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Optimization of Turning Parameters for Material Removal Rate of EN-36 Alloy Steel by Box Behnken Method under RSM

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Abstract: In this project work machining of the EN-36 Alloy Steel (with hardening and without hardening) with the help of coated carbide tool is perform on CNC Turing machine. Material Removal Rate (MRR), the experiment is carried out as per Box Behnken Design under Response Surface Methodology (RSM). Analysis of the Material removal rate is done The experimental study of material removal rate which is perform on CNC machine of EN-36(with hardening and without hardening) material using coated carbide cutting tool by various cutting parameters like feed, cutting speed and depth of cut and determine optimum cutting parameters of material removal rate. The help Minitab 16 software and ANOVA (Analysis of Variance), the most effective parameter selected from the input to obtain the optimal combination for Material removal rate
Keywords: Material Removal Rate, RSM, BBM and Parameters

I. INTRODUCTION

Material Removal Rate (MRR) is the measurement for how much material is removed from a part in a given period of time. Machining is one of the manufacturing processes in which the dimensions, shape or surface properties of machined parts are changed by removing the excess material. The turning process is carried out on a CNC machine and the automatic turning process is performed by Computer numerical control (CNC) lathe machine. The three primary factors in any basic turning operation are cutting speed, feed, and depth of cut. Other factors which further influences the machining are type of material and tool geometry.

A. Turning

Turning is an important process which is employed to produce a wide variety of parts; primarily it is employed to produce cylindrical parts by a single point cutting tool on lathe. The cutting tool is fed either linearly or along a specified path to the direction parallel or perpendicular to the axis of the rotation of the work piece, as per the nature of the job to be accomplished. Turning is done on CNC lathe, and the power to turn the work piece at a definite rotational speed is provided by motor which is joined to the chuck. Basically while performing any turning operation on CNC lathe we have two types of motions i.e. primary motion which rotates the job, while the secondary motion is the feed motion of the cutting tool.

B. Objectives of Work

The objective of this project work is to obtain optimal Material Removal Rate parameters in turning operation using EN-36 alloy steel through experimental investigation and employing design of experiments "Box Behnken Design" technique. The investigation is to be carried out on EN-36 steel with two conditions, with hardening (HRC-30) and without hardening.

II. EXPERIMENTATION

Now after the design matrix has been developed, and the basic working of CNC machine is studied in detail, the experiments were carried out. The machine used for the experimentation process is Midas 6 Industrial type of CNC Lathe. A series of turning tests were conducted to assess the influence of cutting parameters on the Material Removal Rate during the turning operation on EN-36 steel.

A. Work Piece Material

The material which is used for this investigation process is EN-36 alloy steel. EN-36 is a low carbon and high alloy content steel. It has high toughness due to the presence of nickel in it. It is used for making components which have large cross section and require comparatively high toughness and strength. It has huge application in different manufacturing industries such as gears, crane shafts etc. In aero space application it is used to make heavy duty gear. It is most commonly used metal in manufacturing industries.

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Table 2.1 Chemical Composition of EN-36 Steel

Element	Chemical Composition (wt. %)
Carbon-C	0.7
Nickel-Ni	3.2
Chromium-Cr	1.050
Silicon-Si	0.25
Manganese-Mn	0.42
Sulphur-S	0.01
Phosphorus-P	0.012
Molybdenum-Mb	0.140

B. Factors and Levels

The three machining parameters feed, speed and depth of cut are taken as the control factors in this experimental process. Each of the control factors are designed to three levels denoted by level 1, 2 and 3. The experiments are planned using Box Behnken design under RSM process, which helps in reducing the probable number of experiments as the numbers of runs are minimized. The different input parameters and levels with its unit are shown in table 2.2

Table 2.2 Input parameters with level

Factors/Levels	Level 1(low)	Level 2 (medium)	Level 3 (high)
Speed (rpm)	180	200	220
Feed (mm/rev)	0.10	0.15	0.20
Depth of cut (mm)	0.5	0.7	0.9

C. Operational Sequence

1) *Turning On Lathe Machine:* In this operation EN-36 alloy steel bar of 30 mm diameter and 32 cm length is used to get the specimens of 26 mm diameter and 18 mm long. The facing operation is carried out on CNC lathe as shown in fig 2.31. Thirty specimens are prepared.

