

Investigation of Effect of Machining Parameters on Titanium Alloy

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ABSTRACT: Aluminium and aluminium alloys were previously the preferred materials of the aerospace industry, newer aircraft designs are increasingly making use of titanium and titanium alloys. These materials are also used in the biomedical industry. The reasons for their popularity include light weight, high strength, excellent fatigue performance and high resistance to aggressive environments, remaining free of rust and degeneration. Titanium parts last longer and provide better performance and results than other metals and materials. Titanium alloys have been generally classified as difficult to cut materials due to their natural properties. The main drawbacks in machining titanium alloys are high cutting temperatures and tool wear due to high adhesion of tool work interface. Titanium alloys have a low Young's modulus, which causes spring back and chatter during machining. This can create poor surface quality in the finished product. Because of titanium's high work hardening tendency and the stickiness of the alloy, long continuous chips are formed during turning and drilling, which can entangle the tool and impede function. The aim of the project is to find optimal conditions for machining of a titanium alloy and to measure tool life by experimentation, simulation and analysis.

KEYWORDS: Titanium alloys, cutting temperatures, tool wear, machining, tool life

I. INTRODUCTION

Titanium alloys are referred as difficult-to-cut materials since they pose an utmost challenge to manufacturing engineers due to the high temperatures and stresses generated during machining. The low thermal conductivity and diffusivity of these alloys result in the concentration of high temperatures at the tool-work piece and tool-chip interfaces. Consequently, the result will be accelerating tool wear, increasing manufacturing cost and loss of time. Titanium and its alloys have gained widespread applications in aerospace, biomedical industries due to their following favourable properties: They are light weight, possess high strength, have excellent fatigue performance and offer high resistance to an aggressive environment. [5]

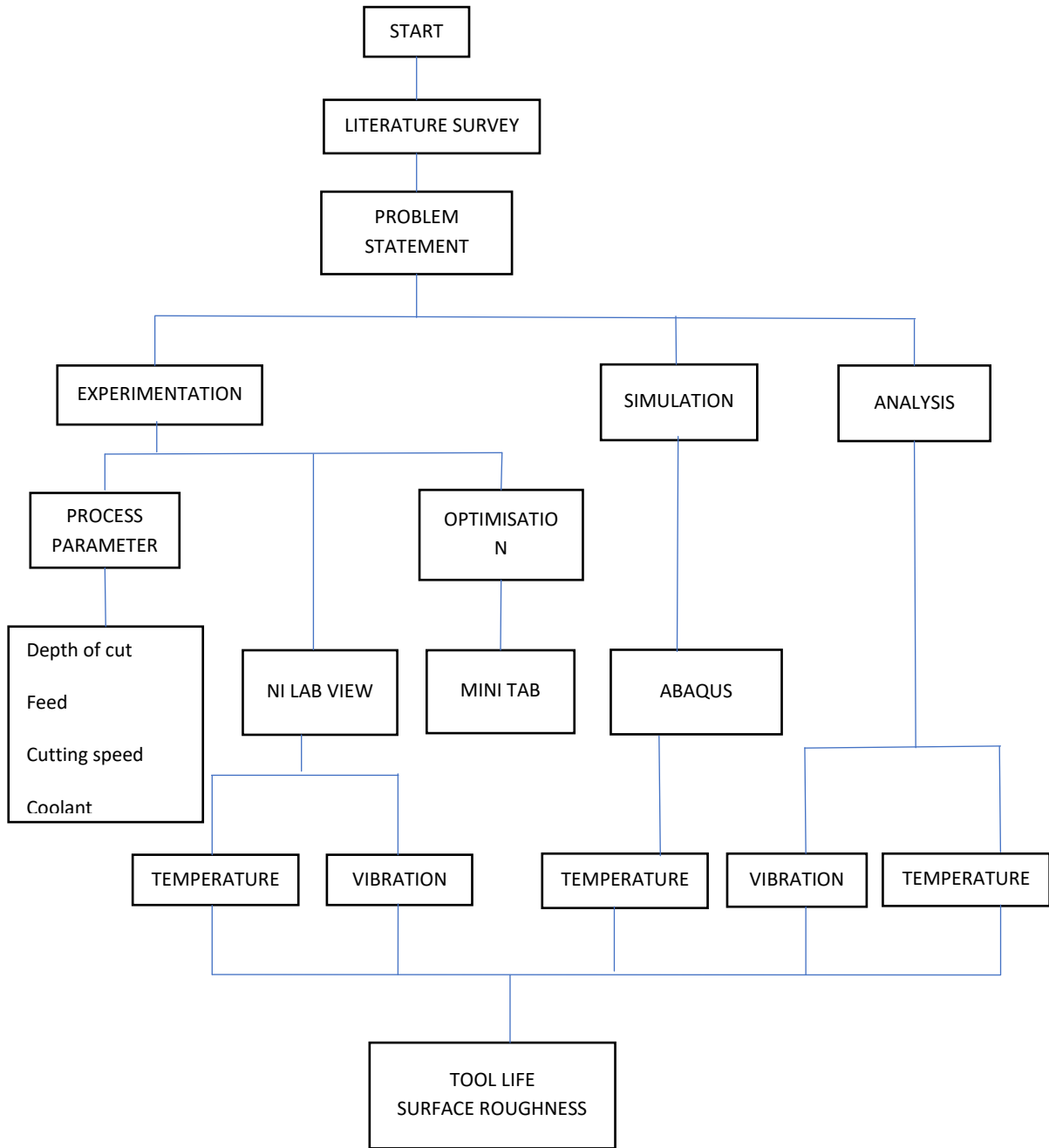
It is unfortunate that the above favourable properties in practical applications, prove to be a curse during machining:

- Titanium alloys due to their high strength, low thermal conductivity and chemical reactivity with tool materials (at elevated temperatures), pose a hazard to the tool and significantly reduce the tool life.
- In addition, a relatively low Young's modulus of titanium alloys leads to spring-back and chatter leading to poor surface quality of the finished product.

Finally, during turning and drilling, long continuous chips are produced; causing their entanglement with the cutting tool and making automated machining near impossible.



II. METHODOLOGY



Titanium and titanium alloys are hard to machine due to their natural material properties. Our literature survey made us aware about the different methods of machining titanium alloys and variations of different cutting parameters that could be used to obtain the required results. We will be tackling the problem at hand by a series of experiments and simulations and we will supplement our approach by rigorous analysis. We will be using software like NI Lab View, Minitab and Ansys.

Common Tool Life Criteria for coated tungsten carbide inserts

The criteria most commonly used for coated tungsten carbide inserts are as follows;

- 1) The maximum width of the flank wear land VBB max=0.8 mm, if the flank wear isn't regularly worn, scratched or badly grooved.
- 2) The average width of their flank wear land VBB=0.3 mm, if the flank wear land is considered to be regularly worn.
- 3) Catastrophic failure.

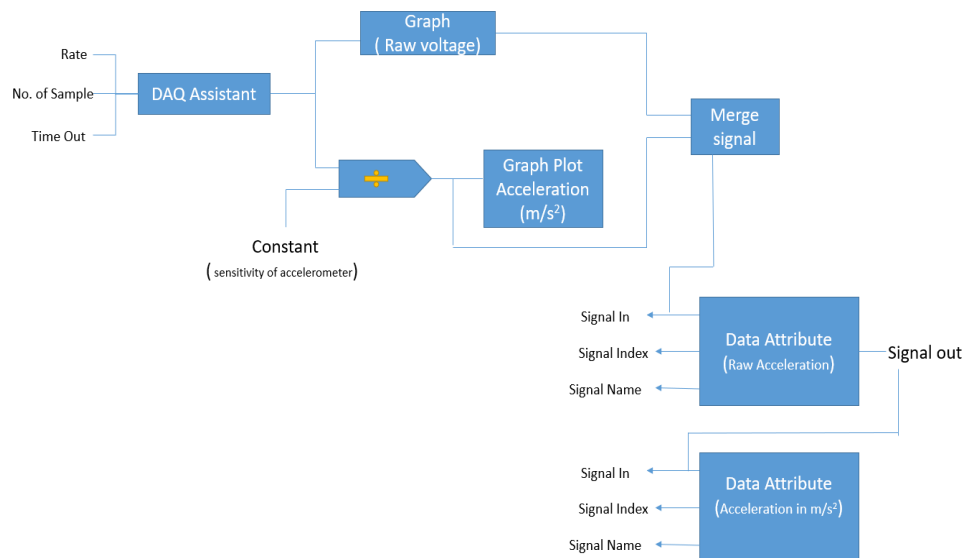
In addition, we planned to compare the tool life results with tool life obtained when using coated tools.

