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Study of cutting forces in machining of magnesium composite by response surface methodology

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Metal Matrix composites (MMCs) has many excellent engineering properties like good strength to weight ratio, stiffness and increased wear resistance etc., These properties are the main requirements in aerospace, automotive industries and hence the MMCs are extensively used in these industries. This paper presents the detailed experimental study on cutting forces and surface roughness aspects in turning of 5% Graphite reinforced AZ91D Magnesium alloy metal matrix composite (AZ91D Magnesium alloy matrix + 5 % Graphite reinforcement). The stir casting process under inert atmosphere is followed for synthesis of the composite. The turning process is followed using Tungsten carbide cutting tool, in a lathe. The effect of machining parameters viz., cutting speed, feed rate and depth of cut, on the cutting forces and surface roughness (Ra) achieved during the machining are analysed and modelled through the response surface methodology (RSM). Study of effect of machining parameters and their interactions are carried out by using the surface, contour plots of RSM. The experimental result shows that the most significant machining parameter affecting surface roughness and cutting forces is cutting speed. The experimental results and predicted values are observed as in good agreement.

1. Introduction Magnesium (Mg) based metal matrix composites and alloys are considered as a very attractive material for a wide range of higher performance applications, extensively in the fields of light weight applications in automobile, aerospace due to their low density, highest strength to weight ratio [1-4].The advantages of magnesium include a unique blend of low density, high specific strength, stiffness, electrical conductivity, heat dissipation, better damping capacity compared to cast iron and aluminium and recyclability [5]. Magnesium is the lightest structural metal and has excellent machinability. Fast machining, lower power requirement, excellent surface finish, well broken chips and reduced tool wear are the advantages in machining of magnesium, when comparing with other metals. Magnesium based alloys are with hexagonal closed packed (HCP) crystal structure and has good workability at elevated temperature than the room temperature. Magnesium composites exhibits poor machining characteristics at lower temperature due to their hexagonal closed packed structure and hence to be processed at elevated temperatures for the better results [6]. Magnesium based metal matrix composites are fabricated by various methods, such as stir casting, powder metallurgy, squeeze casting. In these methods stir casting is easily adaptable and most used method, for manufacturing of near-net shape metal matrix composites.

Magnesium based MMCs has good castability, machining properties and good electromagnetic shielding properties.

To get the required surface finish and dimensional tolerance for the requirements, secondary machining processes are essential [7]. Machining of composites always involves many issues like poor surface finish, more temperature development due to friction between the tool and work piece. Cutting forces are an important factor of machinability evaluation. Higher cutting forces creates high stresses, high temperature, strain hardening and structural variations etc., Hence cutting forces should kept low to minimize the damages [8]. Hence in this analysis, 5% graphite, which is a solid lubricant, added as reinforcement in the magnesium metal matrix, to study the surface roughness and cutting forces during machining. The turning process is predominantly used as material removal process, many researches are carried out to optimize the process to get the desirable responses like surface roughness, minimum cutting forces, and tool life increase. Many performance characteristics like fatigue strength, tribological characteristics, corrosion resistance are function of the surface roughness of the machined component. Hence optimizing the machining parameters like cutting speed, feed, depth of cut, cutting force are essential to get the better result in surface roughness [9]. The effect of machining parameters on tool wear and surface roughness of Silicon carbide particulate reinforced aluminium MMC are analysed and found that the surface roughness was generally affected by feed rate and cutting speed [10].

Nomenclature:

RSM	Response surface method
ANOVA	Analysis of variance
DF	Degree of freedom
Vc	Cutting speed (m/min)
F	Feed speed (mm/rev)
d	Depth of cut (mm)
Ra	Arithmetic average of absolute roughness (μm)
BHN	Brinell hardness number
Seq SS	Sequential sum of squares
Adj SS	Adjusted sum of squares
Adj MS	Adjusted mean squares
PC	Percentage contribution ratio
R^2	Determination coefficient
Xi	Coded machining parameters
BUE	Built up edge
Fc	Cutting force (N)
Fr	Radial force (N)
Ff	Feed force (N)

2 Experimental procedure:

2.1 Development of material: The magnesium metal matrix composite with graphite reinforcement (AZ91D + 5% Graphite) is manufactured thro stir casting process by bottom pouring method. AZ91D magnesium alloy contains Mg (91%), Al (8.29%), Zn (0.695%), small traces of Mn, Si. The reinforcement graphite is used as particles of size 50 μm.

The work piece material is casted as rod with a dimension of 200 mm in length and 30 mm in diameter. The required size and shape of specimens was cut from the castings. The hardness test was carried out based on ASTM E10-01 standard in Brinell hardness scale. The hardness of the MMC is found as 84.9 BHN. This material is suitable for a wide variety of automotive-type applications. Gear box casing and steering wheel are examples of automotive components produced using this material where the turning is the prominent machining process used.

2.2 Experimental setup and cutting condition: Turning tests were performed as dry machining in a medium duty PSG 141 lathe with 2.25kW spindle power, with spindle speed range of 30 – 1600 rpm and feed range of 0.05 – 3.5 mm/rev. The high thermal conductivity, free machining characteristics and low cutting pressures of magnesium allows heat to dissipate quickly and hence dry machining is followed. Arithmetic average of absolute roughness Ra, for each machining condition was measured using Mitutoyo roughness tester. The measurements were repeated at three different locations and the average of these values was considered as value for a given turning pass. Syscon make lathe tool dynamo meter is used for measuring the three components of the cutting forces, during turning process. The Peak value of forces during machining are captured by the lathe tool dynamometer for each machining parameter levels. Table 1 refers the machining parameters and their levels

Table (1): Machining parameters and their levels.

Level	Cutting speed Vc (m/min)	Feed rate f (mm/rev)	Depth of cut d (mm)
-1	50	0.25	0.15
0	75	0.35	0.3
1	100	0.45	0.45

2.3 Cutting tool: Carbide is the widely preferred tooling material for most machining operations in magnesium alloys. It gives a good surface finish. The sharp cutting tool is better for reducing the heat [11]. Tungsten coated carbide (K10) cutting tool insert was used for the turning tests. ISO designation of the insert is TNMG 120404. The tool nomenclature is shown in Table (2).

Table (2): Tool nomenclature

Rake angle (□)	Clearance angle (α)	Approach angle (ψ)	Nose radius (r) mm
5	0	60	0.4

2.4 Response surface methodology: Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for the modeling and analyzing of problems in which a response of interest is influenced by several variables and the objective is to optimizing the response [12]. The RSM able to predict the surface roughness value with 3% error as per Kasim et. al [13]. Choudhury et al. [14] used RSM design to estimate the surface roughness during the turning process of high speed steel. Lalwani et al. [15], analysed the influence of cutting parameter in turning on cutting force and surface roughness.

The process yield (y) is a function of the levels of a control variables (x_1, x_2), which can be represented by

$$y = f(x_1, x_2, \ldots\ldots, x_n) + \varepsilon \tag{1}$$

Where ε is observed error in the response y . If the expected response

$$E(y) = f(x_1, x_2, \ldots\ldots, x_n) = \eta$$

then the surface is given by

$$\eta = f(x_1, x_2, \ldots\ldots, x_n) \tag{2}$$

This is called as response surface. A sequential experimentation strategy is followed in RSM, which the search of input factor space by using first order followed by a second order experiments. If the systems has curvature, usually a second order model is used, which is given below

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_i \sum_j \beta_{ii} x_i x_j + \varepsilon \tag{3}$$

The βvalues are derived by least square method and should be determined in second order model. If the data are collected using proper experimental designs, then the model parameters can be estimated effectively. These designs are known as response surface designs and the central composite design (CCD) is one of the efficient designs used in second order experiment. CCD is a full factorial design with all combinations of the factors at three levels (+1, 0, -1). The star points are at the face of the cube on the design, in which the α value is 1. This design is known as a face centered CCD.

The experiment trails are planned using face centered central composite design. The experimental design layout for the three factor (cutting speed - Vc, feed –f and depth of cut - d) with the experimental results for cutting force components and surface roughness is given in Table 3.

3 Results and discussion:

3.1 Surface roughness: The surface roughness Ra has been measured after completing each trial as per the Table 3 and measured values are entered. The relationship between the surface roughness and machining parameters are expressed as follows

The Analysis of variance (ANOVA) was applied to summarise, the tests for significance of regression and individual model coefficients, which were carried out to check the goodness of fit for the obtained model. To analyse the influence of cutting parameters, the main effect plots and probability plots are illustrated in Fig 1, 2. The ANOVA results, shows that the cutting speed, Vc, feed,f, intraction between cutting speed and depth of cut are significant influence on surface roughness Ra. The most significant factor is the cutting speed, Vc, which contributes 72.53%, followed by the feed (7.15% contribution). The interaction between cutting speed and depth of cut contributes 6.81% in surface roughness. From the main effects plot, it is evident that the cutting speed and feed are the main factors that affecting the surface roughness of the magnesium MMC during the turning process.

