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Studies on the Effect of Turning Operation on Mean Cutting Force and Cutting Power of AISI 3415 Alloy Steel

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Abstract: This exploration is conceded to reveal the outcome of machining factors such as cutting velocity, depth of cut and feed rate on the mean cutting force and the cutting power on turning AISI 3415 cylindrical steel alloy components. The experiments are planned based on the (33) full factorial design and conducted on an All Geared Lathe with TiN coated cutting tool insert of 0.8mm nose radius, simultaneously cutting forces such as feed force, thrust force and tangential force are observed using a calibrated lathe tool dynamometer adapted in the tool holder. A mathematical expression representing mean cutting force and cutting power is created by means of non-linear regression examination. The outcome of each machining factors on the mean cutting force and the cutting power is studied and presented accordingly.

Index Terms: AISI 3415 steel alloy; Cutting force; Cutting power; Full factorial design; Lathe; Regression analysis

I. INTRODUCTION

In past two decades, the utilization of steels has extended massively in various fields in view of good quality, extraordinary hardness, incredible wear obstruction, and so forth [1 – 2]. As of late steel metals are extensively utilized for different functions in vehicle and airplane enterprises. Meanwhile, machining of these steels is a troublesome, which is more repeatedly exposed by the makers and research people for long era. [3 – 4].

The device which expels unwanted materials from the workpiece due to the relative motion from the machine tool is known as cutting tool insert. A cutting tool insert should possess characteristics such as toughness, hardness and wear resistant. The interest for rapid machining forces a permanent attempt for enhancing the technological performances of the cutting tools utilized i.e. wear obstruction, heat exchange, and working time. Layering a cutting device enhances wear opposition and prolongs device life. Layering execution firmly relies upon the substance and the mechanical properties of the layering material [5 – 7]. Titanium-based coatings provided to the cutting tool is familiar in the steel alloy machining due to its hard thin layer deposited onto the base tool [8 – 11]. Titanium Nitride (TiN) is a very fashionable coating applied to the carbide cutting tool insert because TiN acquires some useful properties such as elevated hardness, elevated strength, elevated chemical stability, tremendous resistance to

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Built Up Edge(BUE) formation, little coefficient of friction. Thus, while machining steel alloys TiN coated carbide tool inserts could be applied at higher feed rates and cutting velocities [12 – 13]. Many practitioners and research personalities are working in the field of machining of steel alloy with TiN coated carbide insert, few are presented below; Bhattacharya et al., [14] employed DoE to explore about the impact of factors on surface roughness and forces during rapid machining of AISI1045 steel by TiN covered carbide device. Speed was the huge factor on surface roughness and cutting force, while feed and depth of cut did not generously influence the outcome. Aggarwal.et al., [15], Nur et al., [17] analyzed the cutting force in turning of compound steel utilizing TiN covered carbide embed with DoE approach. The cryogenic condition was the most critical factor in minimizing the cutting force pursued by cutting speed and depth of cut. The possessions of feed rate and nose radius were observed to be less important on the outcome. Cakir et al., [18], Asiltürk et al., [19] made a logical representation for surface roughness in machining of compound steel by TiN covering on carbide embed by Chemical Vapor Deposition(CVD) technique. Higher feed rates conveyed higher surface roughness esteems while the factor speed had contrary outcome and depth of cut did not basically impact. From the journalism expressed above, it turns out to be certain that machining investigations have been completed by different specialists in the field of machining metals. In any case, there stays some trouble in the machining of metal, which uncovers that still additional investigation must be done to locate a sensible arrangement. In this way, examination on machining is completed by making utilization of the demonstrated test plan method.

II. EXPERIMENT DETAILS

- Selection of workpiece – AISI 3415 (ϕ80 mm x 150 mm)
- Cutting tool used – TiN coated carbide insert
- Machine tool – Turning centre
- Cutting fluid – Mineral based (Servocut ‘S’) emulsion
- Coolant application technique – Flooded (wet)
- Planning of experiment – Full factorial design (3^3 = 27 experiments).
- Repeatability of experiments – 3 times
- Output response – Cutting forces, Cutting power

A. *Work Piece*

Round workpiece prepared of AISI3415 steel with a size of (ϕ80mm x 150mm) was preferred for this research. AISI3415 is a nickel-chromium

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steel alloy and is used for the manufacture of main axis, gear shaft, valve rods, mechanical gears, connecting rods, multidiameter shafts, nuts, and bolts. The chemical composition of AISI3415 steel is given in Table1.

