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Research Article

Effect of Cutting Parameter on Material Removal Rate and Surface Roughness in Deep Drilling Process

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ABSTRACT

In the curents study aimed to assess the effects of cutting conditions (spindle speed, feed rate, tool diameter) parameters as input impact on material removal rate (MRR) and surface roughness (Ra) as output of steel (AISI 1015). A number of drilling experiments were conducted using the L9 orthogonal array on conventional drilling machine with use feed rate (0.038,0.076,0.203) mm/rev and spindle speed (132,550,930) rpm and tool diameter (11,15,20) mm HSS twist drills under dry cutting conditions. Analysis of variance (ANOVA) was employed to determine the most significant control factors affecting on surface roughness and MRR. The result shown the tool diameter the important factor effect with (64.08%) and (76.12%) on MRR and surface roughness respectively.

Keywords: Taguchi, ANOVA, surface roughness, MRR, Tool diameter.

1. Introduction

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. Drilling operation is widely used in the aerospace, aircraft and automotive industries, although modern metal cutting methods have improved in the manufacturing industries, but conventional drilling still remains one of the most common machining.

YogendraTyagi. et.al. (2012) [1] states the impact process parameters- Spindle speed, Feed rate and Depth of cut on Surface Roughness and Material Removal Rate for CNC drilling machine operation by using the high speed steel Tool and by applying the Taguchi methodology. It was observed that, as spindle speed increases, there is an increase in the material removal rate(MRR) and the surface roughness initially decreases with increase in spindle speed while after some process there is an increase in surface roughness. As there is an increase in the feed rate, lead to a decrease in both the MRR and the surface roughness. The result shown spindle speed is large effect parameter on surface roughness and MRR.

A. Navanth and T. Karthikeya Sharma (2013)[2]use basis of Taguchi's L18 orthogonal array of experiments. The important input drilling parameters were chosen as tool diameter spindle sp eed, point angle and feed rate and the responses namely. In order to minimize the values of all the above mentioned performance characteristics, an optimal combination of input drilling parameters is required. The Taguchi optimization technique is used for the optimization of drilling parameters; ANOVA is used to find the highly influential drilling parameter(s) that contributes to a high quality product. The result shown tool diameter is a large effect parameter (58.1% and 69.81%) on surface roughness and MRR.

Tyagi et al. (2012)[3]used L9 orthogonal based Taguchi methodology for optimized machining parameters for minimum surface roughness and maximum MRR during drilling of mild steel. The drilling operations have been carried out on a CNC drilling machine using HSS Tool. The spindle speed, feed, and depth of holes have been considered as drilling parameters. ANOVA analysis has also been employed to identify the most significant drilling parameter. An attempt has also been made to develop surface roughness and MRR prediction models. The result show that MRR increases with an increase in feed rate.

Sundeep et al. (2014)[4]employed L9 orthogonal array based Taguchi methodology to optimize the drilling parameters for maximum MRR, minimum surface roughness, minimum thrust force and minimum torque during the drilling of AISI 316 austenitic stainless steel. ANOVA analysis has also been employed to investigate the main influencing parameters that affect the responses. The spindle speed, feed rate and drill diameter have been considered as drilling parameters. The results show that the cutting speed has been found main influencing parameter that affects the surface roughness and MRR with (78.54% and 59.71%). As the cutting speed increases the thrust force and torque also increases.

In recent research has been considered the different parameters which affected on drill process.

This research aimed to study the effect of tool diameter, feed rate and spindle speed on material removal rate (MRR) and surface roughness (Ra) values for drill hole with using HSS as a tool material and Carbon steel AISI 1015 as a workpeice.

2. Theory of Taguchi Method

In the early 1950s, a Japanese engineer, Dr. Genichi Taguchi introduces a new concept of quality control technique known as Taguchi parameter design [5].His concept is based on that the manufacturing quality should be measured by the amount of deviation from the desired value. He concerned not only with the mean of the process, but also with the amount of variation or "noise" produced by changing the input variables or process parameters. His method is based on two main categories; a special type of matrix known as orthogonal array (OA), each column consists of a number of experiments based on the number levels of control factors; and the signal to noise S/N ratio [6]. In this technique, the term ‘signal’ refers to the desirable value (mean) for the output characteristic and the term ‘noise’ refers to the undesirable value (standard deviation). The determination of S/N ratio differs according to the objective function, i.e., a characteristic value. There are two character values in the present work as “Smaller is Better (SB)” and “Larger is Better (LB)”. Generally, the signal to noise (S/N) ratio represents the response of the data observed in the Taguchi design of experiments [7].