Tool coating: A coated tool is a new type of tool where long tool life is achieved by hard coatings. tool manufacturers are currently trying to shift the tool cutting performance toward high wear resistance and high toughness, by advanced tool coating technology. By coating a tool, the cutting performance of the tool can be upgraded significantly in many aspects, such as tool life and machining dynamics, etc[19].

The coating chosen for comparison was Latuma coating by Oerlikon Balzers.

CNC Machine: CNC machining is a manufacturing process in which pre-programmed computer software dictates the movement of factory tools and machinery. The process can be used to control a range of complex machinery, from grinders and lathes to mills and routers. With CNC machining, three-dimensional cutting tasks can be accomplished in a single set of prompts.

NI LabView:The DAQ assistant is given 3 inputs which are Rate , No. of Sample , Time out. The DAQ acts as an analog-to-digital converter and converts the signal (vibration) from analog to digital form but the unit of the output is not standard. The signal value is divided with sensitivity of accelerometer for conversion of vibration data into standard unit which is m/s^2 and plotting graph to the according value of vibration. The other line is use to plot the graph of Raw acceleration. Afterwards the signals are merged and one output line is given as input line to data attribute for formulation of tabular data set of Raw acceleration and Standard acceleration



NI LabView circuit diagram

Minitab Analysis: A statistics package developed by some researchers to help six sigma professionals analyze and interpret data to help in the business process is called Minitab. The data input is simplified so that it can be easily used for statistical analysis and it also helps in manipulating the dataset. If trends, patterns and charts are given, those are analyzed and interpreted so that final conclusions can be made.

Levels of Minitab Analysis

Cutting speed, v (m/min)	Feed, f (mm/rev)	Depth of cut, d (mm)	Surface Roughness, Ra (mm)	Acceleration, a (mm/s ²)
120	0.1	0.5	2.334	0.935
120	0.1	0.75	2.476	3.092
120	0.1	1	2.599	1.653
120	0.15	0.5	2.371	0.863
120	0.15	0.75	2.481	2.777
120	0.15	1	2.573	2.516
120	0.2	0.5	2.425	0.301
120	0.2	0.75	2.524	1.392
120	0.2	1	2.596	1.149
180	0.1	0.5	1.962	1.261
180	0.1	0.75	2.106	3.377
180	0.1	1	2.21	2.62
180	0.15	0.5	2.019	1.952
180	0.15	0.75	2.194	3.306
180	0.15	1	2.229	1.757
180	0.2	0.5	2.012	2.288
180	0.2	0.75	2.186	2.105
180	0.2	1	2.224	2.327
240	0.1	0.5	1.598	1.93
240	0.1	0.75	1.736	5.049
240	0.1	1	1.826	3.314
240	0.15	0.5	1.645	4.168



240	0.15	0.75	1.837	4.302
240	0.15	1	1.848	5.2
240	0.2	0.5	1.704	3.909
240	0.2	0.75	1.866	4.472
240	0.2	1	1.908	3.479