Table 1: Chemical composition

Element	% Composition	
	Standard	Tested
C	0.1-0.2	0.17
Ni	2.75-3.25	3.12
Cr	0.6-0.95	0.87
Mn	0.3-0.5	0.41
P	0.04max.	0.030
Si	0.15-0.3	0.270
S	0.05max.	0.041
Fe	Rest	95.090

B. Cutting Tool

A universal CNMG diamond finishing TiAlN layered carbide insert of 0.8mm nose radius and PCLNR tool holder was utilized to do the turning operation on AISI3415 steel components.

C. Cutting Fluid

Mineral oil blended with a stream of water was utilized as cutting fluid for this investigation. The properties of the base oil are specified in Table2.

Table 2: Properties of oils

Property	Value
Flash Point(^{0}C)	150
Kinematic Viscosity at 40^{0}C(cSt)	20
Specific gravity(No Unit)	0.877

D. Experimental Conditions

The most influencing turning factors such as feed rate, cutting velocity and depth of cut considered for the experimentation and their levels are indicated in Table 3. The trials were arranged in view of (3^3) full factorial design in a turning centre (All Geared Lathe), appeared in Figure 1 and the conditions of the Lathe is specified in Table 4. The turning operation is done on AISI 3415 cylindrical components of 80 mm diameter by utilizing TiN layered carbide insert in traditionally flooded machining condition and the machining operation is publicized in Figure 2.

Table 3: Control factors and Levels

Notation	Control factors	Unit	Levels		
			1	2	3
v	Cutting velocity	m/min	225	275	325
f	Feed rate	mm/rev	0.1	0.15	0.2
d	Depth of Cut	mm	0.2	0.4	0.6

Figure 1: Experimental setup

Table 4: Conditions of the lathe

Condition	Range
Longitudinal feed(mm)	0.05 – 0.752
Cross feed(mm)	0.025 – 0.376
Speed(rpm)	40-2800

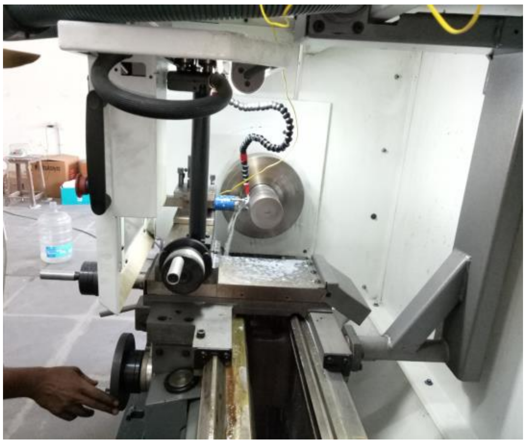

Figure 2: Turning of AISI 3415 steel in a flooded condition

III. RESULTS AND DISCUSSION

A. Experimental plan and results

Table 5: Experimental plan and results

Sl. No.	Control factors			Cutting forces (N)				Cutting power	
	v	f	d	Fa	Fc	Fp	Fm	Cp (W)	Cp (kW)
1	225	0.1	0.2	11.29	24.02	44.14	51.50	90.06	0.090
2	225	0.1	0.4	16.66	31.47	67.69	76.48	118.00	0.118
3	225	0.1	0.6	21.43	40.63	98.53	108.72	152.36	0.152
4	225	0.15	0.2	11.88	27.42	52.53	60.44	102.83	0.103
5	225	0.15	0.4	13.64	35.64	73.20	82.55	133.63	0.134
6	225	0.15	0.6	27.56	51.67	105.67	120.81	193.76	0.194
7	225	0.2	0.2	19.06	41.63	58.03	73.92	156.12	0.156