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}(y_i^{2})\right]; \qquad i=1, 2,\ldots\ldots n \qquad \ldots\ldots\ldots\ldots(1)$$

This equation is used to determine the S/N ratio (decibels) for surface roughness Ra. The quality characteristic for residual stresses is of the-higher-the-better type in case of compression or negative residual stresses. Therefore, the S/N ratio is given by:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\left(1/y_i^{2}\right)\right]; \qquad i=1,2,\ldots\ldots n \qquad \ldots\ldots\ldots\ldots(2)$$

Where n is the number of measurements (input), and yi the measured characteristic value (output). The unit of S/N ratio is the decibel.

3. Analysis of Variance

The results of experimental work can be analyzed by analysis of variance (ANOVA) to find the effect of cutting parameters on the surface roughness which are dependent on cutting parameters side step, spindle speed and feed rate while others are independent variables. The results of the ANOVA for surface roughness are shown in Tables (5). In the analysis, F-ratio is a ratio of mean square error of residual and is traditionally used to determine the significance of a factor. F ratio corresponding to 95% confidence level in calculation of process parameters accurately is F0.05, 2, 26=3.369. P value reports the significance level (suitable and unsuitable). Percent (%) is defined as the significance rate of process parameters on surface roughness. The percent numbers indicate that cutting results, feed rate, and side step have significant effects on surface roughness[8]. The side step, spindle speed, and feed rate parameters present statistical and physical significance on surface roughness, because test F>Fα=5%.

3.1 ANOVA Analysis

$\text{dfbetween} = K - 1$ .... (3)

$\text{dftotal} = N - 1$ .... (4)

$\text{dfwithin} = \text{dftotal} - \sum \text{dfbetween}$ .... (5)

where:

df = degree of freedom, K = the number of levels, N = the number of experiments.

$ss_{between}$ = from ANOVA table

ss_{total} = from ANOVA table

$ss_{within} = ss_{total} - \sum ss_{between}$ .... (6)

$Ms_{between}(\text{variance}) = \frac{ss_{between}}{df_{between}}$ .... (7)

$\text{MSwith in}(\text{variance}) = \frac{ss_{within}}{df_{within}}$ .... (8)

$\text{Fbetween} = \frac{MS_{between}}{MS_{within}}$ .... (9)

$P(\%)\text{between} = \frac{ss_{between}}{ss_{total}} \times 100$ .... (10)

$P(\%)\text{within} = \frac{ss_{within}}{ss_{total}} \times 100$ .... (11)

where: SS is sum of squares, MS is mean square error [8].

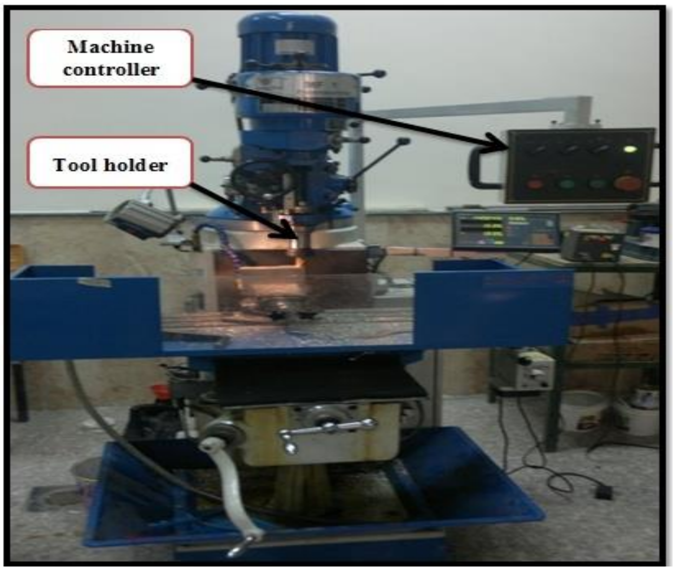
4. Experimental Work

4.1 Machine used

The experimental work has been performed on universal drill (KNUTH) model (MF1), It has the following specification listed in Table (1). And shown in Figure (1):

Table (1): Specification of machine used.