The surface finish Ra value reduces while the cutting speed increase. Fast material removal is with in short duration during higher cutting speeds and hence lowers the tendency of development of BUE. It improves the surface finish. Also the graphite particles added as reinforcement is act as solid lubricant while turning. At higher cutting speeds, the graphite reinforcement provided burnishing effect. The graphite particles prevents the direct contact between the work piece and tool by lubrication action and improves the surface finish, at high cutting speeds. These findings are inline with Shanmugasundaram et al.[16] in their analysis of influence of graphite presence in Al-fly ash/graphite hybrid composite machining.

Table (3): Experimental conditions, results for surface roughness and cutting forces

Run order	Coded Factors			Cutting speed Vc (m/min)	Feed rate f (mm/rev)	Depth of cut d (mm)	Surface roughness Ra (µm)	Cutting force(N)		
	X1	X2	X3					Fc	Ff	Fr
1	1	-1	-1	100	0.25	0.15	3.846	304.11	186.39	58.86
2	0	0	0	75	0.35	0.30	4.786	412.02	225.63	78.48
3	0	0	0	75	0.35	0.30	6.016	421.83	225.63	78.48
4	1	1	-1	100	0.45	0.15	5.576	362.97	196.20	58.86
5	0	0	0	75	0.35	0.30	6.219	431.64	225.63	88.29
6	0	-1	0	75	0.25	0.30	6.249	402.21	196.20	68.67
7	-1	-1	1	50	0.25	0.45	8.214	470.88	255.06	117.72
8	-1	1	1	50	0.45	0.45	9.122	480.69	274.68	117.72
9	0	0	0	75	0.35	0.30	6.564	431.64	215.82	78.48
10	1	0	0	100	0.35	0.30	4.311	323.73	196.20	49.05
11	0	0	1	75	0.35	0.45	6.308	451.26	235.44	78.48
12	0	0	-1	75	0.35	0.15	5.382	402.21	215.82	78.48
13	0	0	0	75	0.35	0.30	5.356	421.83	225.63	88.29
14	1	-1	1	100	0.25	0.45	3.111	333.54	225.63	68.67
15	1	1	1	100	0.45	0.45	3.814	382.59	225.63	58.86
16	-1	0	0	50	0.35	0.30	7.975	470.88	255.06	107.91
17	0	0	0	75	0.35	0.30	6.066	412.02	215.82	78.48
18	-1	-1	-1	50	0.25	0.15	5.636	441.45	245.25	88.29
19	0	1	0	75	0.45	0.30	5.660	461.07	235.44	88.29
20	-1	1	-1	50	0.45	0.15	8.925	470.88	255.06	107.91

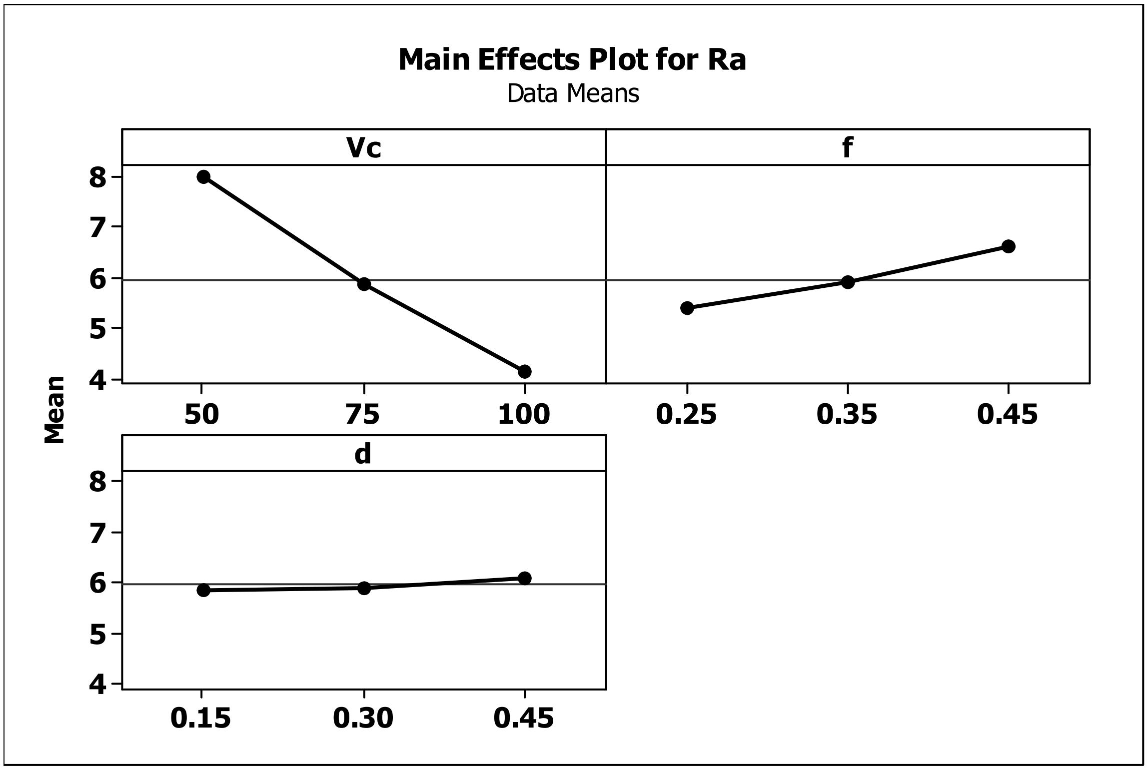

Figure (1): Main effects plot for surface finish: Ra

The surface roughness increased with using higher feed rates, due to increased friction between cutting tool and work piece, which increases the temperature in the cutting zone. The material behaves as ductile manner due to the reduction in shear strength at high temperature. Hence the detachment of chips will be affected, which increases the surface roughness [8]. At higher feeds, the fine chips those produced, will tend to clog at the tool tip,due to high temperature, which increase the surface roughness. The depth of cut and the interactions between feed, depth of cut has less influence on the surface roughness. They doesn't has any significance in surface roughness

From the results of Table 3, the quadratic model of response equation for surface roughness is obtained is as follows

$$Ra = 5.87003 - 1.92040\ Vc + 0.60310\ f + 0.11940\ d + 0.21968\ Vc^2 + 0.03118\ f^2 - 0.07832\ d^2 - 0.21925\ Vc.f - 0.65775\ Vc.d - 0.42725\ f.d \qquad (4)$$

$(R^2 = 90.79\ \%)$

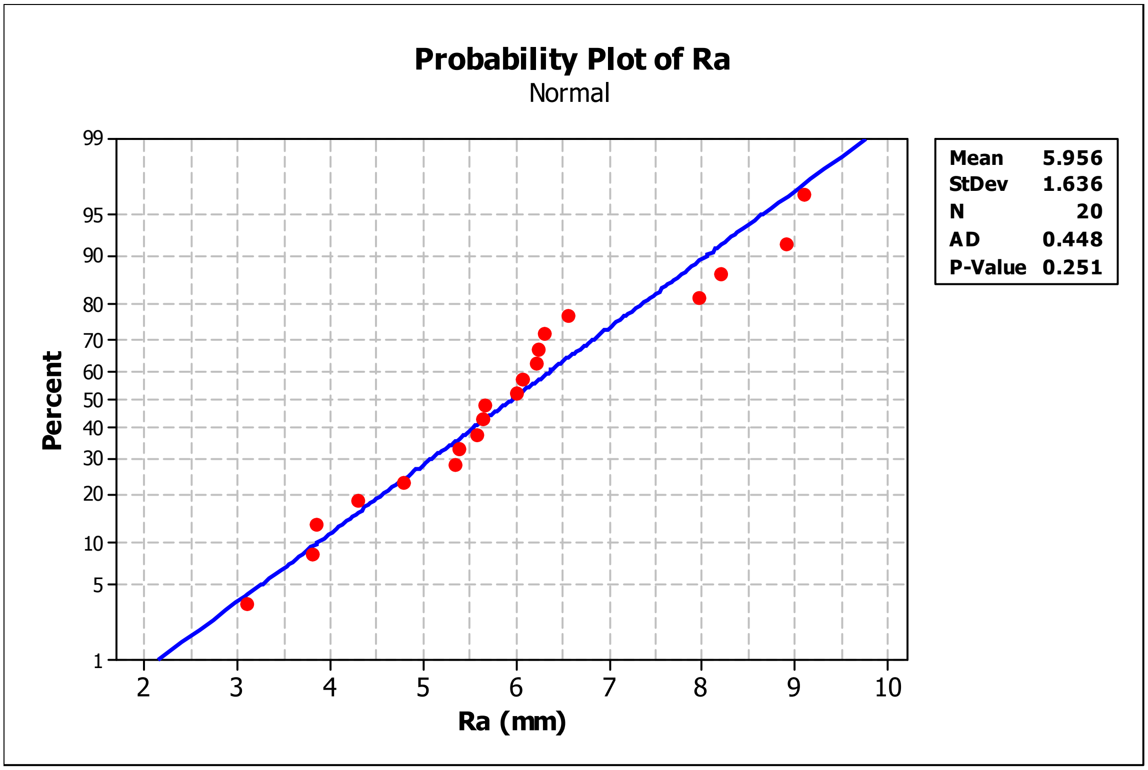

Figure (2): Probability plot for surface finish: Ra

The Anderson-Darling test and normal probability plots of the residuals versus the predicted response for the surface roughness Ra are shown in Fig 2. The data follows almost the straight line. The P value from the above normal plot is greater than 0.05, which implies that the model proposed is adequate.

