The resulting value does not seem very strong.

Table 10. ANOVA table for moment values

ANOVA					
	SD	*KT*	*KO*	*F*	*Significance F*
Regression	2	65778,0	32889,0	5,7	0,052
Difference	5	29046,9	5809,4		
Total	7	94824,9			

	Coefficents	*Standard errors*	*t Stat*	*P-values*
Intersection	2603,6	255,9	10,2	0,000
Drill type *(Mt)*	16,9	53,9	0,3	0,766
Cutting rate *(Vc)*	-20,2	6,0	-3,4	0,020

Since the significance coefficient of ANOVA output is too small at 0,05 than 0,05, the regression models are meaningless. The linear regression equations for the system's moment value (Mo) are given in Eq (2).

$$Mo = 2603{,}6 - 16{,}9Mt - 20{,}2Vc \qquad (2)$$

Fig. 5 shows the predicted values of the torque values with different regression models and the torque values increased by 10%, which is not carried out as an experiment.

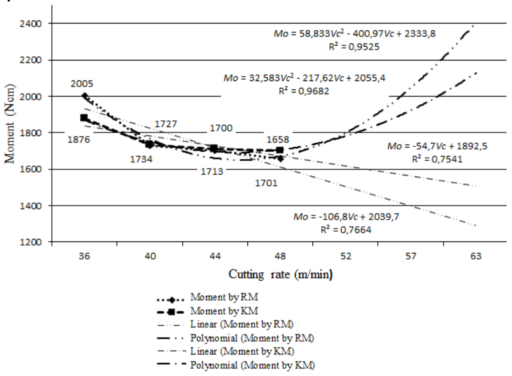

Fig. 5. Moment value change graph against increasing untested test parameters at 10%

In Fig. 5, there is a difference of less than 1% on average at speeds of 40-44-48 m / min. However, in the test results at a cutting speed of 36 m / min, a difference of about 6% between the drills can be explained as the RM drill has exposed the reamer's armor to the extra surface. Table 11 contains the R^2 values and equations that occur in Fig. 5.

When the R^2's are examined, interpreting the polynomial regression estimates is more successful because the linear regression values of the self-aligning drill and the uncoated carbide drill are lower than the polynomial values.

3.4. Analysis of surface quality

The model summarized using the obtained average surface roughness values is given in ANOVA analysis, Table 10 and Table 11.

Table 10. Average surface roughness model

Regression Statistics	
Multi R	0,986
R^2	0,973
Arranged R^2	0,962
Standard error	0,076
Observation	8

Since the value of R2 of the resulting model is 0,973 and 97,3%, it is very strong.

Table 11. ANOVA table for average surface roughness values

ANOVA					
	SD	*KT*	*KO*	*F*	*Significance F*
Regression	2	1,049	0,525	90,155	0,000
Differences	5	0,029	0,006		
Total	7	1,078			

	Coefficents	*Standard errors*	*t Stat*	*P-values*
Intersections	2,636	0,256	10,293	0,000
Drill type *(Mt)*	-0,696	0,054	-12,902	0,000
Cutting rate *(Vc)*	-0,022	0,006	-3,721	0,014

The regression models are significant because the significance coefficient in the ANOVA output is less than 0,05 in 0,05. The linear regression equations for the surface roughness values (Yp) of the system are given in Equation 3.

$$Yp = 2{,}636 - 0{,}696Mt - 0{,}022Vc \quad (3)$$

Fig. 6 shows the predicted values of different regression models and average surface roughness values of the cut-off speed parameters, which are increased by 10%, which are not carried out as experiments.

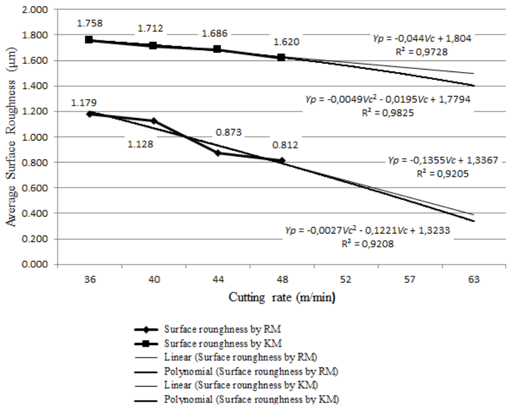

Fig. 6. Average surface roughness value change graph against increasing untested test parameters at 10%

In figure 6, the value obtained by the RM drill at a cutting speed of 48 m / min produced a smoother surface than the other cutting speeds. The improvement from 48 m / min to 44 m / min in the RM drill is about 7%. However, at a cutting speed of 48 m / min, less smoothness was obtained with a value of about 4% compared to the speed of 44 m / min in the PM drill. Compared to the best values of the two cutting tools, it is observed that the RM drill has a clearly better surface. This difference can be considered as beneficial to the reamer armor and its coating that the RM drill is different from the MM drill. When the R^2's were examined, it was observed that the obtained values were quite good but in general polynomial values were more successful.

3.5. Diameter Deviation Analysis

The model summarized using the obtained deviation values is given in ANOVA, Table 12 and Table 13.

Table 12. Diameter Deviation model

Regression Statistics	
Multi R	0,931
R^2	0,866
Arranged R^2	0,813
Standard error	0,003
Observation	8

Table 13. ANOVA table for dimension deviation

ANOVA					
	SD	*KT*	*KO*	*F*	*Significance F*
Regression	2	0,000	0,000	16,190	0,007
Difference	5	0,000	0,000		
Total	7	0,000			

	Coefficients	*Standard error*	*t Stat*	*P-values*
Intersection	-0,036	0,009	-3,909	0,011
Drill type (Mt)	0,005	0,002	2,801	0,038
Cutting rate*(Vc)*	0,001	0,000	4,953	0,004

Since the value of R^2 of the resulting model is 86,6%, the value appears strong.