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8	225	0.2	0.4	24.98	47.30	89.32	104.11	177.37	0.177
9	225	0.2	0.6	35.39	85.77	131.26	160.74	321.64	0.322
10	275	0.1	0.2	4.42	8.44	38.01	39.18	38.66	0.039
11	275	0.1	0.4	10.37	20.40	38.72	44.97	93.49	0.093
12	275	0.1	0.6	18.29	38.75	77.00	88.12	177.60	0.178
13	275	0.15	0.2	3.60	6.44	24.51	25.60	29.51	0.030
14	275	0.15	0.4	12.35	20.52	40.94	47.43	94.07	0.094
15	275	0.15	0.6	19.55	37.16	79.71	90.09	170.32	0.170
16	275	0.2	0.2	9.89	21.56	40.94	47.32	98.84	0.099
17	275	0.2	0.4	23.18	55.66	63.11	87.28	255.10	0.255
18	275	0.2	0.6	33.09	87.03	110.56	144.55	398.89	0.399
19	325	0.1	0.2	0.93	4.92	34.07	34.43	26.62	0.027
20	325	0.1	0.4	8.74	18.06	44.37	48.70	97.85	0.098
21	325	0.1	0.6	23.15	46.57	65.02	83.26	252.27	0.252
22	325	0.15	0.2	2.33	5.25	19.12	19.97	28.44	0.028
23	325	0.15	0.4	10.41	20.82	41.70	47.75	112.75	0.113
24	325	0.15	0.6	24.84	51.22	72.48	92.16	277.44	0.277
25	325	0.2	0.2	7.75	17.03	29.14	34.62	92.23	0.092
26	325	0.2	0.4	17.56	37.60	48.18	63.59	203.68	0.204
27	325	0.2	0.6	34.19	81.54	114.00	144.27	441.69	0.442

Table 6: Analysis of variance for mean cutting force

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
v	1	4065.2	11.04%	314.6	314.64	1.87	0.187
f	1	4513.8	12.26%	12.1	12.08	0.07	0.792
d	1	23165.5	62.90%	97.2	97.24	0.58	0.456
vf	1	56.2	0.15%	56.2	56.24	0.33	0.570
vd	1	57.4	0.16%	57.4	57.44	0.34	0.566
fd	1	1603.4	4.35%	1603.4	1603.39	9.53	0.006
Error	20	3366.1	9.14%	3366.1	168.30		
Total	26	36827.7	100.00%				
R^2-0.91				**R^2(Adj)-0.88**			

Table 7: Analysis of Variance for cutting power

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
v	1	0.000422	0.14%	0.011316	0.011316	7.11	0.015
f	1	0.067057	22.47%	0.000298	0.000298	0.19	0.670
d	1	0.164863	55.25%	0.003920	0.003920	2.46	0.132
vf	1	0.000365	0.12%	0.000365	0.000365	0.23	0.637
vd	1	0.021281	7.13%	0.021281	0.021281	13.36	0.002
fd	1	0.012554	4.21%	0.012554	0.012554	7.88	0.011
Error	20	0.031846	10.67%	0.031846	0.001592		
Total	26	0.298389	100.00%				
R^2-0.89				**R^2(Adj)-0.86**			

$$Fm = \sqrt{(Fa^2 + Fc^2 + Fp^2)} \quad (1)$$

$$Cp = Fc * v \quad (2)$$

The mean cutting force (Fm) and the cutting power (Cp) is calculated using equation (1) and equation (2) respectively.

B. *Analysis of variance*

The noteworthy factor on the response output (mean cutting force and cutting power) was analyzed through ANOVA and F-test with a chance of probability (*p*=0.05), which was shown in Table 6 and Table 7.

The estimation of "Prob.>F" in Table 6 and Table 7 for the model is under 0.05, which demonstrates that the representation is important, which is pleasing as it shows that the terms in the representation significantly affect the yield responses (mean cutting force and cutting power). From ANOVA results, it is obvious that the depth of cut impacts more on the mean cutting force and cutting power, trailed by the feed rate and cutting velocity. This is harmonizing with the current hypotheses of machining.