3.2 Cutting Forces: The three force components during turning process are cutting force (Fc), feed force (Ff) and radial force (Fr). The force acting tangential to turned surface is cutting force. The force which acts along the direction of feed is feed force where as radial force is the force acting perpendicular to turned surface. The Fc and then Ff are major components among the three force components.

The cutting force decreases when the speed is increased, whilst it increases when the feed or depth of cut is increased [17]. During machining process, the material is subjected to extremely high strains and plastic deformation, hence all the energy is converted into heat. Conversion of energy into heat is in two regions of plastic deformation: Shear zone and secondary deformation zone. The heat generated is removed by work piece, chip and tool material. Of all cutting variables, the temperature generation rate is higher when the cutting speed is high, which makes the material soft at cutting zone. The tendency of raising of BUE is high for MMCs and it can be minimized by adopting the high cutting speeds. This helps in removing the material at lower cutting force during turning. When feed is increased, the cutting force is increasing due to the increase in the contact area between the tool and the composite.

Cutting forces are mainly controlled by the matrix materials rather than the reinforcements, but the pressure peaks on the cutting edges are influenced by the reinforcement type and volume. Also by the interface bond strength [18]. The Addition of small amount of graphite in the aluminium matrix increases the machinability of aluminium based metal matrix composites [16]. The reduction of machining forces due to the presence of graphite in MMC matrix. The graphite reinforcement has solid lubricating property, which reduces the friction between the chip and the tool and the reduction of shear flow stress of the material [8].

From Table (4) and Figure (3), it is observed that all the cutting parameters - cutting speed, feed and depth of cut are the significant factors affecting the cutting force Fc, since their P – value is less than 0.05. The cutting speed, Vc, contributes 79.11 %, the feed, f, contributes 8.51 % and the depth of cut, d, contributes 3.78 % in generation of the cutting force Fc. The interaction between cutting speed and feed (Vc.f), also has significant influence. The contribution is 1.18%.

Table (4): Analysis of variance for cutting force: Fc.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Regression	9	48635.8	48635.8	5403.97	45.39	0.000	97.61
Linear	3	45548.5	45548.5	15182.8	127.54	0.000	91.41
Vc	1	39418.3	39418.3	39418.3	331.11	0.000	79.11
f	1	4244.0	4244.0	4244.0	35.65	0.000	8.51
d	1	1886.2	1886.2	1886.2	15.84	0.003	3.78
Square	3	2377.5	2377.5	792.5	6.66	0.010	4.77
Vc * Vc	1	2122.0	1968.5	1968.5	16.53	0.002	4.25
f * f	1	235.8	158.0	158.0	1.33	0.276	0.47
d * d	1	19.7	19.7	19.7	0.17	0.693	0.04
Interaction	3	709.7	709.7	236.6	1.99	0.180	1.42
Vc * f	1	589.4	589.4	589.4	4.95	0.050	1.18
Vc * d	1	12.0	12.0	12.00	0.10	0.757	0.02
f * d	1	108.3	108.3	108.3	0.91	0.363	0.21
Residual Error	10	1190.5	1190.5	119.0			2.38
Lack –of-Fit	5	805.5	805.5	161.1	2.09	0.218	1.61
Pure Error	5	384.9	384.9	77.0			0.77
Total	19	49826.2					

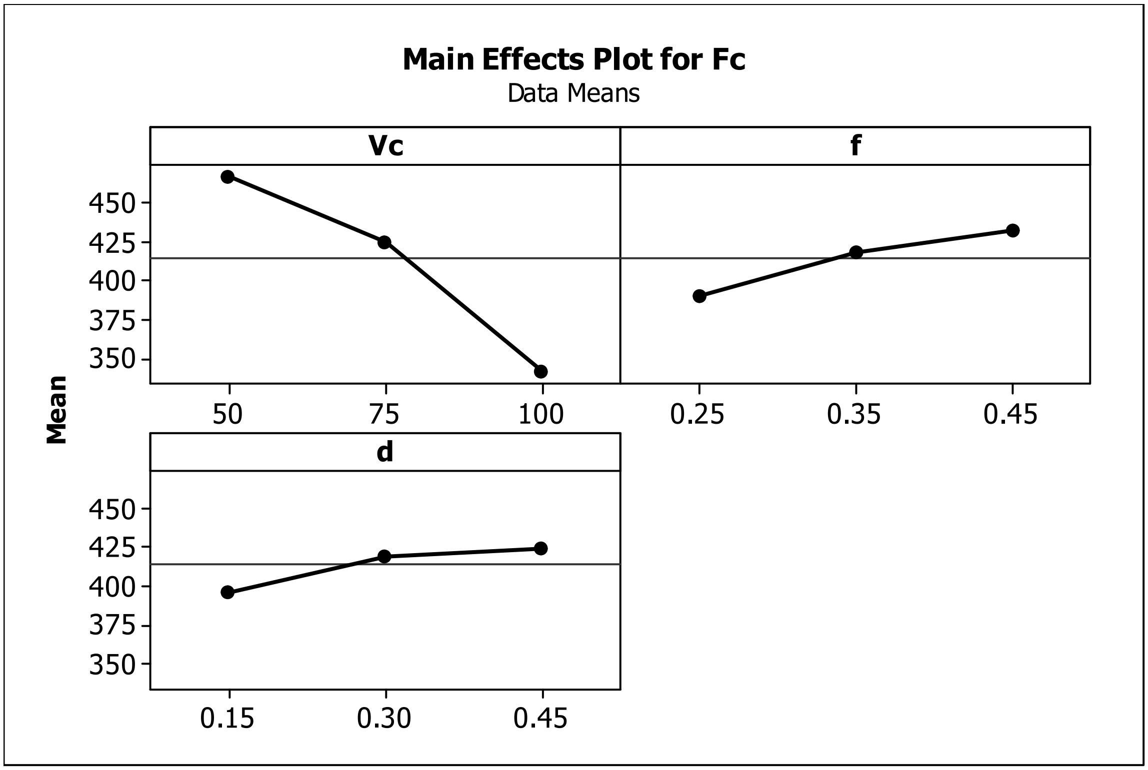

Figure (3): Main effects plot for cutting force : Fc

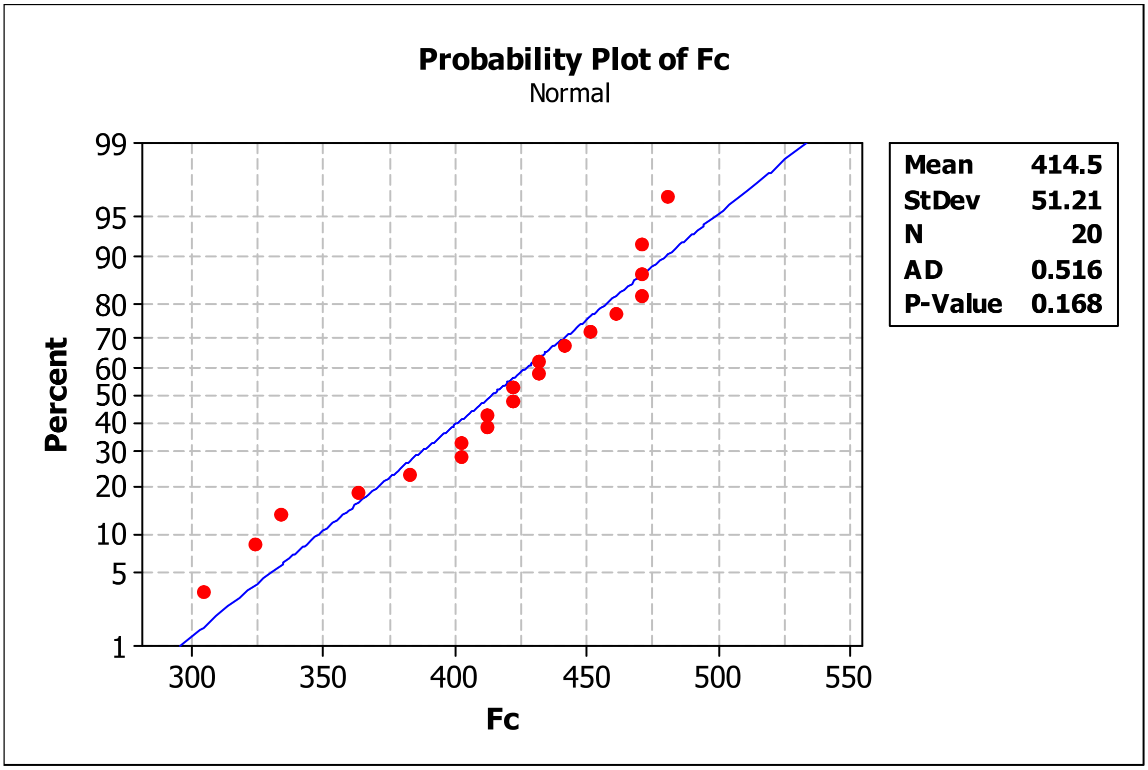

Figure (4): Probability plot for cutting force : Fc

The quadratic model of response equation for cutting force Fc, is obtained is as follows

$$Fc = 422.722 - 62.784\, Vc + 20.601\, f + 13.734\, d - 26.755\, Vc^2 + 7.580\, f^2 + 2.675\, d^2 + 8.584\, Vc.f + 1.226\, Vc.d - 3.679\, f.d \quad (5)$$

$(R^2 = 97.61\ \%)$

The Anderson-Darling test and normal probability plots of the residuals versus the predicted response for the surface roughness Fc are shown in Fig 4. The P value from the above normal plot is greater than 0.05, which implies that the model proposed is adequate one

The influence of cutting parameters on Fc, are illustrated as the response surface plots, contour plots in Figure (5) to Figure (10).