Spindle speed	**(80-4500) rpm**	**Travel –z**	**370mm**
Feed rate	(0.038-0.203)mm/rev	Motor main drive	3hp
Motor rating main drive	2,2 kW	overall dimensions	2000x1600x2088 mm
weight	1100 kg	axis	3-axis position indicator



Figure(5): Drilling machine

4.2 Work Piece

The metal machined is Carbon steel AISI 1015 Carbon Steel (UNS G10150) with cubic 30mm dimensions which is inspected in [the state company for inspection and engineering rehabilitation] / (Lab. And engineering inspection Dept.). The chemical composition and mechanical properties are listed in Tables (2) and (3) respectively. The work piece is inspected at a temperature of 27ºC and a humidity of 45%.

Table (2): Chemical composition of AISI 1015 Carbon Steel (UNS G10150).

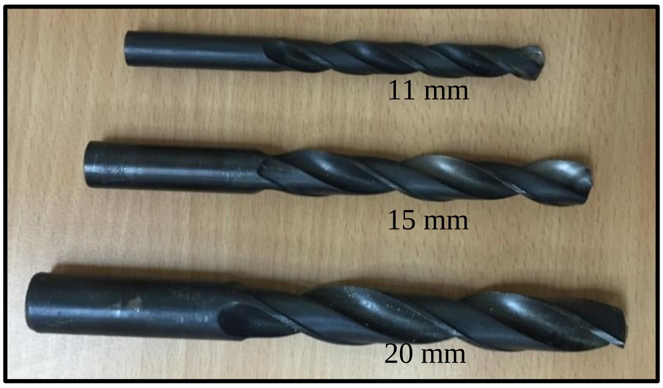
Material	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Co%	Cu%	Fe%
Weight	0.138	0.301	0.392	0.014	0.024	0.221	0.089	0.006	0.232	Bal.
Material	Mo	Al	Nb	Ti	V	W	Ta	Sn	Zr	Zn
Weight	0.030	0.001	0.001	0.001	0.0005	0.005	0.014	0.011	0.001	0.002

Table (3): Mechanical properties of AISI 1015 Carbon Steel (UNS G10150).

Property	Values
Tensile strength.	385 MPa
Yield stress.	325 MPa
Bulk modulus (typical for steel)	140 GPa
Shear modulus (typical for steel)	80.0 GPa

4.3 Cutting Tool

Three types of drill tool were used HSS material with (11, 15, 20) mm diameter with 2-flute and shown in Figure (2).



Figure(2): 4-fluteHSS drill tool.

4.4. Weighing Process

To measure MRR use equation (12) experimental need to weigh the workpiece before and after the drilling process using the device as shown in Figure (3) with specification in Table (4).

Figure(3):Weighing Devise Use

Table (4): Specifications of Weighing Devise

Gram (g)	**4100 x 0.01**
Decimal Ounce (Oz)	144 x 0.0005
Decimal Pound (lb)	9.0 x 0.00005
Troy Ounce (ozt)	131 x 0.0005
Pennyweight (dwt)	2636 x 0.01
Carat (ct)	20500 x 0.05
Momme (mm)	1093 x 0.005
Grain Unit (GN)	63274 x 0.2
Tola (t)	351 x 0.001
Tael (TL)	108 x 0.0005

4.5 Design of Experiments

The design of experiments has an important role on the number of experiments needed. Therefore, cutting experiments should be well-designed. The total number of cutting experiments is (9 experiments) based on three levels three parameters (33). A full factorial design was performed to obtain MRR and surface roughness values. The parameters were tool diameter, feed rate , spindle speed. The levels of cutting parameters are listed in Table (5) and the parameter use for each nine experimental in Table (6) Design according to MINITAB16 software as follows program step.