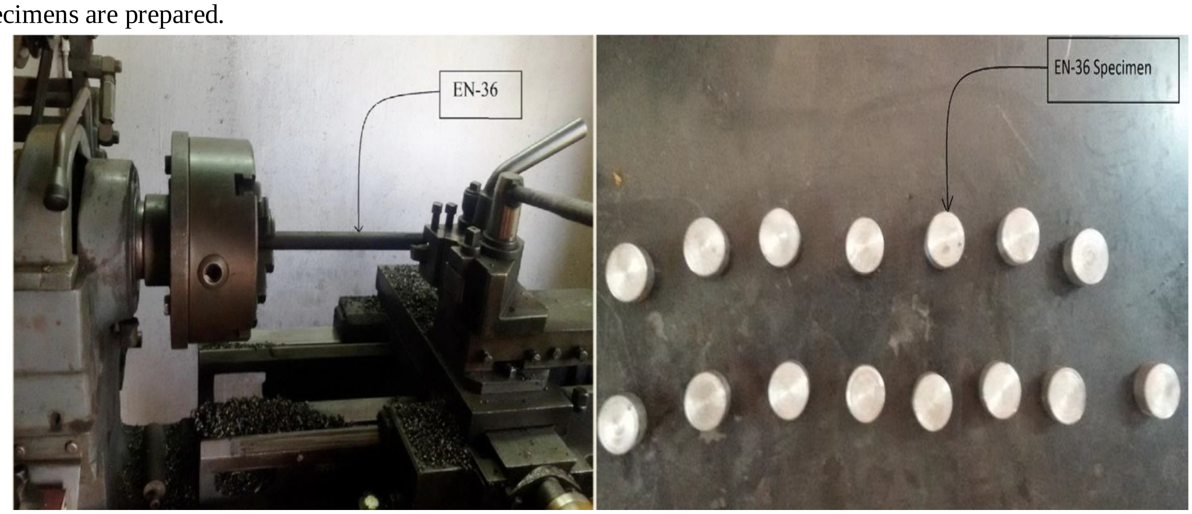

Fig 2.3.1 Preparation of work piece on lathe and Specimen after cutting on lathe machine

2) *Heat Treatment:* During the heat treatment of EN-36 alloy steel (case hardening) it is heated to a temperature of 620^{0}C for 8 hrs, quenched in furnace oil and then cooled to change the hardness and strong structure. EN-36 steel alloy exhibit a very good stability in heat treatment process. Heat treatment unit is shown in fig and specimen before heat treatment and after heat treatment is shown in fig 2.3.2

Fig 2.3.2 Heat treatment of specimens on Quenching oil furnace

3) *Weigh Work Piece:* Now after the completion of turning operation on lathe machine, the weight of the specimen is taken with the help of highly precise digital weighing machine.
4) *Turning on CNC:* The machine used in order to carry out this experimental process is Midas 6 Industrial type of CNC lathe.

Fig 2.3.4 Specimens ready for machining on CNC

Table 2.3.1 Design matrix obtained from Minitab V-16

Std Order	Run order	Pt Type	Blocks	Cutting speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
3	1	2	1	180	0.20	0.7
9	2	2	1	200	0.10	0.5
13	3	2	1	200	0.15	0.7
10	4	2	1	200	0.20	0.5
1	5	2	1	180	0.10	0.7
11	6	2	1	200	0.10	0.9
6	7	2	1	220	0.15	0.5
8	8	2	1	220	0.15	0.9
2	9	2	1	220	0.10	0.7
4	10	2	1	220	0.20	0.7
15	11	2	1	200	0.15	0.7
5	12	2	1	180	0.15	0.5
12	13	2	1	200	0.20	0.9
7	14	2	1	180	0.15	0.9
14	15	0	1	200	0.15	0.7