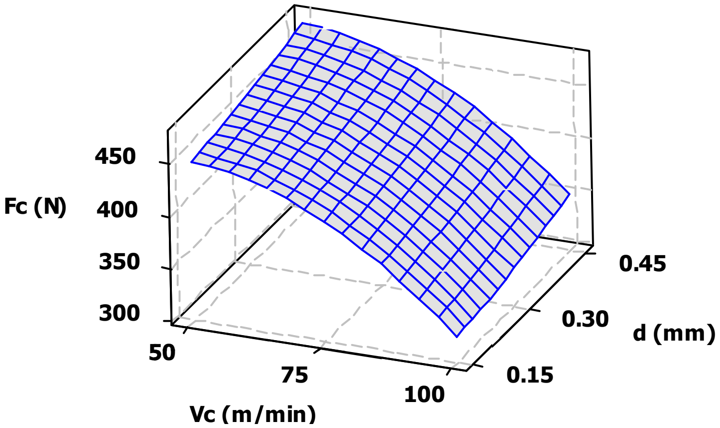

Figure (5): Response surface of cutting force Fc versus Vc and d

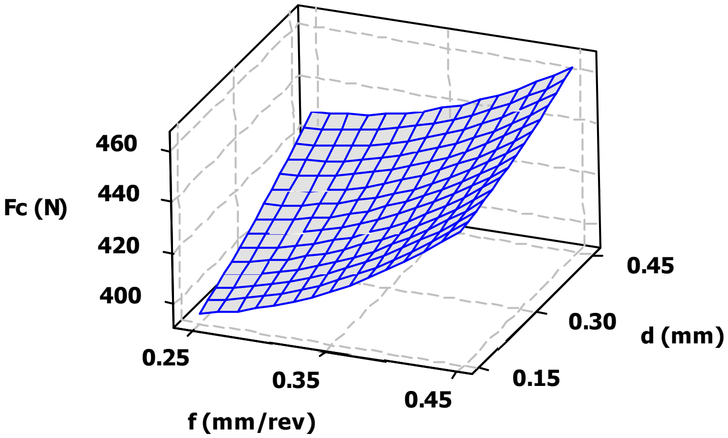

Figure (6): Response surface of cutting force Fc versus f and d

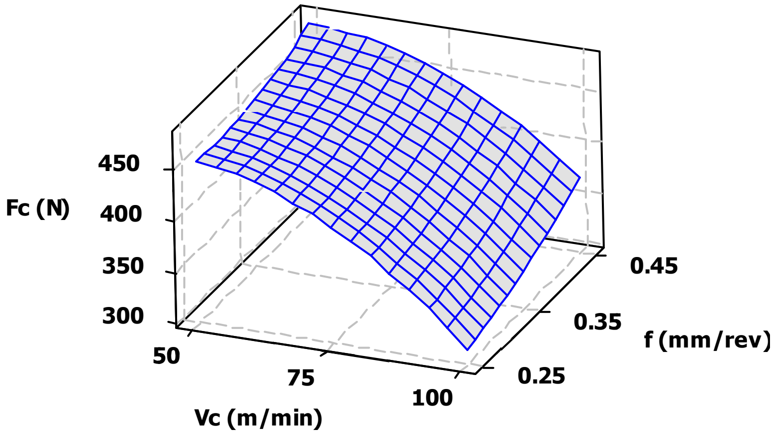

Figure (7): Response surface of cutting force Fc versus Vc and f

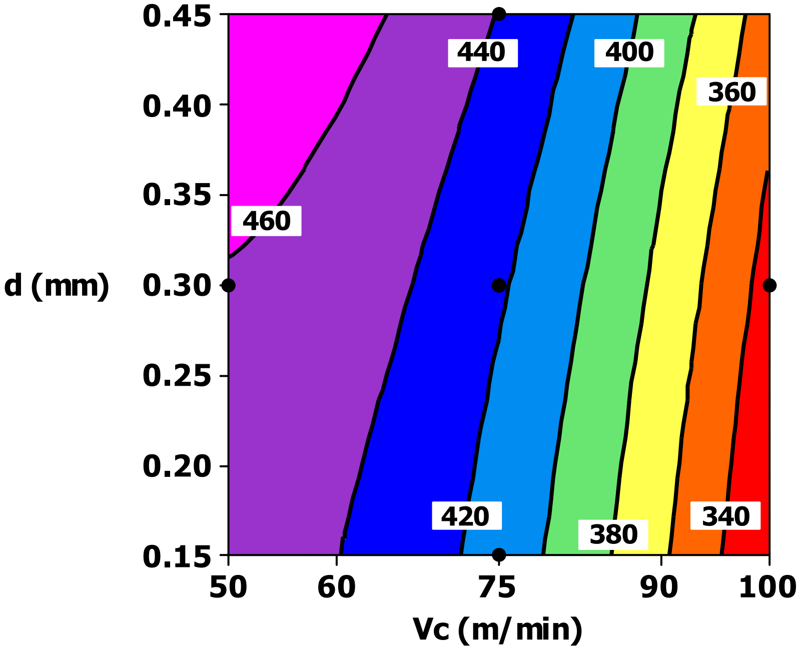

Figure (8): Contour plots of cutting force Fc versus Vc and d

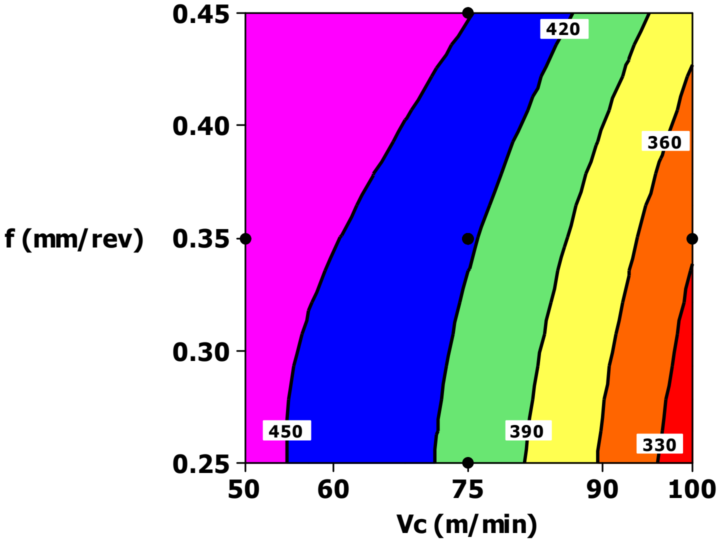

Figure (9): Contour plots of cutting force Fc versus Vc and f

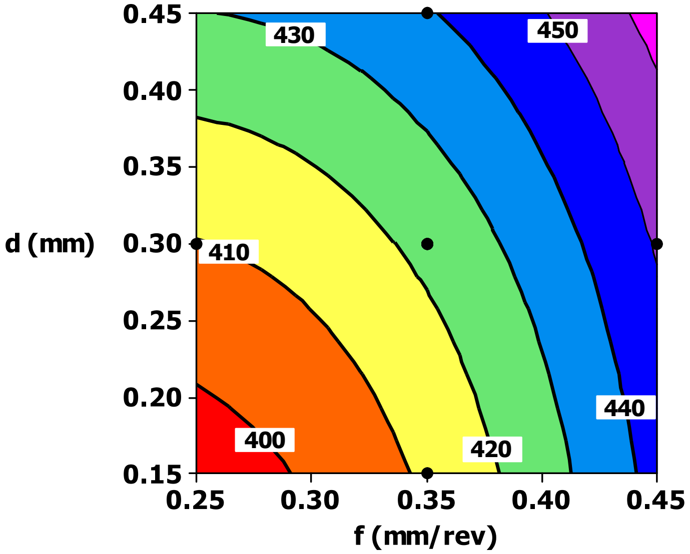

Figure (10): Contour plots of cutting force Fc versus f and d

From Table 5. on ANOVA of feed force Ff, and main effect plot as in Fig 11, it is observed that all the cutting parameters - cutting speed, feed and depth of cut are the significant factors affecting the feed force Ff, since their P value is less than 0.05. The cutting speed, Vc, contributes 65.12 %, the feed, f, contributes 6.16 % and the depth of cut, d, contributes 13.87 % in generation of the force force Ff. The interaction between parameters are doesn't have any significant contribution to feed force Ff.