START → DOE → Taguchi → Create Taguchi Design

Table (5): Cutting conditions used

No	Parameter	Symbol	Level 1	Level 2	Level 3	Units
1	Tool diameter	D	11	15	20	mm
2	Feed rate	F	0.038	0.076	0.203	mm/rev
3	Spindle speed	S	132	550	930	r.p.m

The final distribution of the experiments and their levels are shown in Table (6) according to the Theory of Taguchi Method:

Table (6): Experimental design for the work

No	Tool diameter	Feed rate	Spindle speed	Surface roughness	MRR
1	11	0.038	132	2.02	1,000
2	11	0.076	550	2.11	1,312
3	11	0.203	930	2.31	1,401
4	15	0.038	550	2.52	1,600
5	15	0.076	930	2.25	1,702
6	15	0.203	132	3.89	2,685
7	20	0.038	930	3.35	1,899
8	20	0.076	132	3.73	3,082
9	20	0.203	550	3.82	3,325

4.6. Machining Using drill

In Figure (4) the 9 specimens are displayed after implementation of drill process under various cutting conditions.

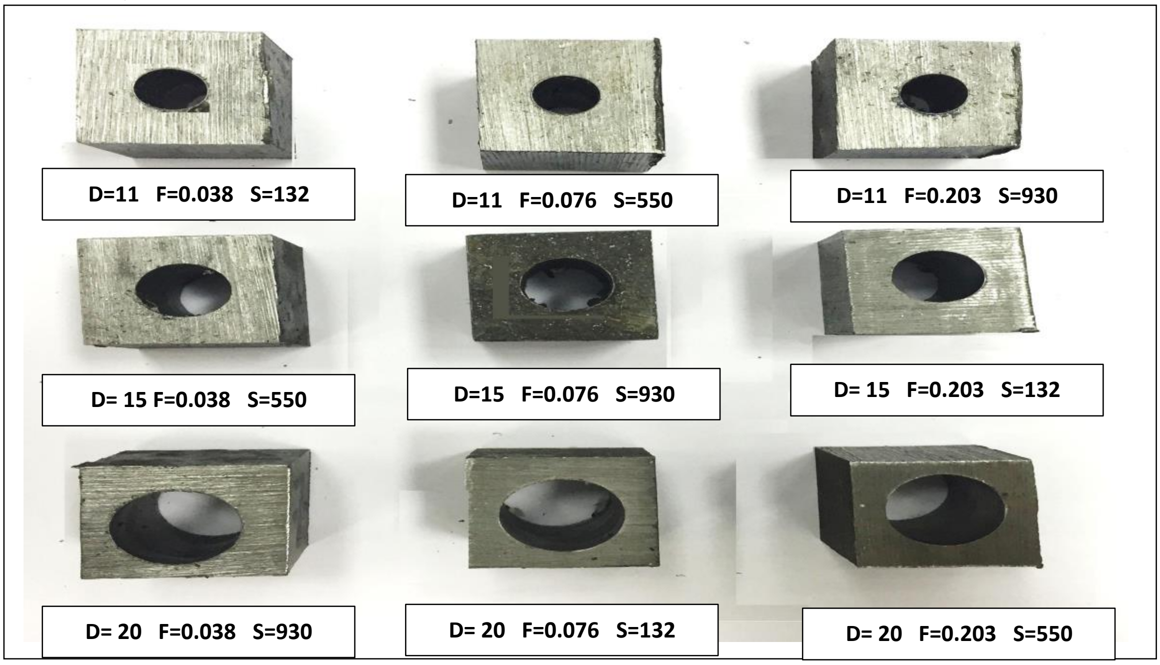


Figure (4): The nine specimens.

4.7 Surface Roughness Tester

Pocket Surf, the portable surface roughness gauge Mahr Federal's patented is available at measurements laboratory / production engineering and metallurgy Department / university of technology. The Pocket Surf gauge is a pocket-sized economically priced, completely portable instrument, performs traceable surface roughness measurements on a wide variety of surfaces. The Pocket Surf gauge shown in Figure (5) is solidly built, with a durable cast aluminum housing, to provide years of accurate, reliable surface roughness gauging.

Figure(5):The Pocket Surf gauge.

The specifications of pocket surf are listed in Table (7).