C. *Mathematical model*

By means of regression examination with the aid of MINITAB17 numerical software, the outcome of control factors on mean cutting force (Fm) and cutting power (Cp) was modeled as follows.

Fm=47.9-15.1v–3f+8.4d-2.16vf+2.19vd+11.56fd (3)

Cp=0.1573-0.0904v-0.0147f-0.0532 d+0.0055vf+0.0421vd+0.0323fd (4)

For equation (3), it was found that R^2 = 0.91 and for equation (4) also, R^2 = 0.89. Where 'R' is the correlation coefficient and the value of 'R^2' shows the nearness of the mathematical representation in lieu of the yield response.

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D. Effect of machining factors

The effect of machining factors on the mean cutting force and cutting power was studied and presented in the below section.

Figure 3 depicts the outcome of cutting velocity and feed rate on the mean cutting force, where the depth of cut is kept constant. From Figure 3 it is obvious that, feed rate influences more than the cutting velocity, at a maximum feed rate and maximum cutting velocity, lesser cutting forces were observed. Figure 4 portrays the outcome of cutting velocity and depth of cut on the mean cutting force, where feed rate is kept constant. From Figure 4 it is obvious that the depth of cut influences more than the cutting velocity, at a maximum depth of cut and maximum cutting velocity, increased cutting forces were observed. Figure 5 depicts the outcome of feed rate and depth of cut on the mean cutting force, where cutting velocity is kept constant. From Figure 5 it is obvious that, the depth of cut influences more than feed rate on cutting forces, at a maximum feed rate and a maximum depth of cut, increased cutting forces were observed.

Figure 6 depicts the outcome of cutting velocity and feed rate on the cutting power, where the depth of cut is kept constant. From Figure 6 it is obvious that, cutting velocity influences more than the feed rate, at a maximum cutting velocity and minimum feed rate lesser cutting power was consumed. Figure 7 portrays the outcome of cutting velocity and depth of cut on the cutting power, where feed rate is kept constant. From Figure 7 it is obvious that the depth of cut influences more than the cutting velocity, at a maximum depth of cut and maximum cutting velocity, increased cutting power was consumed. Figure 8 depicts the outcome of feed rate and depth of cut on the cutting power, where cutting velocity is kept constant. From Figure 8 it is obvious that, feed rate has an influence on cutting power, the interaction between the feed rate and depth of cut has a significant influence on the cutting power.

While machining cylindrical AISI3415 steel alloy components in flooded machining condition, the cutting forces observed axially, tangentially and radially and the corresponding cutting power played a major role. Maximum cutting forces and cutting power was observed at higher levels of control factors such as 325 m/min of cutting velocity, 0.2 mm/rev of feed rate and 0.6 mm of the depth of cut. The cutting forces and the power required for machining might increase in the increase of the control factors namely cutting velocity, feed rate and depth of cut. The increase in cutting forces ultimately reduces the tool life, which reflects poorly in the production economy. In lieu consideration of the above said facts, the optimum condition for mean cutting force such as 325 m/min of cutting velocity, 0.15 mm/rev of feed rate and 0.2 mm of depth of cut and for optimum cutting power it is 325 m/min of cutting velocity, 0.10 mm/rev of feed rate and 0.2 mm of depth of cut was observed.

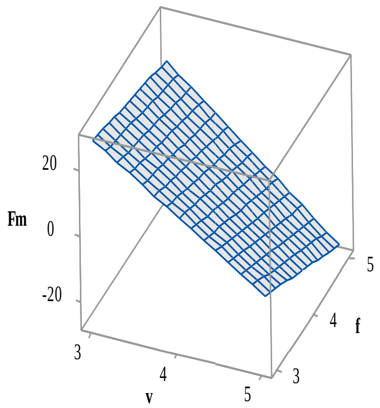

Figure 3: Surface plot of mean cutting force versus cutting velocity and feed rate