The quadratic model of response equation for cutting force Ff, is obtained is as follows

$$Ff = 220.814 - 25.506\,Vc + 7.848\,f + 11.772\,d + 7.135\,Vc^2 - 2.675\,f^2 + 7.135\,d^2 - 2.453 Vc.f + 4.905\,Vc.d + 0.\,f.d \quad (6)$$

$(R^2 = 93.79\ \%)$

Table (5): Analysis of variance for feed force (Ff).

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC(%)
Regression	9	9369.02	9369.02	1041.00		0.000	93.79
Linear	3	8507.27	8507.27	2835.76	16.78	0.000	85.16
Vc	1	6505.56	6505.56	6505.56	45.72	0.000	65.12
f	1	615.91	615.91	615.91	104.88	0.010	6.16
d	1	1385.80	1385.80	1385.80	9.93	0.001	13.87
Square	3	621.16	621.16	207.15	22.34	0.064	6.21
Vc * Vc	1	481.18	139.98	139.98	3.34	0.164	4.81
f * f	1	0.00	19.68	19.68	2.26	0.586	0
d * d	1	139.98	139.98	139.98	0.32	0.164	1.40
Interaction	3	240.59	240.59	80.20	2.26	0.330	2.40
Vc * f	1	48.12	48.12	48.12	1.29	0.399	0.48
Vc * d	1	192.47	192.47	192.47	0.78	0.109	1.92
f * d	1	0.00	0.00	0.00	3.10	1.000	0
Residual Error	10	620.29	620.29	62.03	0.00		6.20
Lack –of-Fit	5	491.97	491.97	98.39		0.083	4.92
Pure Error	5	128.31	128.31	25.66	3.83		1.28
Total	19	9989.31					100

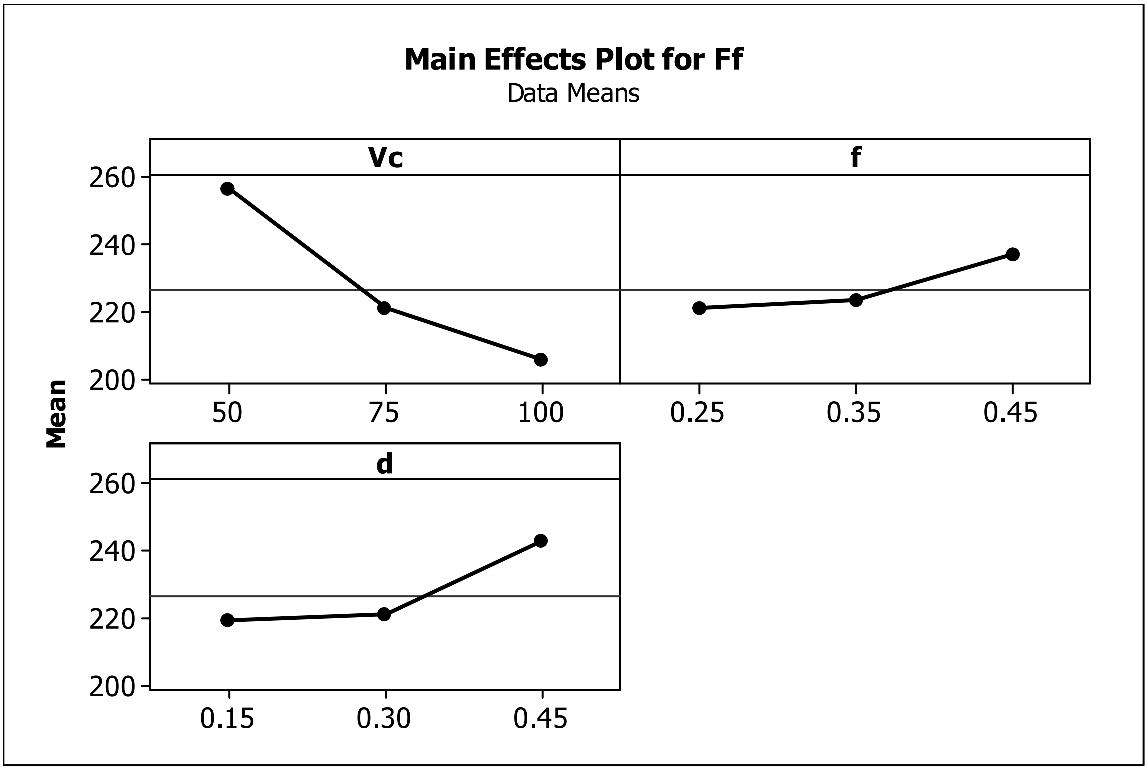

Figure (11): Main effects plot for feed force : Ff

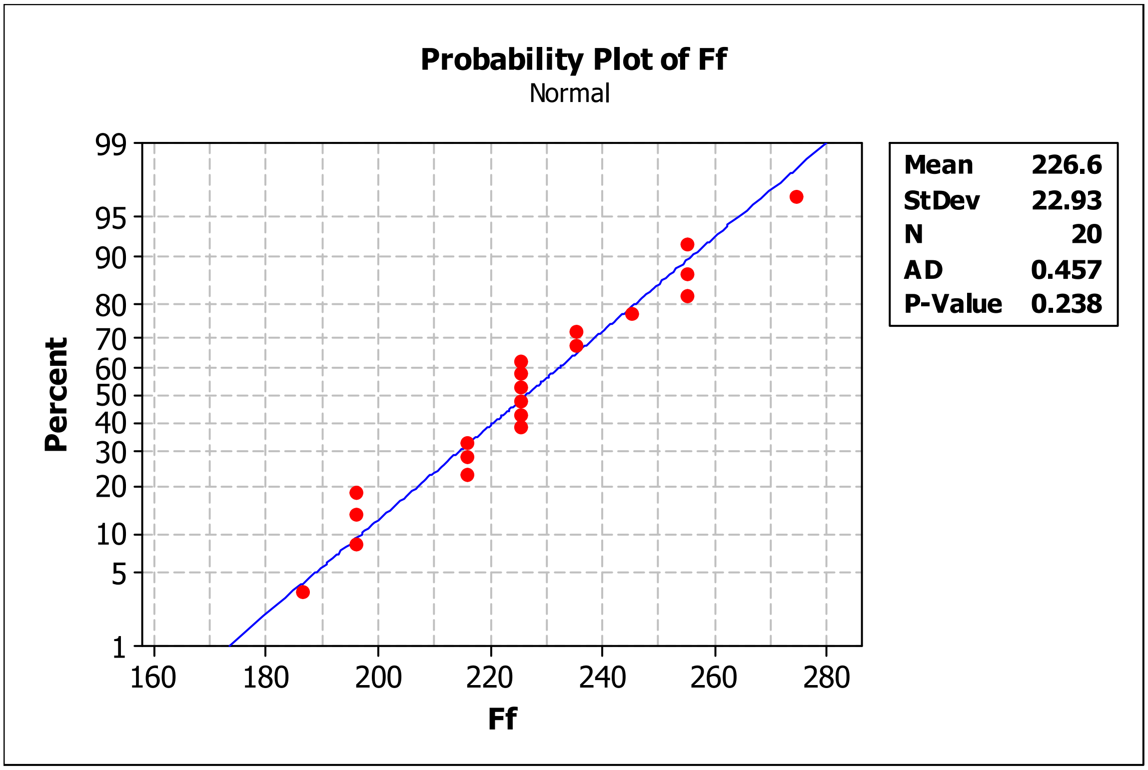

Figure (12): Probability plot for feed force : Ff

The Anderson-Darling test and normal probability plots of the residuals versus the predicted response for the feed force Ff are shown in Fig 12. The data follows almost the straight line. The null hypothesis is that the data distribution law is normal and the alternative hypothesis is that it is abnormal. The P value from the above normal plot is greater than 0.05, which implies that the model proposed is adequate.

The influence of cutting parameters on Ff, are illustrated as the response surface plots, contour plots in Figure (13) to Figure (18).