Table (7): Specifications of Pocket Surf

Overall Dimensions	**140 mm x 76 mm x 25 mm**
Weight	435 g
Measuring Ranges	Ra (0.03 - 6.35 μm), Ry (0.2 -25.3 μm)
Display Resolution	0.01 μm

Figure (6) shows the process of measuring roughness using a special holder to give the Pocket Surf more freedom in measuring.

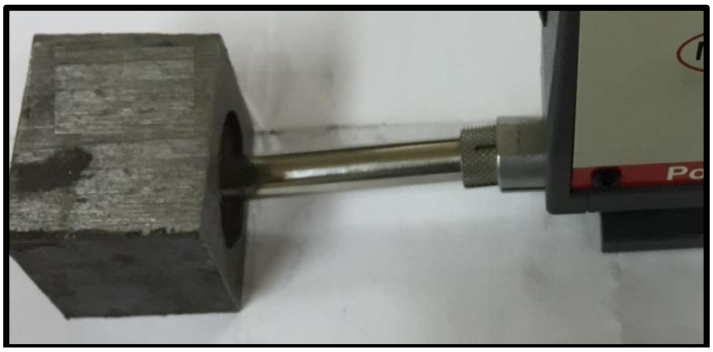


Figure (6): Pocket Surf holder of the proposed work.

4.8 Material Removal Rate Calculation

The material removal rate can be calculated as follows [9]:

$$MRR=\frac{((\text{Initial wt of work piece (gms)})-(\text{final wt of work piece (gms)}))}{((\text{density in gms})*(\text{Maching time (min)}))} \qquad \text{---------------- (12)}$$

5. Results and discussion

5.1 Effect of Tool Diameter and Spindle Speed on the MRR

Figure (7) shows the effect of tool diameter and spindle speed on MRR at a constant feed rate. It can be seen that the increase in tool diameter leads to increase MRR. This is due to the large tool causes large chip during machining which leads to high melting rates of material. Also, the increase in spindle speed leads to decrease MRR. From this Figure, it can be seen, that high rates of MRR can be reached at low levels of spindle speed, and these (low speed) height levels of MRR give better surface roughness with constant feed.

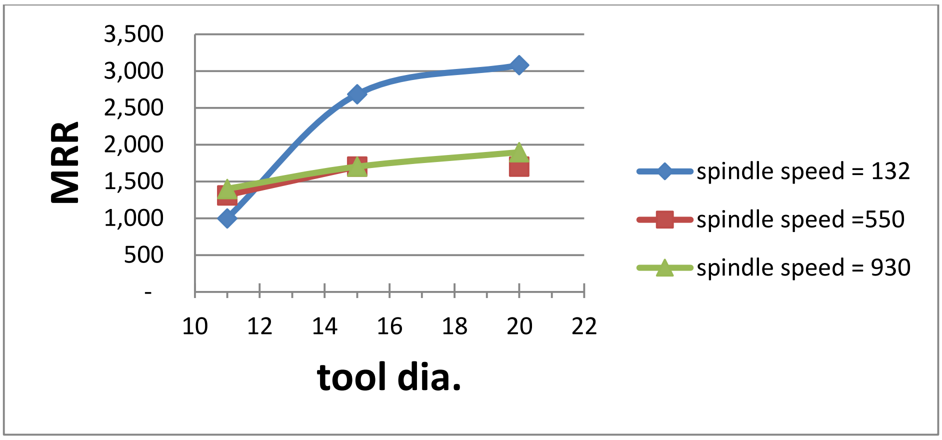
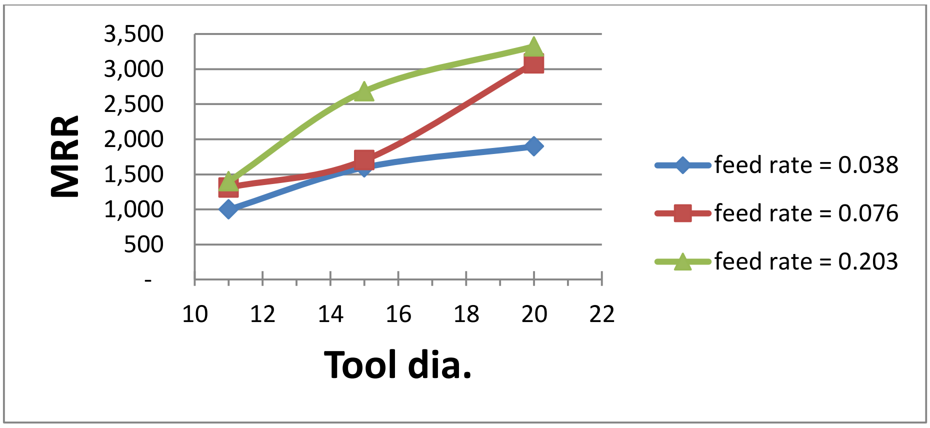


Figure (7): Effect of tool diameter and spindle speed on the MRR.