5) *Weigh The Work Pieces After Machining:* Now after the completion of turning operation on lathe machine, the weight of the specimen is taken. The weight of the specimen is taken before and after machining to find out Material Removal Rate (MRR).
6) *Calculation of Material Removal Rate:* The Material Removal Rate (MRR) can be calculated by deducting the weight of the specimen after experiment from the weight of the specimen before experiment, and then dividing it by the density of work piece material and time taken to complete the operation.

$$\textbf{Material removal rate} = \frac{W_i - W_f}{\rho \times t}$$

Where,

W_i= Initial weight of the specimen in gms
W_f= Final weight of the specimen in gms

t= Machining time in sec
ρ=Density of EN-36 alloy steel ($15.7*10^{-3}$ gm/mm^3)

The data obtained for the hardened specimens is tabulated and MRR calculated is shown in table.

Table 2.3.2 Material removal Rate of EN-36 (Hardness 30 HRC)

Std Order	Run Order	Pt Type	Blocks	Speed (rpm)	Feed (mm/rev)	Depth of Cut(mm)	Initial wt.(gm)	Final wt.(gm)	Time (sec)	MRR (mm^3/sec)
3	1	2	1	180	0.20	0.7	67.28	61.34	8	47.2929
9	2	2	1	200	0.10	0.5	66.89	62.46	9	31.796
13	3	0	1	200	0.15	0.7	63.81	59.04	8	37.961
10	4	2	1	200	0.20	0.5	67.91	62.09	8	46.337
1	5	2	1	180	0.10	0.7	67.46	61.34	10	38.980
11	6	2	1	200	0.10	0.9	62.7	59.13	7	32.484
6	7	2	1	220	0.15	0.5	66.67	61.23	8	43.312
8	8	2	1	220	0.15	0.9	65.64	59.88	8	45.859
2	9	2	1	220	0.10	0.7	65.97	61.03	10	31.464
4	10	2	1	220	0.20	0.7	67.52	60.98	7	59.490
15	11	0	1	200	0.15	0.7	65.04	59.89	9	36.433
5	12	2	1	180	0.15	0.5	65.63	60.97	7	42.401
12	13	2	1	200	0.20	0.9	64.73	59.13	8	45.585
7	14	2	1	180	0.15	0.9	67.66	60.16	10	47.770
14	15	0	1	200	0.15	0.7	64.8	59.94	9	34.394

The data obtained for non hardened specimens is tabulated and MRR calculated is shown in table.

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Table 2.3.3Material Removal Rate of EN 36 (without hardening)

Std Order	Run Order	Pt Type	Blocks	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	Initial wt.(gm)	Final wt.(gm)	Time (sec)	MRR (mm^3/sec)
3	1	2	1	180	0.20	0.7	64.18	58.67	8	43.869
9	2	2	1	200	0.10	0.5	65.92	61.34	10	29.171
13	3	0	1	200	0.15	0.7	63.45	58.86	9	32.484
10	4	2	1	200	0.20	0.5	67.62	61.09	8	51.990
1	5	2	1	180	0.10	0.7	65.65	60.07	9	39.490
11	6	2	1	200	0.10	0.9	63.32	59.08	8	33.757
6	7	2	1	220	0.15	0.5	65.16	60.12	8	40.127
8	8	2	1	220	0.15	0.9	65.4	59.17	7	56.687
2	9	2	1	220	0.10	0.7	65.76	61.36	9	31.139
4	10	2	1	220	0.20	0.7	69.68	59.88	10	62.420
15	11	0	1	200	0.15	0.7	64.57	60.16	9	31.210
5	12	2	1	180	0.15	0.5	64.57	59.96	8	36.703
12	13	2	1	200	0.20	0.9	65.64	60.32	7	48.407
7	14	2	1	180	0.15	0.9	67.04	60.56	9	45.859
14	15	0	1	200	0.15	0.7	64.08	59.76	8	34.394

III. RESULT AND CONCLUSION:

This chapter mainly emphasis on the results obtained from the experimental exploration and inspection with respect to the material removal rate in turning operation. The results are analyzed which factors among speed, feed and depth of cut are more significant applying Box Behnkan design of experiments under Response Surface Methodology.