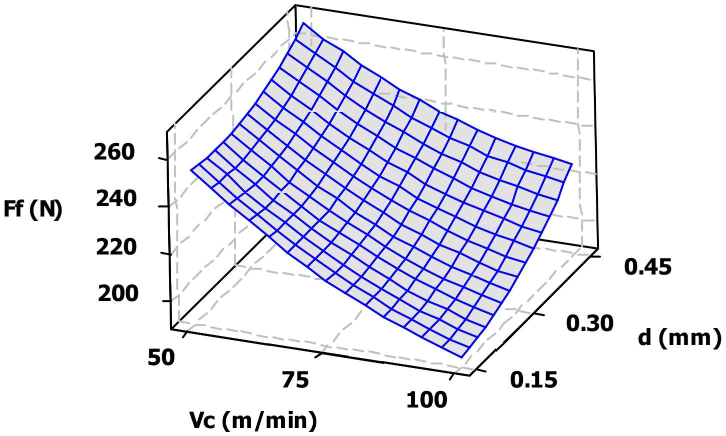

Figure (13): Response surface of cutting force Ff versus Vc and d

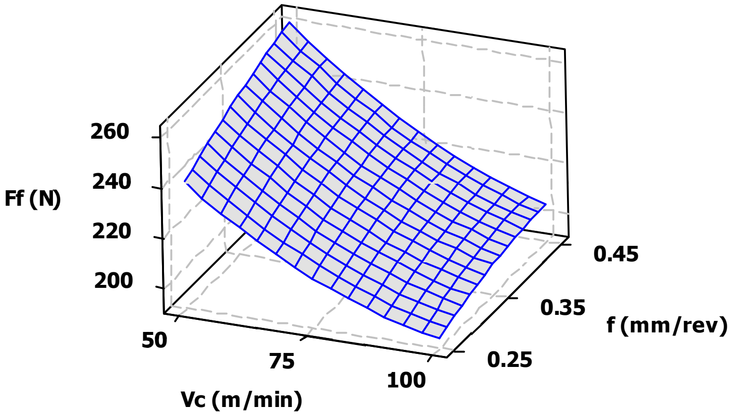

Figure (14): Response surface of cutting force Ff versus Vc and f

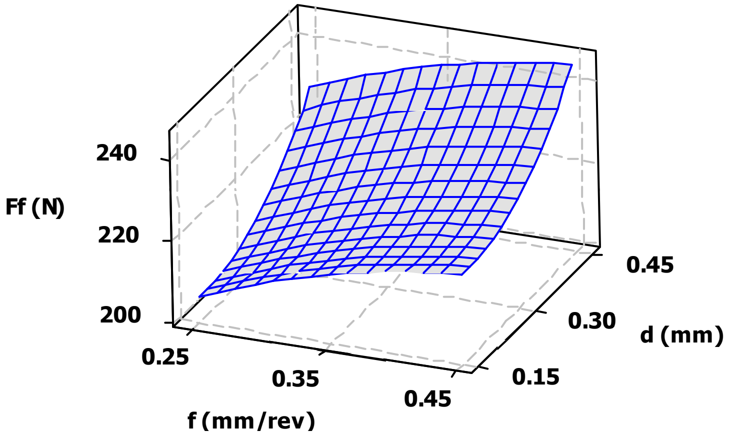

Figure (15): Response surface of cutting force Ff versus f and d

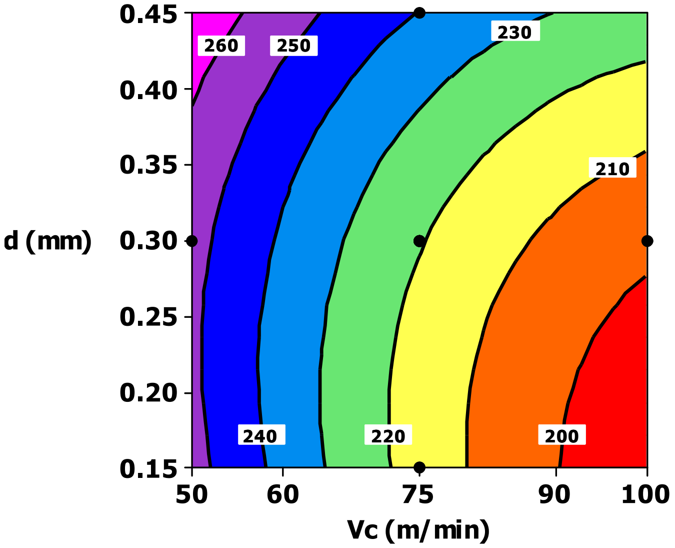

Figure (16): Contour plots of cutting force Ff versus Vc and d

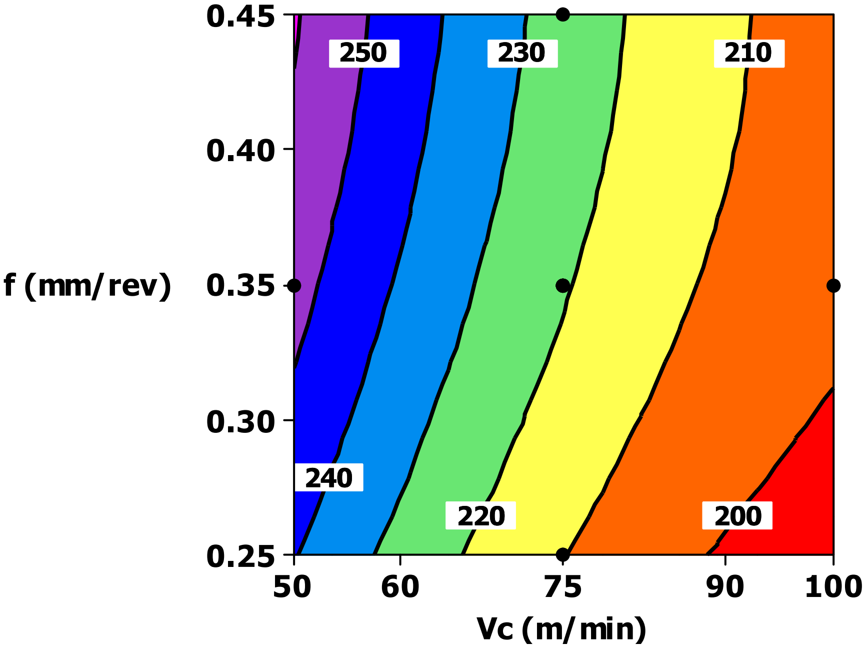

Figure (17): Contour plots of cutting force Ff versus Vc and f

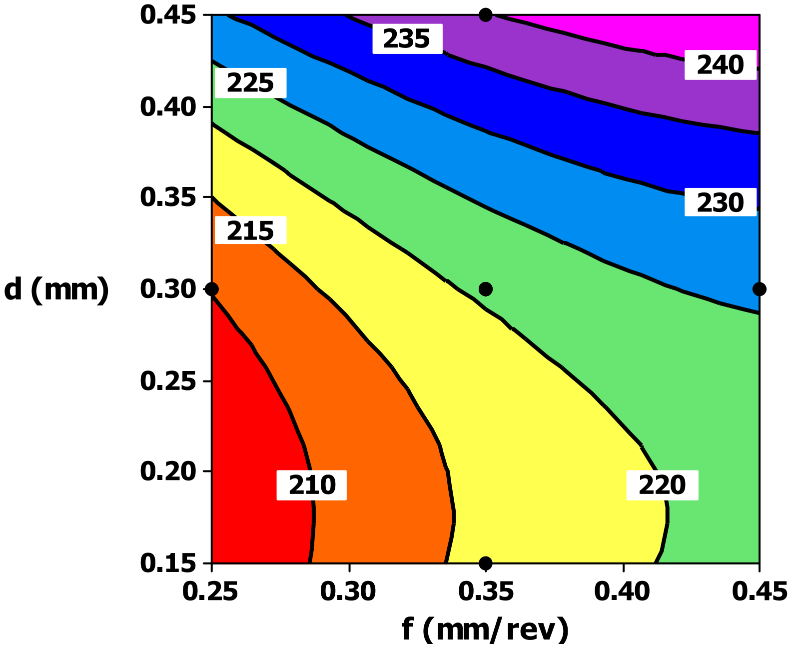

Figure (18): Contour plots of cutting force Ff versus f and d

Table (6): Analysis of variance for cutting force : Fr.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	PC (%)
Regression	9	6725.81	6725.81	747.31			93.74
Linear	3	6341.96	6341.96	2113.99	16.66	0.000	88.39
Vc	1	6014.76	6014.76	6014.76	47.12	0.000	83.83
f	1	86.61	86.61	86.61	134.08	0.000	1.20
d	1	240.59	240.59	240.59	1.93	0.195	3.35
Square	3	59.05	59.05	19.68	5.36	0.043	0.82
Vc * Vc	1	43.31	4.92	4.92	0.44	0.730	0.60
f * f	1	10.83	4.92	4.92	0.11	0.747	0.14
d * d	1	4.92	4.92	4.92	0.11	0.747	0.06
Interaction	3	324.80	324.80	108.27	0.11	0.747	4.52
Vc * f	1	108.27	108.27	108.27	2.41	0.127	1.50
Vc * d	1	108.27	108.27	108.27	2.41	0.151	1.50
f * d	1	108.27	108.27	108.27	2.41	0.151	1.50
Residual Error	10	448.59	448.59	44.86	2.41	0.151	6.25
Lack –of-Fit	5	320.28	320.28	64.06			4.46
Pure Error	5	128.31	128.31	25.66	2.50	0.169	1.78
Total	19	7174.40					100