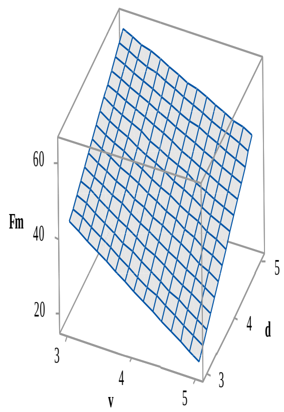

Figure 4: Surface plot of mean cutting force versus cutting velocity and depth of cut

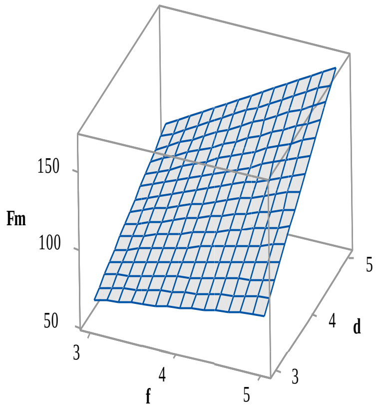

Figure 5: Surface plot of mean cutting force versus feed rate and depth of cut

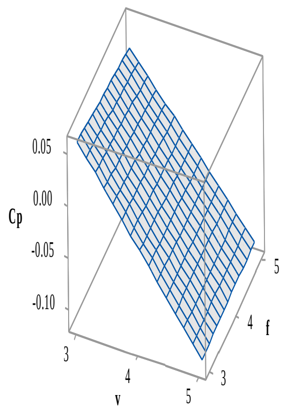

Figure 6: Surface plot of mean cutting power versus cutting velocity and feed rate

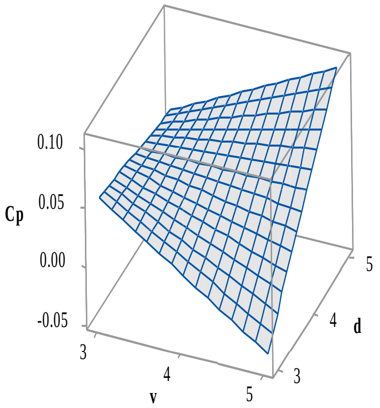

Figure 7: Surface plot of mean cutting power versus cutting velocity and depth of cut

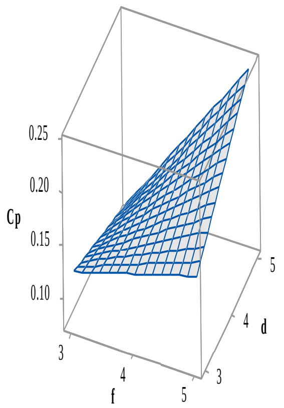

Figure 8: Surface plot of mean cutting power versus feed rate and depth of cut

IV. CONCLUSION

In this background, the study reported in this paper was mean cutting force and cutting power test conducted during turning operation of AISI 3415 steel with a TiN layered carbide insert. The following conclusions were drawn out from the present study;

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i. The ANOVA and F-test of the experimented results exposed that the depth of cut has a greater influence on the mean cutting force and cutting power, subsequently by the feed rate and cutting velocity.
ii. Generalized mathematical models were developed through regression analysis using Minitab statistical software for mean cutting force and cutting power. From those equations, the mean cutting force and cutting power values could be calculated if the factors namely feed rate, cutting velocity and depth of cut are recognized.
iii. From the experimentation optimum condition for mean cutting force such as 325 m/min of cutting velocity, 0.15 mm/rev of feed rate and 0.2 mm of depth of cut was observed and incase of cutting power it is 325 m/min of cutting velocity, 0.10 mm/rev of feed rate and 0.2 mm of depth of cut was observed.
iv. The optimum turning conditions found in this research work can be used when AISI 3415 steel alloy are turned for the typical applications like mechanical gears, gear shaft, main axis, valve rods, connecting rods etc.

Nomenclature

v	Cutting velocity in m/min
d	Depth of cut in mm
f	Feed rate in mm/rev
TiN	Titanium Nitride
R	Correlation coefficient
Mn	Manganese
C	Carbon
S	Sulphur
P	Phosphorus
Si	Silicon
Fe	Iron
^0C	Degree Celsius
cSt	Centistokes
PCLNR	ISO designation for tool holder
AISI	American Iron and Steel Institute
CNMG	ISO designation for tool

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