In this proposed work, Minitab version-16 software is used to draw the graphs and plots for both surface roughness and material removal rate. As the process parameters change from one level to another, its main effects and interactions on Material Removal Rate (MRR) are calculated and plotted. In order to check the sufficiency of the second order model, analysis of variance (ANOVA) has been employed.

A. Regression Analysis For Material Removal Rate

Regression is employed to investigate the interrelation ship that exists between the response variable and the unknown variables. Now after completion of the experiments the results are tabulated and fed in to Minitab version-16 software. Then after the following regression, estimate table and the table for analysis of variance were obtained for MRR without material hardening and with material hardening to 30HRC. The analysis is carried out using uncoded units.

Table 3.1.1: Estimated Regression Coefficients for MRR for the specimens without hardening

Terms	Coeff.	SE Coeff.	T test	P value
Constant	1072.87	238.839	4.492	0.006*
Cutting speed	-8.95	2.185	-4.097	0.009*
Feed	-1470.56	504.733	-2.914	0.033*
Depth of cut	-198.34	130.610	-1.519	0.189
Cutting speed* Cutting speed	0.02	0.005	3.645	0.015*
Feed*Feed	1504.15	852.921	1.764	0.138
Depth of cut *Depth of cut	109.37	53.308	2.052	0.095*
Cutting speed*Feed	6.73	2.049	3.283	0.022*
Speed*Depth of cut	0.46	0.512	0.904	0.408
Feed*Depth of cut	-204.23	204.865	-0.997	0.365
S = 0.0643292	**R-Square = 94.15%**		**R-Square(adjusted) = 86.62%**	

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Table 3.1.2: Analysis of Variance for MRR on the specimens without hardening

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	1351.09	1351.09	150.121	8.94	0.013
Linear	3	832.46	379.69	126.562	7.54	0.027
Cutting speed	1	74.74	281.82	281.820	16.79	0.009
Feed	1	668.48	142.51	142.508	8.49	0.033
Depth of Cut	1	89.24	38.71	38.713	2.31	0.189
Square	3	307.32	307.32	102.440	6.10	0.040
Cutting speed* Cutting speed	1	193.11	223.09	223.095	13.29	0.015
Feed*Feed	1	43.54	52.21	52.211	3.11	0.138
Depth of Cut*Depth of Cut	1	70.67	70.67	70.669	4.21	0.095
Interaction	3	211.32	211.32	70.439	4.20	0.078
Cutting Speed*Feed	1	180.93	180.93	180.929	10.78	0.022
Cutting speed*Depth of Cut	1	13.70	13.70	13.705	0.82	0.408
Feed*Depth of Cut	1	16.68	16.68	16.683	0.99	0.365
Residual Error	5	83.94	83.94	16.788		
Lack-of-Fit	3	78.80	78.80	26.268	10.23	0.090
Pure Error	2	5.14	5.14	2.568		
Total	14	1435.03				

Multiple linear equation was developed to inter relate between the divergent process parameters to estimate the material removal rate for any combinations of elements in a range specified. The model equation developed from table in order to predict MRR for the material condition without hardening is given in equation.

MRR (In uncoded units) =1072.87-8.95 * cutting speed -1470.56 * feed +0.02 * cutting speed * cutting speed +109.37 *DOC *DOC+6.73* cutting speed* feed

Table 3.1.3: Estimated Regression Coefficients for MRR on the specimens with hardening