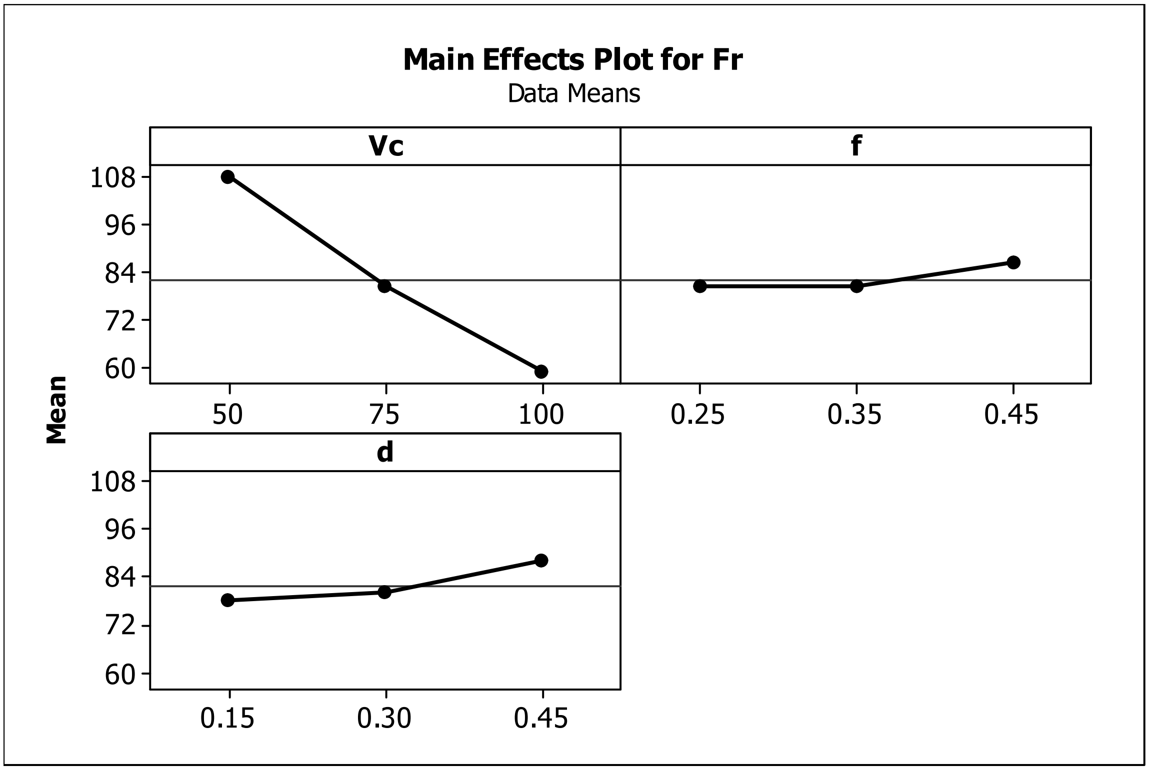

Figure (19): Main effects plot for feed force : Fr

From Table 6. on ANOVA of radial force Fr, and main effect plot as in Fig 19, it is observed that the cutting parameters - cutting speed and depth of cut are the significant factors affecting the radial force Fr, since their P value is less than 0.05. The cutting speed, Vc, contributes 83.83 %, and the depth of cut, d, contributes 3.35 % in generation of the radial force Fr. The feed and the interactions between the cutting forces are doesn't have any significance on the radial force.

The quadratic model of response equation for radial forces - Fr is obtained is as follows

$$Fr = 79.907 - 24.525\ Vc + 2.943\ f + 4.905\ d + 1.338\ Vc^2 + 1.338\ f^2 + 1.338\ d^2 - 3.679 Vc.f - 3.679\ Vc.d - 3.679\ f.d \qquad (7)$$

$(R^2 = 93.75\ \%)$

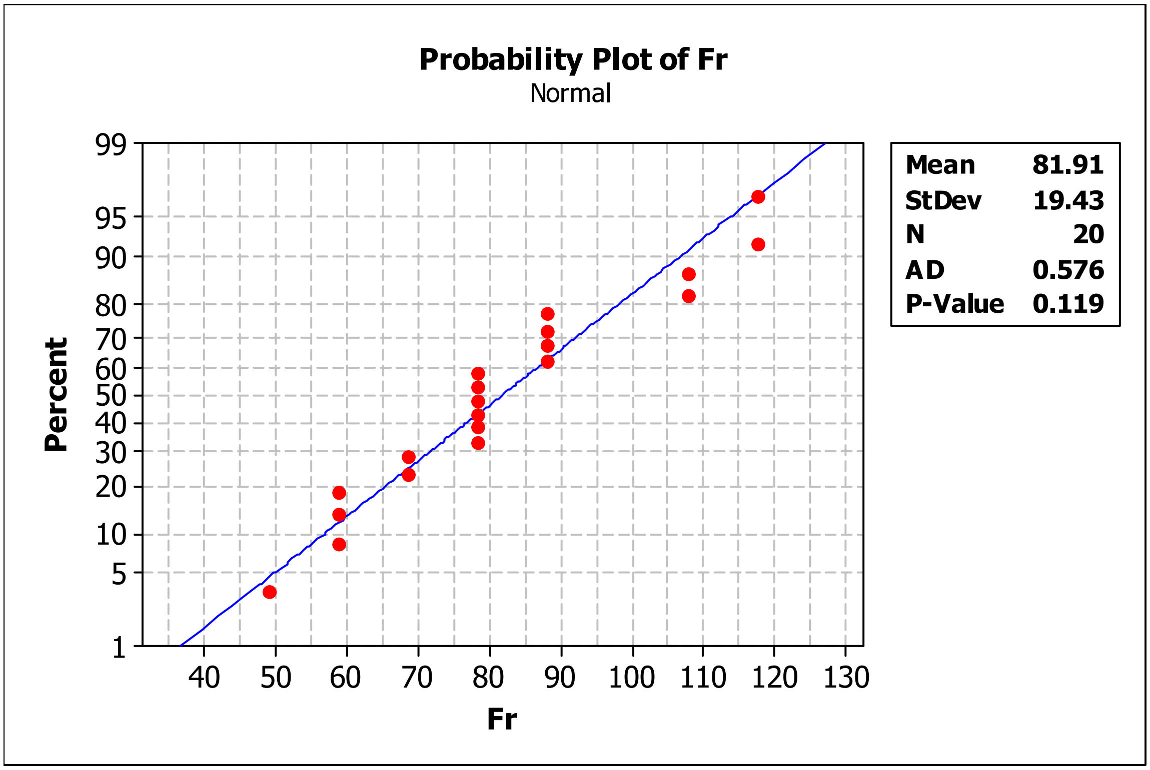

Figure (20): Probability plot for feed force : Fr

Anderson-Darling test and normal probability plots of the residuals versus the predicted response for the feed force are shown in Figure (20). The data follows almost the straight line . The P value from the above normal plot is greater than 0.05, which implies that the model proposed is adequate one

The response surface plots and contour plots of radial force versus cutting speed, feed and depth of cut are depicted in the Figure (21) to Figure (26). For each plot, the variable that not represented is held at a constant value, that is in middle value. These plots confirm the points observed during the above analysis.