5.2 Effect of Tool Diameter and Feed Rate on the MRR

A Figure (8) shows the effect of tool diameter and feed rate on MRR while maintaining Spindle speed constant. From these Figures, it can be seen, that the increase in tool diameter leads to increase MRR due to the large chip during machining which leads to high melting rates of material, and the increase in feed rate leads to increase MRR. This is due to large amount of metal remove with little time.



Figure(8):Effect of tool diameter and feed rate on the MRR.

5.3 Analysis of Variance on the MRR

The experimental results are analyzed by using analysis of variance (ANOVA) to determine the effect of machining parameters on the MRR, MRR as the dependent variable, D, F and S as independent variables.

The F ratio value of 572.65for the tool diameter is greater among the parameters (as shown in Table (8). Therefore, the most influential parameter is the tool diameter (64.08%) which is about three times of the feed rate (25.84%). The spindle speed has a small influence with 9.97%. In the analysis, F- ratio is a ratio of mean square error of residual, and is traditionally used to determine the significance of a factor.

The main effects plots are used to determine the optimal design conditions to obtain the optimum MRR and hence select the better machining parameters using the help of the SPSS software package. Figure (9) shows the main effect plot for MRR with the process input .This plot shows the variation of individual response with three parameters, i.e. D, F and S separately. The results show the optimal conditions for maximum MRR were: tool diameter at level-3(20mm), spindle speed at level-1(132 rpm), and feed rate at level-3(0.203mm/rev), this is consistent with the reference [10].

Table (8): ANOVA for MRR.

Source of variance	DOF	Sum of squares	Variance, V	F ratio	P (%)
Tool Diameter, D	2	3516054	1758027	572.65	64.08
Feed Rate, F	2	1417709	708854	230.90	25.84
Spindle Speed ,S	2	546817	273408	89.06	9.97
Error ,e	2	6140	3070	-	0.11
Total	9	5486720	-	-	100