Terms	Coeff.	SE Coeff.	T test	P value
Constant	845.542	137.584	6.146	0.002*
Cutting speed	-7.507	1.259	-5.964	0.002*
Feed	-936.046	290.753	-3.219	0.023*
Depth of cut	-12.458	75.238	-0.166	0.875
Cutting speed* Cutting speed	0.017	0.003	5.629	0.002*
Feed*Feed	451.812	491.328	0.920	0.400
Depth of cut*Depth of cut	41.458	30.708	1.350	0.235
Cutting speed*Feed	4.928	1.180	4.176	0.009*
Cutting speed*Depth of cut	-0.176	0.295	-0.598	0.576
Feed*Depth of cut	-36.000	118.013	-0.305	0.773
S = 0.03869	R-Square = 96.65%		R-Square(adjusted) = 90.61%	

The p-value with asterisk mark (*) indicates the significant factors. Here cutting speed, feed, cutting speed* cutting speed and cutting speed*feed are highly significant factors. The R-square value of 0.9665 suggest that the variation in the response at the confidence interval of 90 % can be predicted satisfactorily considering only the significant factors for the model so far developed. The R-Square adjusted value 0.9061 is in agreeable range. The model equation developed from table 4.8 in order to calculate MRR for the material condition with hardening is given in equation.

MRR (In uncoded units) =845.552 – 7.507* cutting speed - 936.046*feed + 0.017* cutting speed* cutting speed + 4.928* cutting speed*feed

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Table 3.1.4: Analysis of Variance for MRR on the specimens with hardening

Source	DOF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	802.999	802.999	89.222	16.02	0.004
Linear	3	521.095	234.467	78.156	14.03	0.007
Cutting speed	1	1.694	198.151	198.151	35.57	0.002
Feed	1	511.694	57.739	57.739	10.36	0.023
Depth of Cut	1	7.707	0.153	0.153	0.03	0.875
Square	3	182.243	182.243	60.748	10.90	0.012
Cutting speed* cutting speed	1	168.361	176.532	176.532	31.69	0.002
Feed*Feed	1	3.729	4.711	4.711	0.85	0.400
Depth of Cut * Depth of Cut	1	10.154	10.154	10.154	1.82	0.235
Interaction	3	99.661	99.661	33.220	5.96	0.042
Cutting speed*Feed	1	97.152	97.152	97.152	17.44	0.009
Cutting speed*Depth of Cut	1	1.991	1.991	1.991	0.36	0.576
Feed*Depth of Cut	1	0.518	0.518	0.518	0.09	0.773
Residual Error	5	27.854	27.854	5.571		
Lack-of-Fit	3	21.449	21.449	7.150	2.23	0.324
Pure Error	2	6.405	6.405	3.203		
Total	14	830.853				

B. Main effect plot for Material Removal Rate

The impact of various factors on the Material Removal Rate (MRR value).