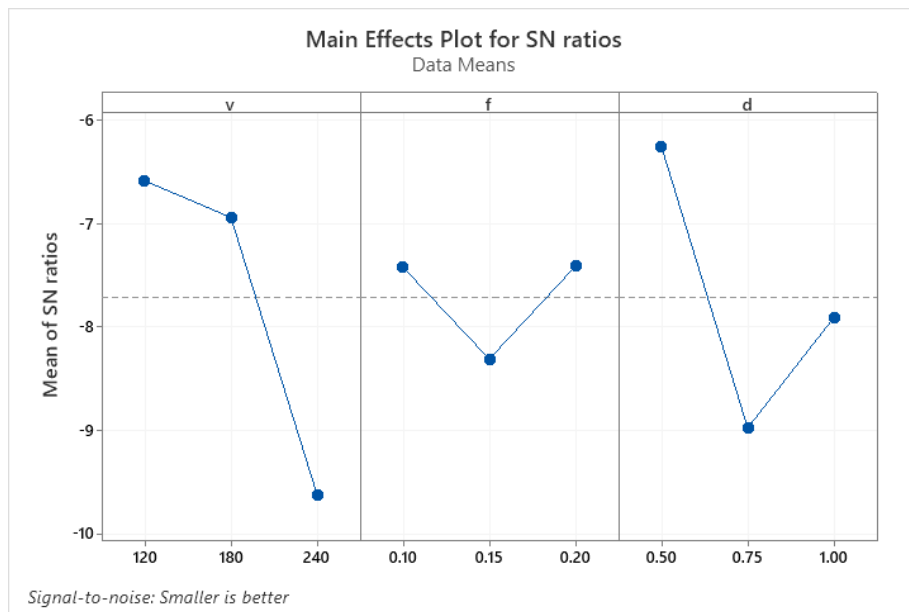
Taguchi Methods

Signal-to-noise ratio	Goal of the experiment	Data characteristics	Signal-to-noise ratio formulas
Larger is better	Maximize the response	Positive	$S/N = -10 \cdot \log(\Sigma(1/Y^2)/n)$
Nominal is best	Target the response and you want to base the signal-to-noise ratio on standard deviations only	Positive, zero, or negative	$S/N = -10 \cdot \log(\sigma^2)$
Nominal is best (default)	Target the response and you want to base the signal-to-noise ratio on means and standard deviations	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero	$S/N = 10 \times \log((\bar{Y}^2) \div \sigma^2)$ The adjusted formula is: $S/N = 10 \times \log((\bar{Y}^2 - s^2 \div n) \div s^2)$
Smaller is better	Minimize the response	Non-negative with a target value of zero	$S/N = -10 \cdot \log(\Sigma(Y^2)/n)$

Response Table for Signal to Noise Ratios

Smaller is better

Level	Cutting speed	Feed rate	Depth of cut
1	-6.583	-7.420	-6.258
2	-6.937	-8.306	-8.972
3	-9.615	-7.408	-7.905
Delta	3.032	0.898	2.714
Rank	1	3	2

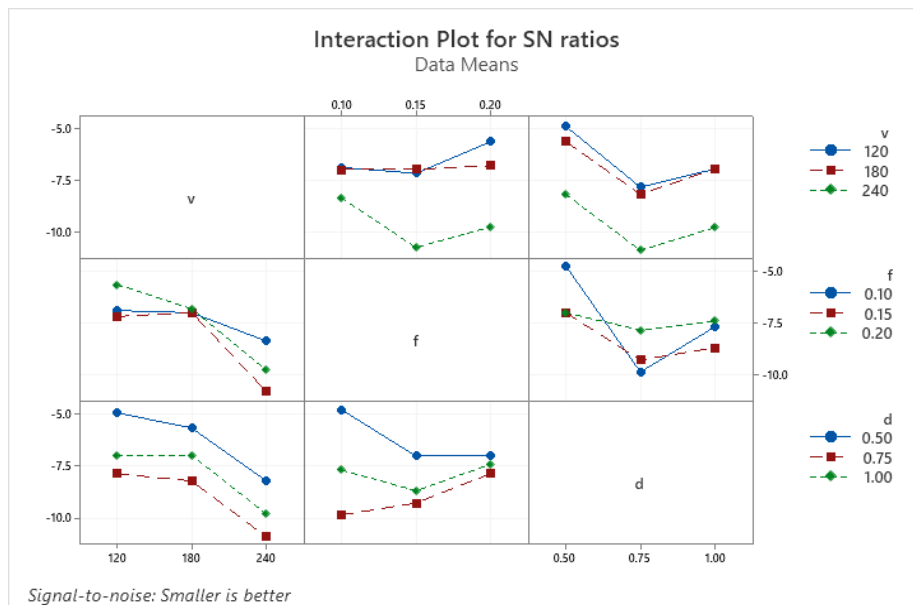


Main effects plots show how each factor affects the response characteristic. In these results, the main effects plot for S/N ratio indicates that cutting speed (v) and depth of cut (d) have widely affected S/N ratio, whereas feed rate (f) has less affected S/N ratio.

Interaction plot :-Interaction plots show how the relationship between one categorical factor and a continuous response depends on the value of the second categorical factor. This plot displays means for the levels of one factor on the x-axis and a separate line for each level of another factor.