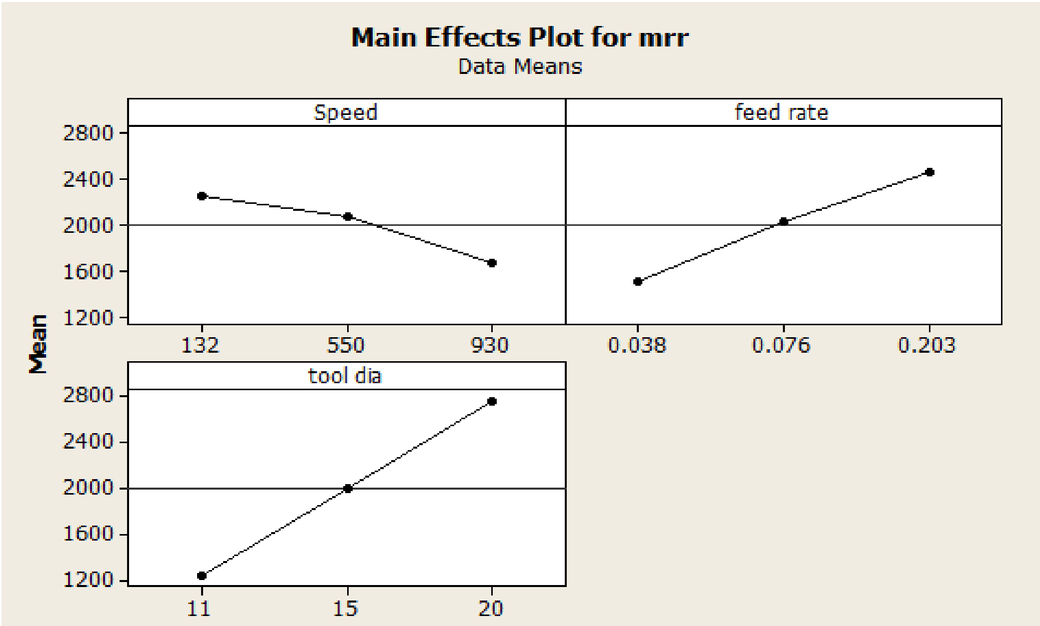


Figure (9): Mean effects plot for MRR

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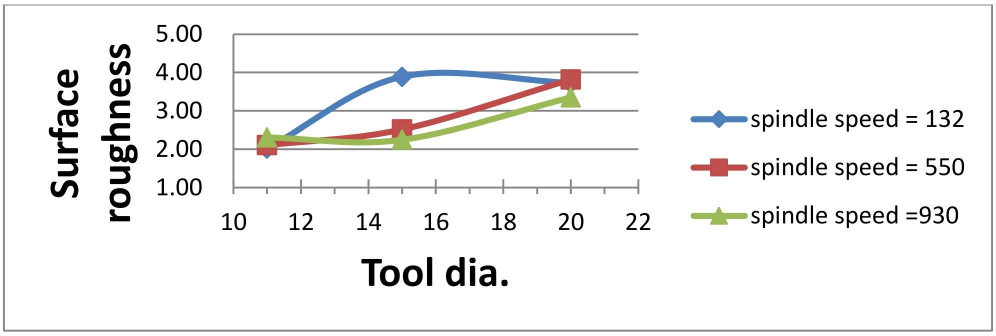
5.4 Effect of Tool Diameter and Spindle Speed on the Surface roughness

Figure (10) shows the effect of tool diameter and spindle speed on Surface roughness at a constant feed rate. It can be seen that the increase in tool diameter leads to increase Surface roughness. This is due to the high energy generated during machining, but the increase in spindle speed leads to decrease Surface roughness. Also, from these Figures, it can be seen, that low rates of Surface roughness can be reached at large levels of spindle speed (930 rpm), with constant feed rate.



Figure(10):Effect of tool diameter and spindle speed on the Surface roughness

5.5 Effect of Tool Diameter and Feed Rate on the Surface roughness

A Figure (11) shows the effect of tool diameter and feed rate on Surface roughness while maintaining spindle speed constant. From these Figures, it can be seen, that the increase in tool diameter leads to increase Surface roughness, and the increase in feed rate leads to increase Surface roughness. This is due to large rates of metal remove at high values of tool diameter and feed rate has a large effect on Surface roughness.

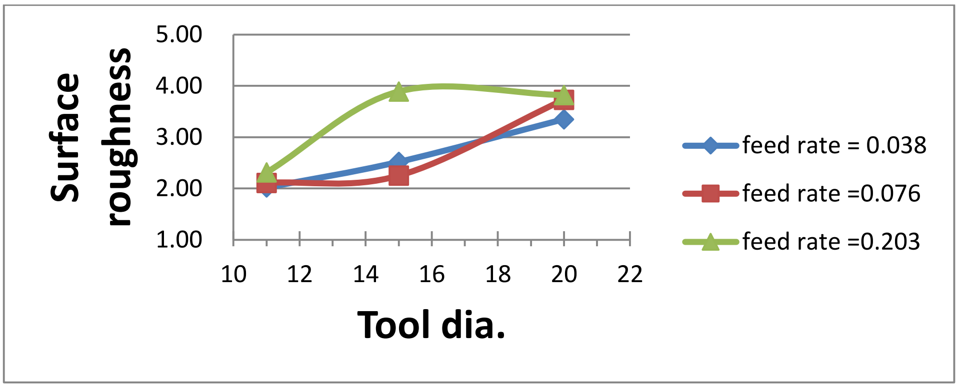


Figure (11):Effect of tool diameter and feed rate on the surface roughness

5.6 Analysis of Variance on the Surface roughness

The experimental results are analyzed by using analysis of variance (ANOVA) to determine the effect of machining parameters on the Surface roughness, Surface roughness as the dependent variable, D, F and S as independent variables.
The F ratio value of 32.72 for the tool diameter is greater among the parameters (as shown in Table (9)). Therefore, the most influential parameter is the tool diameter (76.12%), feed rate (16.83%) which is about three times of the spindle speed (5.17%).