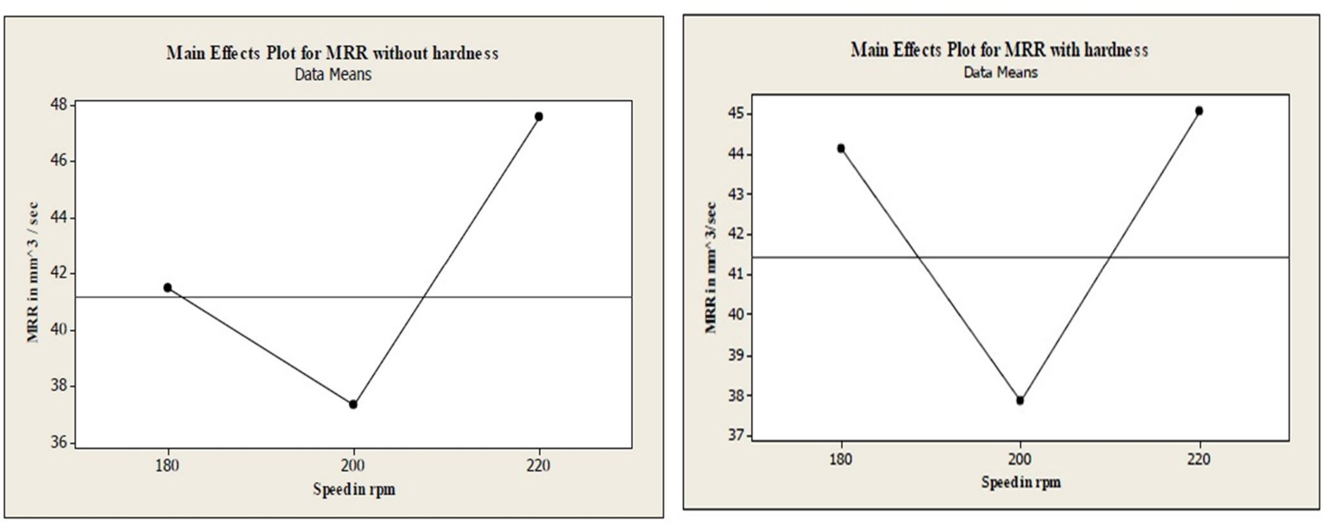
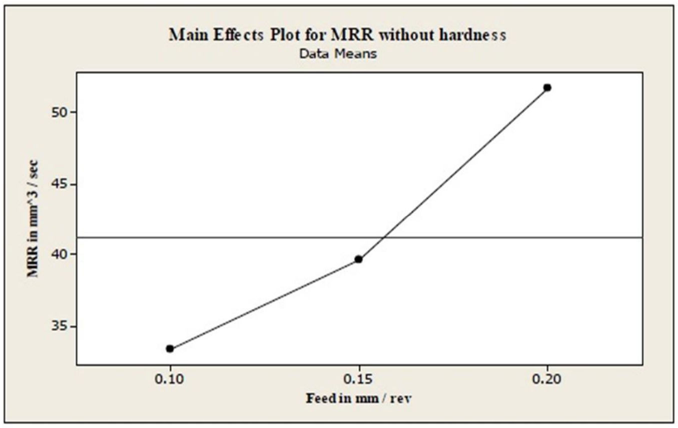


Fig 3.2.1: Main effect plot for MRR v/s speed on the specimens without hardening and with hardening



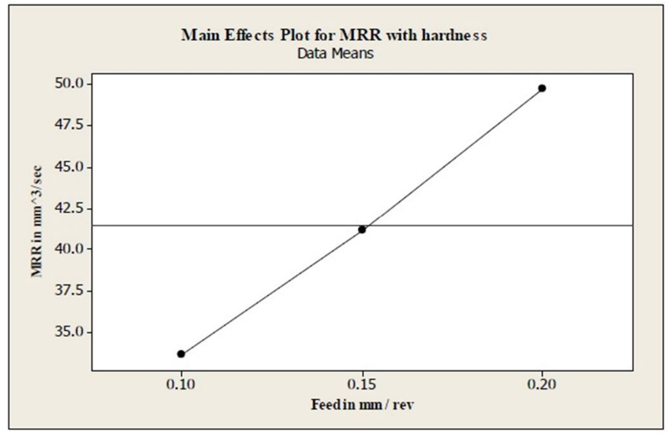


Fig 3.2.2: Main effect plot for MRR v/s feed on the specimens without hardening and with hardening

C. Interaction plot for Material Removal Rate

Interaction plot are obtained, when we feed the results obtained to Minitab version-16 software. Interaction plots are used to show the effect of two parameters on the response variable.