Parallel lines :-No interaction occurs.

Nonparallel lines:-An interaction occurs. The more nonparallel the lines are, the greater the strength of the interaction. Although you can use this plot to display the effects, be sure to perform the appropriate ANOVA test and evaluate the statistical significance of the effects. If the interaction effects are significant, you cannot interpret the main effects without considering the interaction effects.





Average S/N Ratios for each factor

Level	Cutting Speed		Feed		Depth	
	Sum(S_{sj})	Avg S/N ratio	Sum(S_{fj})	Avg S/N ratio	Sum(S_{dj})	Avg S/N ratio
1	-59.2440	-6.5826	-65.052	-7.228	-56.3194	-6.2577
2	-62.4537	-6.9393	-74.7539	-8.3059	-80.7663	-8.9740
3	-86.5336	-9.6148	-66.6945	-7.9105	-71.1456	-7.9050

Optimum Parameters

Optimum conditions for machining titanium alloy are:

Cutting speed	Feed	Depth of Cut
120 m/min	0.1 mm/rev	0.5mm

ANOVA

Factor Information

Factor	Type	Levels	Values
Cutting speed	Fixed	3	120, 180, 2400
Feed rate	Fixed	3	0.10, 0.15, 0.2
Depth of cut	Fixed	3	0.50, 0.75, 1.00

Surface Roughness vs Cutting Speed, Feed, Depth of Cut

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cutting speed	2	2.28346	1.14173	1611.07	0.000
Feed rate	2	0.02006	0.01003	14.15	0.000
Depth of cut	2	0.21958	0.10979	154.92	0.000
Error	20	0.01417	0.00071		
Total	26	2.53727			



Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.12922	0.0052	415.60	0.000	
Cutting Speed					
120	0.35733	0.0075	49.32	0.000	1.33
180	-0.00233	0.0075	-0.32	0.751	1.33
Feed					
0.10	-0.03511	0.0075	-4.85	0.000	1.33
0.15	0.00378	0.0075	0.52	0.608	1.33
Depth of Cut					
0.50	-0.12144	0.0075	-16.76	0.000	1.33
0.75	0.02700	0.0075	3.73	0.001	1.33

Acceleration vs Cutting Speed, Feed, Depth of Cut

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cutting speed	2	26.182	13.0911	29.02	0.000
Feed rate	2	1.691	0.8457	1.87	0.179
Depth of cut	2	8.363	4.1814	9.27	0.001
Error	20	9.023	0.4512		
Total	26	45.260			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.648	0.129	20.48	0.000	
Cutting Speed					
120	-1.017	0.183	-5.56	0.000	1.33
180	-0.315	0.183	-1.73	0.100	1.33
Feed					



0.10	-0.067	0.183	-0.36	0.719	1.33
0.15	0.334	0.183	1.83	0.082	1.33
Depth of cut					
0.50	-0.692	0.183	-3.78	0.001	1.33
0.75	0.671	0.183	3.67	0.002	1.33

Significance of ANOVA

Sum of all squares of all deviations

Parameter	DOF	SS		SS%	
		Ra	a	Ra	a
Cutting speed	2	2.28346	26.182	89.9935	54.8479
Depth of cut	2	0.02006	1.691	8.2663	18.4776
Feed	2	0.21958	8.363	0.7831	2.5828
Error	20	0.01417	9.023	0.9569	19.9359
Total	26	2.53727	45.260	100	100

It can be seen from the analysis table the surface finish (Ra), the contribution of cutting speed (89.9935%) is more significant than depth of cut which is (8.266%). These factors are more significant than the feed rate (0.7831%). It is clear that the effect of noise factor (0.95869%) on surface finish is low as compared to the control factors. Further, In the Acceleration (a), the contribution of cutting speed (57.8479%) is more significant than depth of cut which is (18.4776%). These factors are more significant than the feed rate (2.5328.%). It's clear that the effect of noise factor (0.95869%) on vibration is low as compared to the initial two control factors.

Regression Analysis

A regression analysis generates an equation to describe the statistical relationship between one or more predictors and the response variable and to predict new observations. Linear regression usually uses the ordinary least squares estimation method which derives the equation by minimizing the sum of the squared residuals.