The main effects plots are used to determine the optimal design conditions to obtain the optimum Surface roughness and hence select the better machining parameters using the help of SPSS software package. Figure (12) shows the main effect plot for Surface roughness with the process inputs .This plot shows the variation of individual response with three parameters, i.e. D, F and S separately. The results show the optimal conditions for maximum Surface roughness were: tool diameter at level-3(20 mm), feed rate at level-3 (0.203mm/rev), and spindle speed at level-1(132rpm), and that is harmonious with the reference [11].

Table (9):ANOVA for Ra.

Source of variance	DOF	Sum of squares	Variance, V	F ratio	P (%)
Tool Diameter, D	2	3.533	1.767	32.72	76.12
Feed Rate, F	2	0.760	0.380	7.04	16.38
Spindle Speed ,S	2	0.240	0.120	2.22	5.17
Error ,e	2	0.108	0.054	-	2.30
Total	9	4.641	-	-	100

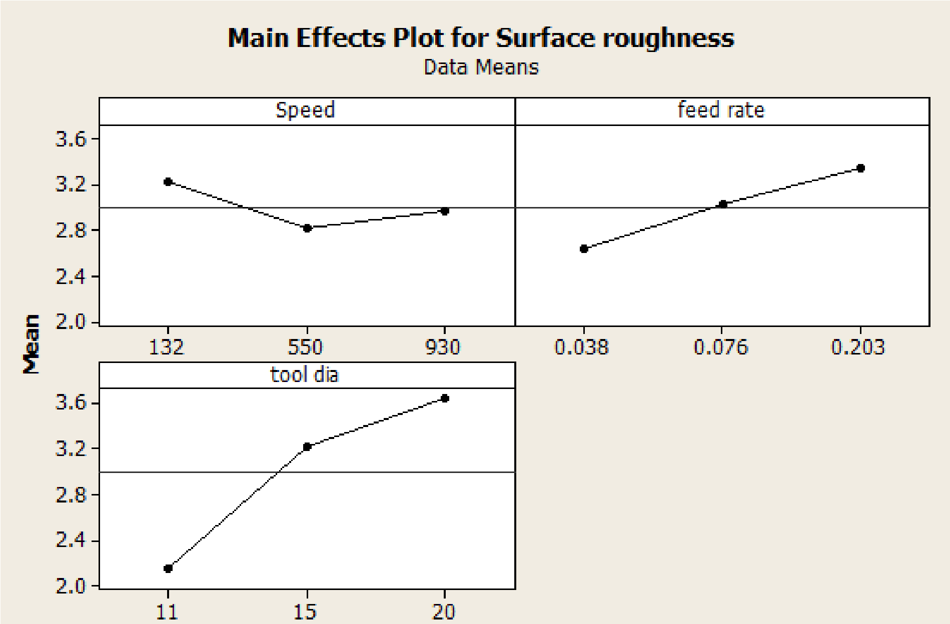


Figure (12): Mean effects plot for Surface roughness

6. Conclusion

In this study, drilling of steel 1015 alloy, Drilling process is concerned with minimizing surface roughness. For instance, the optimum Ra is obtained at the highest level of spindle speed,. To acquire a minimal surface finish of workpiece, spindle speed should be set as high as possible and the feed rate should be set as low as possible. The important conclusions drawn from the present work are summarized as follows:

MRR increases with an increase in feed rate,but decreases MRR with increase in spindle speed.

The Maximum MRR has been obtained at spindle speed 132 rpm, and feed rate 0.203 mm/rev.

The Maximum Surface roughness when tool diameter at (20 mm), feed rate at (0.203 mm/rev), and spindle speed at (132 rpm).

Through ANOVA, it is found that the tool diameter the important factor effect with (64.08%) and (76.12%) on MRR and surface roughness respectively .

7. Recommendations

Further study could consider more factors (drill properties, point angle, helix angle, flute number, types of drills and run out of drill, thrust force, torques etc.) in the research to see how these factors would affect the hole quality.

Acknowledgements

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