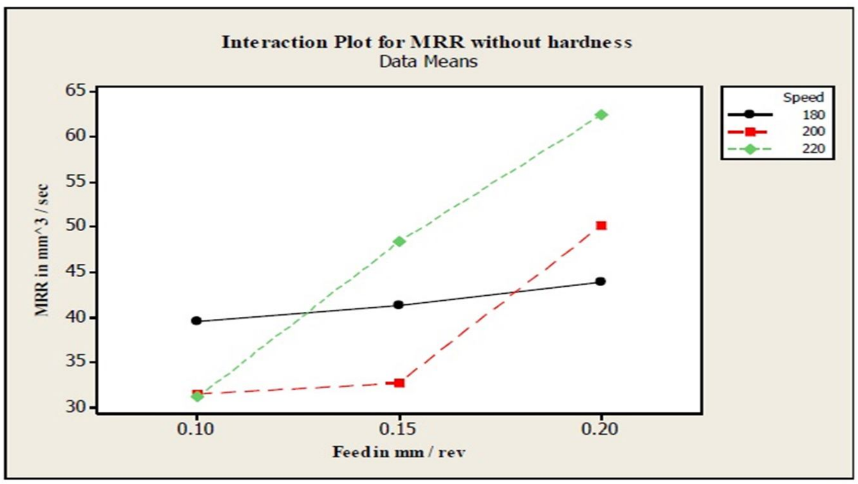


Fig 3.3.1: Interaction plot for MRR v/s feed on the specimens without hardening

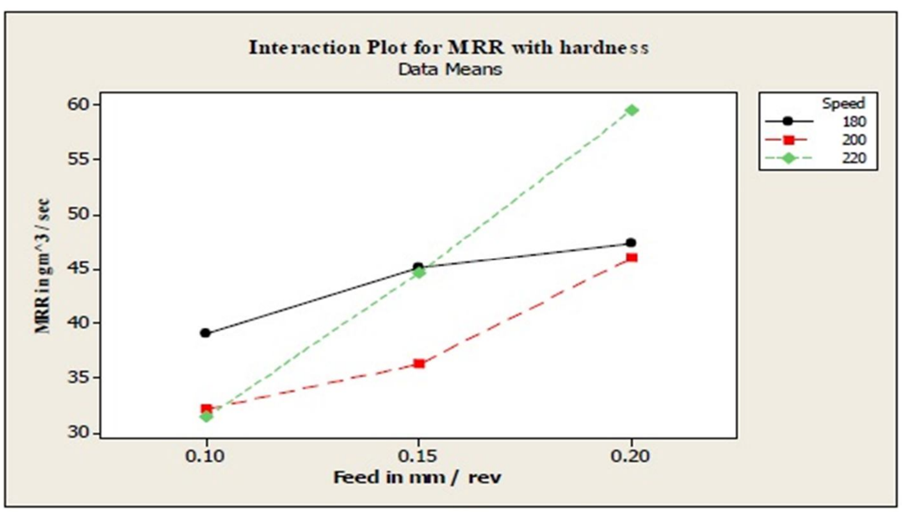


Fig 3.3.2: Interaction plot for MRR v/s feed on the specimens with hardening

D. Machining Parameters for Optimum Material Removal Rate

From the responses, the optimum set of machining parameters for MRR for different material conditions i.e. without hardening and with hardening.

Table 3.4.1 Optimum machining parameters for MRR

Material condition	Feed (mm/rev)	Speed (rpm)	Depth of cut (mm)	MRR (mm^3/sec)
Without hardening	0.20	220	0.7	62.42
With hardening	0.20	220	0.7	59.49

IV. CONCLUSION

This dissertation work is mainly focused on the optimization of Material Removal Rate (MRR). Suitable combination of different process parameters are done to produce high Material Removal Rate possible. The experiment was planned as per Box Behnken design under Response Surface Methodology (RSM) in order to carry out the machinability study. Analysis of variance (ANOVA) is used to check adequacy of the proposed model. After the completion of the experiment and detailed analysis, following conclusions were drawn:

A. The optimum Material Removal Rate (MRR) is obtained for EN-36 without hardening is 62.42mm^3 /sec at a feed rate of 0.20 mm/rev, speed of 220 rpm and depth of cut of 0.7 mm and the MRR for EN-36 material hardened to 30 HRC is 59.49 mm^3/sec at a feed rate of 0.20 mm/rev, speed of 220 rpm and depth of cut of 0.7 mm.

B. The result of ANOVA for Material Removal Rate shows that speed and feed are the most significant parameters for both the material without hardening and material hardened to 30 HRC, where as the least significant parameter is depth of cut.

C. The experiment model obtained helps the designer in selecting a best suitable combine of design parameters to get optimum Material Removal Rate during the turning operation. This helps in reducing the machining time, cost and tool wear rate

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