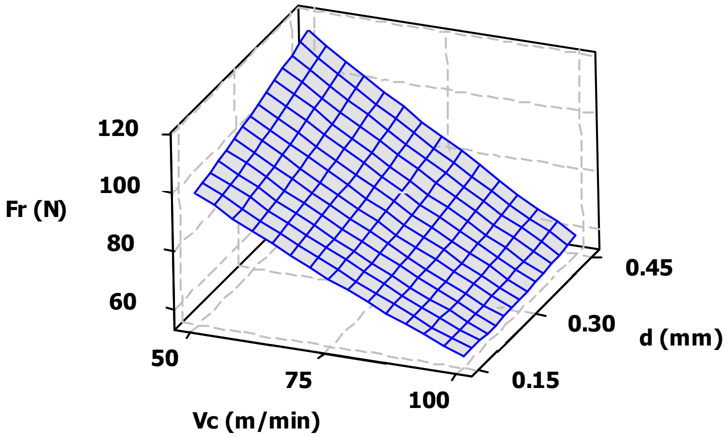

Figure (21): Response surface of cutting force Fr versus Vc and d

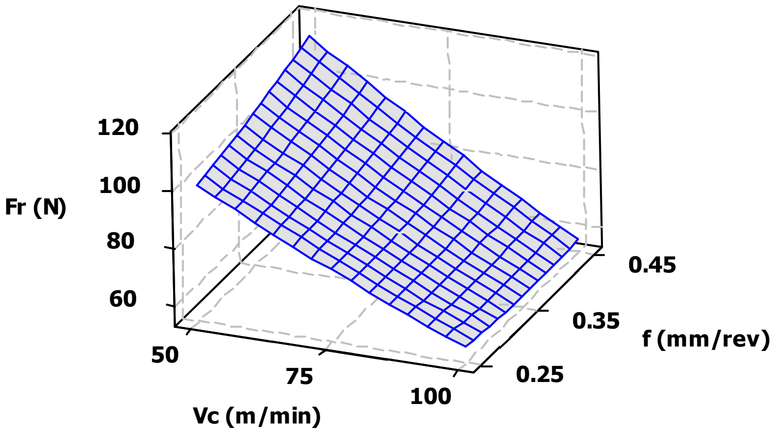

Figure (22): Response surface of cutting force Fr versus Vc and f

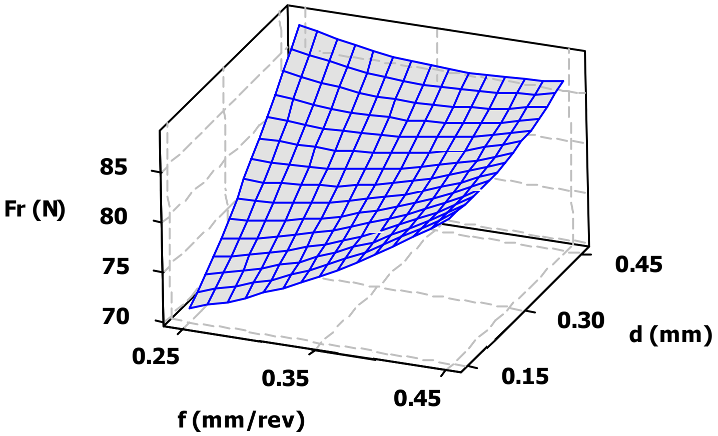

Figure (23): Response surface of cutting force Fr versus f and d

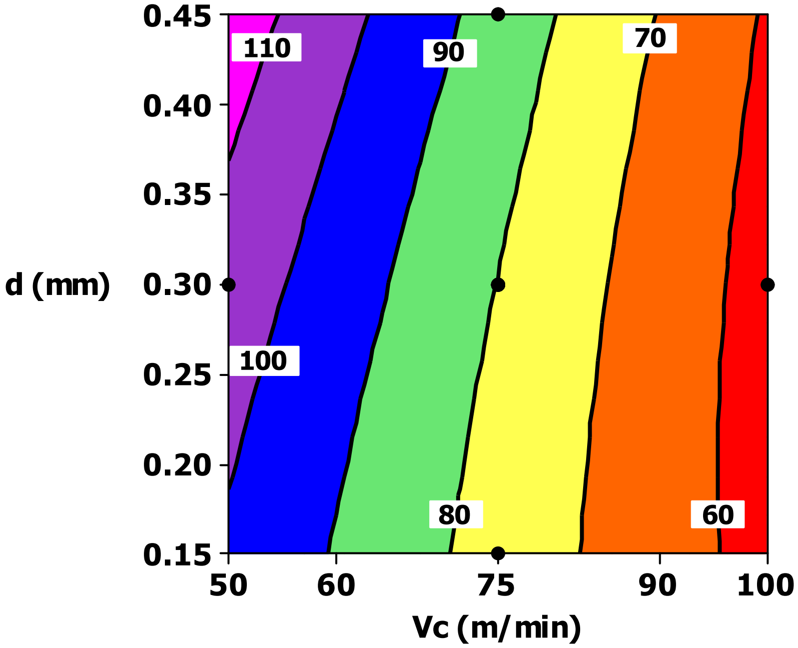

Figure (24): Contour plots of cutting force Fr versus Vc and d

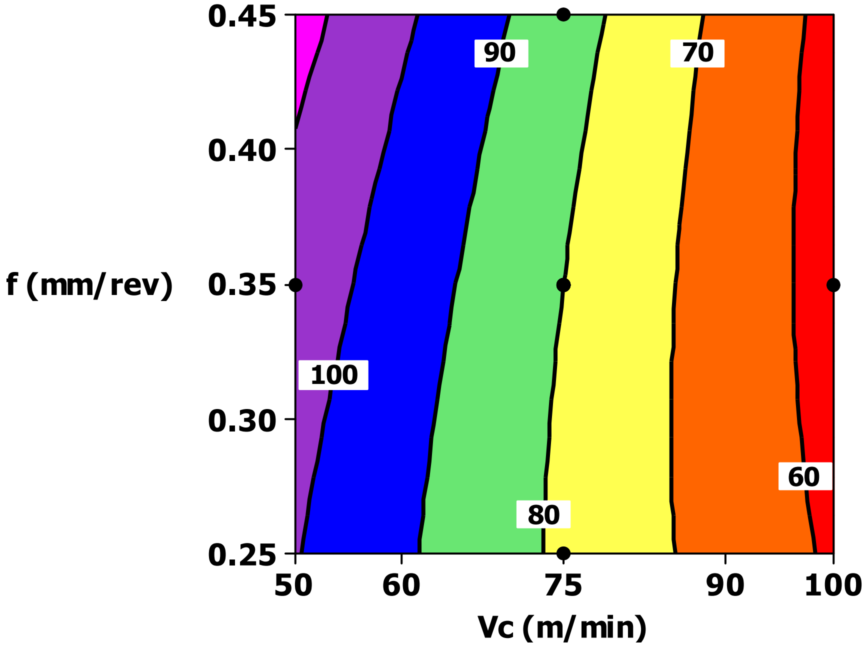

Figure (25): Contour plots of cutting force Fr versus Vc and f

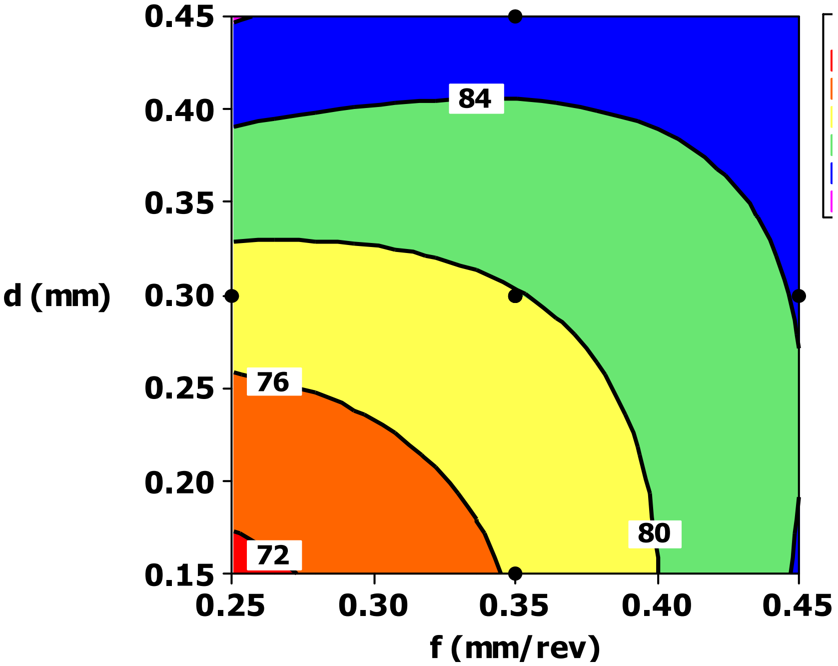

Figure (26): Contour plots of cutting force Fr versus f and d

3.3 Chip formation: The chip formation influences the surface finish, dimensional accuracy, cutting temperature as well as tool life, hence it is an important parameter to be studied. The graphite particles reinforcement dispersed in the metal matrix composites acts as chip breakers and hence the continuous chip formation reduced, results in short chips and also reduction in surface roughness [16,19]. The chips formed during the machining of Magnesium MMC were shorter. Since magnesium MMC has high thermal conductivity, the machining increases a layer of material undergoes warming and mean temperature of the cutting zone decreases. Hence the chip formation is tends to be more fragmented due to brittleness and the chips are short. Also the addition of 5% graphite increases the brittleness of the matrix, due to which the chips are short in length, during turning process.

4. Conclusions: The surface roughness and components of forces during machining - cutting force, Fc, feed force, Ff and radial force, Fr, has been evaluated in the magnesium metal matrix composite are with 5% graphite as reinforcement, in the turning process, using the response surface methodology. The following conclusions are drawn.

- The quadratic model explaining relationship between the machining parameters and the responses like surface finish, cutting force, Fc, feed force, Ff and radial force, Fr are arrived.
- Cutting speed and feed rate has significant influence on surface roughness. Higher the cutting speed Vc and lower the feed rate f , better the surface finish and vice versa. The variation in depth of cut has not affects the surface roughness significantly.
- The presence of graphite reinforcement in the metal matrix acts as a solid lubricant and at high speed cutting speeds, it reduces the interface between the work piece and cutting edge. Due to this, improvement in surface finish and the reduction in cutting forces are achieved.

- The cutting force decreases with increase in cutting speed. The cutting forces increases when the feed or depth of cut is increased.
- The cutting force Fc is the largest force component when compared to feed force, Ff and radial force Fr.
- The chip formation is tends to be more fragmented due to brittleness of heat affected cutting zone and the chips are short.
- Contour, surface plots of cutting forces were constructed in planes containing two independent variables and can be used for prediction within the investigated limits.

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