Surface Roughness vs Cutting Speed, Feed, Depth of Cut

Regression Coefficients

Term	Coeff	SE Coeff	T-Value	P-Value	VIF
Constant	2.7742	0.0403	68.87	0.000	
v	-0.005936	0.000128	-46.51	0.000	1.00
f	0.664	0.153	4.34	0.000	1.00
d	0.4318	0.0306	14.10	0.000	1.00



Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2.51299	0.83766	793.46	0.000
v	1	2.28338	2.28338	2162.90	0.000
f	1	0.01987	0.01987	18.82	0.000
d	1	0.20974	0.20974	198.67	0.000
Error	23	0.02428	0.00106		
Total	26	2.53727			

Regression Equation

$$Ra = 2.7742 - 0.005936 v + 0.664 f + 0.4318 d$$

Acceleration vs Cutting Speed, Feed, Depth of Cut

Regression Coefficients

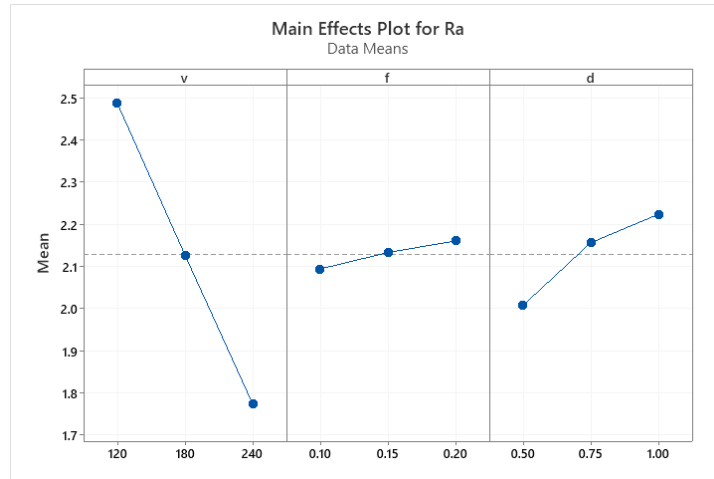
Term	Coeff	SE Coeff	T-Value	P-Value	VIF
Constant	-1.64	1.10	-1.50	0.147	
v	0.01958	0.00347	5.64	0.000	1.00
f	-2.01	4.17	-0.48	0.634	1.00
d	1.424	0.833	1.71	0.101	1.00

Analysis of Variance

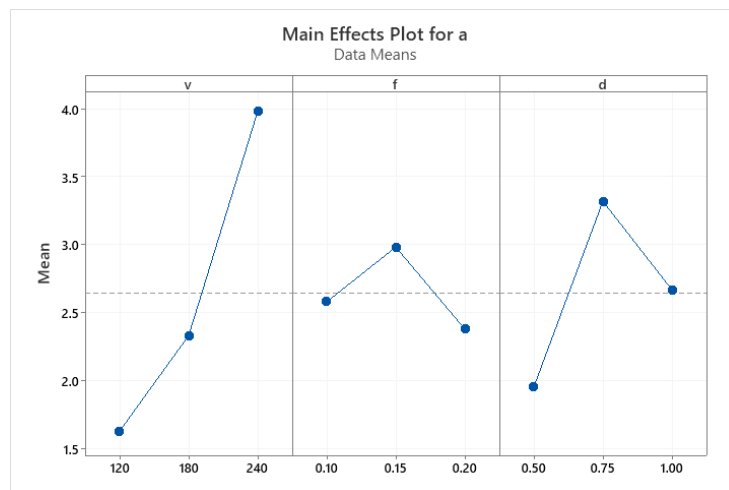
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	27.3026	9.1009	11.66	0.000
v	1	24.8395	24.8395	31.81	0.000
f	1	0.1818	0.1818	0.23	0.634
D	1	2.2812	2.2812	2.92	0.101
Error	23	17.9573	0.7808		
Total	26	45.2599			

Regression Equation

$$a = -1.64 + 0.01958 v - 2.01 f + 1.424 d$$



In the above graph we can see that cutting speed has the largest effect on surface roughness and feed rate has almost no effect on surface roughness.