The regression models are significant because the significance coefficient of ANOVA outputs is less than 0,07. The linear regression equations for the system deviation (EQ) are given in Eq. (4).

$$Çs = -0{,}036 + 0{,}005Mt + 0{,}001Vc \quad (4)$$

Fig. 7 shows the predicted values of the cut-off speed parameters, which are not realized in the experiment but increased depending on the 10% increase, with different regression models.

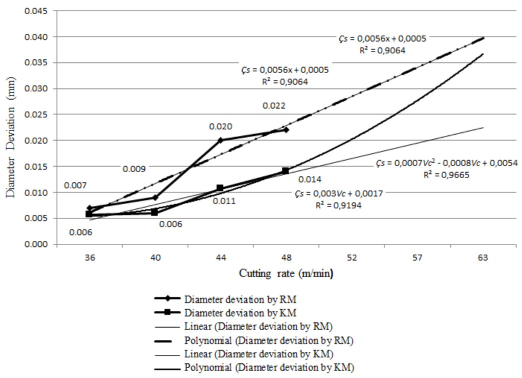

Fig. 7. Diameter dimension value change graph against increasing untested test parameters at 10%

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In product processing, reaching the finished product and performing the operation within acceptable geometric tolerance while performing this operation is the biggest goal of the manufacturer. At this point, job efficiency will be increased, and unwanted expenses and losses will be avoided. This is why it is necessary to determine the quality of the work and to investigate and use the possibilities to save time. When the values in the graphs in Figure 7 are examined, it is seen that the deviation values decrease with decreasing cutting speed in general. Although there is no significant difference between the drill bit graphs of 36 and 40 m/min in both drill graphs, there is an increase of about 222% in the RM drill at the speed of 44 m / min and about 83% at the drill bit. The cutting speed of 36 m / min was determined as the speed at which extreme deviations occurred in both drills. When R^2 were examined, linear and polynomial regression values for RM drill values were found to be the same. It was observed that the linear regression gave a more positive result for the KM mathematics than the obtained results.

Table 15. ANOVA table of Deviation from Circularity

ANOVA					
	SD	*KT*	*KO*	*F*	*Significance F*
Regression	2	0,001	0,001	11,939	0,012
Difference	5	0,000	0,000		
Total	7	0,001			

	Coefficients	*Standard error*	*t Stat*	*P-value*
Intersection	0,128	0,022	5,841	0,002
Drill type(Mt)	-0,002	0,005	-0,487	0,647
Cutting rate (Vc)	-0,003	0,001	-4,862	0,005

The regression models are meaningful because the significance coefficient of ANOVA outputs is less than 0,05 as 0,012. The linear regression equations for the system deviation (Ds) are given in Eq. (5).

$$Ds = 0,128 - 0,002Mt - 0,003Vc \quad (5)$$

Fig. 8 shows the predicted values of the various regression models and deviation from the circularity of the cut-off speed parameters, which are increased by 10%, which are not performed as experiments.

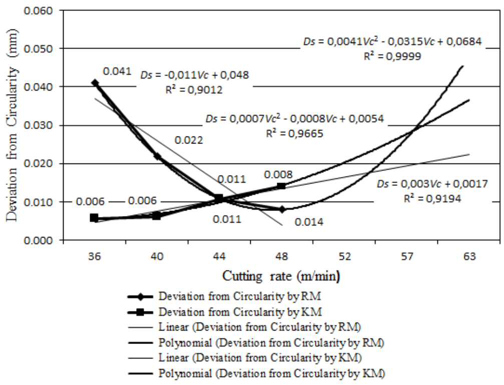

Fig. 8. Deviation from circularity value change graph against increasing untested test parameters at 10%

3.6. Deviation from Circularity

The model summarized using the deviation values obtained from the obtained circularity is given in ANOVA analysis, Table 14 and Table 15.

Table 14. Deviation from Circularity model

Regression Statistics	
Multi R	0,909
R^2	0,827
Arranged R^2	0,758
Standard error	0,007
Observation	8

The resulting value is strong due to the fact that the R^2 value of the resulting model is 82,7%.

When checking the graphs in Figure 8, it is clear that, in general, there is no significant change in the PM drill at 40-44 m/min of deviation from the circularity, but there is more change in the RM drill at the same speed. The cutting speed of 36 m/min was found to be the least ideal of the values applied in both drills, so that the deviations from the drill were small. When R^2 was examined, it was found that the polynomial regression values were better than linear values, and the 99,99% value obtained for RM drill shows that there is a correlation between them.

4. CONCLUSION

The results obtained in the light of the values obtained by removing the chips by drilling with different quality cutters on the cold work tool steel are summarized below.

- The force and torques generated during cutting on the Sleipner cold work tool steel are seen in the moment diagram of the RM drill, which cuts more easily than the KM drill. However, RM is forced to cut at low cutting speed because the reamer armor forced to cut for RM drill.
- A difference of about 93% was observed in the surface roughness of the RM drill at a speed of 44 m / min compared to the KM drill bit. The reamer armor on this side showed its quality in this work. If sensitivity is

required on the desired surface, the RM drill is better in terms of machining time because it makes two operations together.

- In the deviation tolerance values of the dimension, it is seen that at low cutting speed, RM drill has very similar values like 15% with KM drill. The KM drill bit that the dimension deviations performance was better, while at cutting speed of 44 m/min of the RM drill, the KM matched the positive result with a difference of 54%.
- Even though the self-reamed drill bit is costlier than the other drill, it is more suitable than the uncoated carbide drill bit with the surface quality and the amount of time it is saved and the amount of workmanship.

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