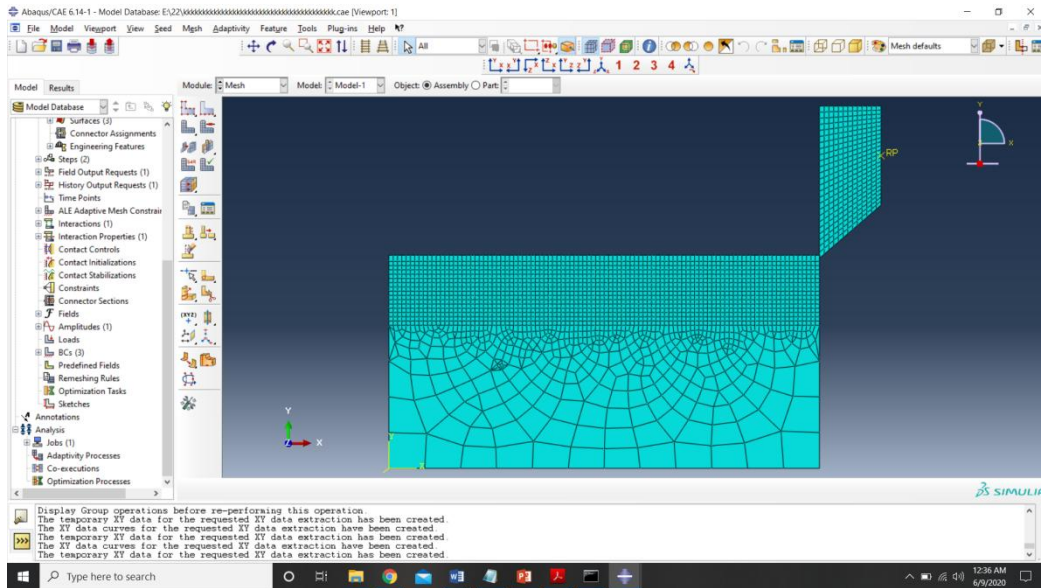


As seen for main plot for roughness we can say that in main plot for acceleration, cutting speed has the largest effect on acceleration (a) as compared to feed rate and depth of cut.

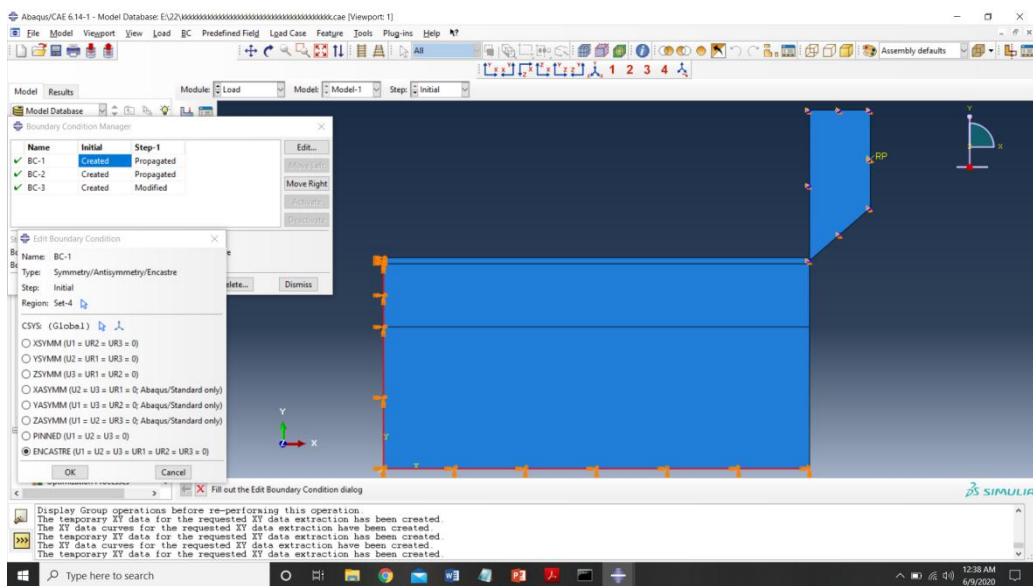
Abaqus 2D Simulation

In the 2D simulation, the model was generated with workpiece of 70mm x 35mm and a tool of 5mm x 5mm with an inclination of 10°. This model was then meshed with an element size of 0.7 mm in horizontal line where ALE type of meshing is applied to control excessive distortion. Boundary conditions were applied to the meshed model.

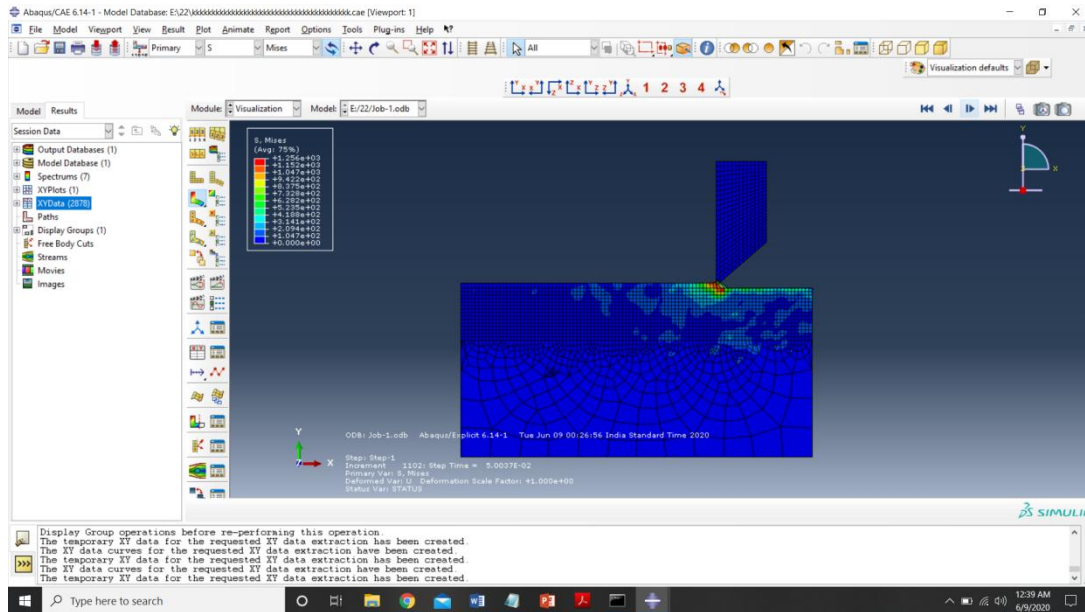
The workpiece was fixed at bottom periphery of model. The tool was given a feed of 0.210 mm/rev in the x-direction of the geometry. The screen shots of the above discussed model are given below.



Meshed work piece in Abaqus



Boundary condition for simulation



Stress distribution & Material Cutting Simulation

Model for Vibration

Radial forces are the main problem in matters of radial deflection and vibration. Therefore, factors influencing in these forces must be strictly controlled. Potential measures to minimize vibration tendencies:

- Large entering angle and positive rake face
- Small nose radius and point angle
- Positive macro geometry
- Controlled wear pattern and ER-treatment on the micro geometry.
- Larger depth of cut than the nose radius, making sure the proper distribution of forces.

The workpiece can be visualised as a cantilever beam.

Max deflection of a cantilever beam (y_{max}):

$$y_{max} = (-F_r L^3) / (3EI)$$

$$= -F_r * 1.9755 * 10^{-8} \text{ m}$$

Where,

F_r is the radial component of cutting force

E is Young's modulus = 110 GPa

L is length of bar = 0.05 m

I is moment of inertia = $\pi d^4 / 64 = 1.9174 \times 10^{-8} \text{ m}^4$

Frequency of vibration (f) is given by:

$$f = (1/2\pi) * (3EI / F_r L^3)^{(1/2)}$$

$$= (1132.352) / (F_r)^{(1/2)} \text{ Hz}$$

Cutting forces can be found out using a dynamometer.

III. CONCLUSION

- From the present study, with the proposed optimal parameters it is possible to increase the efficiency of machining process and decrease production cost in an automated manufacturing environment.
- In the case of a plot of s/n ratio the lines don't show changes suddenly, it shows some parallelism in between.
- The intervals between the depth of cut are small so there is not much variation in the value of surface roughness in the interaction plot of means.
- Response Table for Signal to Noise Ratios shows that for the surface finish (Ra), the contribution of cutting speed is more significant than depth of cut which is. These factors are more significant than the feed rate.
- Optimal values of process parameters were successfully found for good surface finish and low vibration.
- It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters.

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