Prediction of Tool Life During Turning Process Using Cemented Carbide Tool

J. Ganesh, M. Srikanth[1]
B. Amarendar Students of Mechanical Engineering

Dr. VVSH Prasad[2]
Professor, Department of Mechanical Engineering from
Institute of Aeronautical Engineering College, Hyderabad

Abstract:- The lubrication by the cutting fluid affects the surface finish of a workpiece and tool life in turning process. The proper lubrication ensures higher performance of the machine. Empirical tests were conducted to study the influence of the machining parameters on a single point cutting tool with redesigned geometry. Surface roughness on the rake surface of the tool was performed by compromising physical characteristics. Lubrication is used to improve the tool life in CNC lathe machine operations. Using both standard and specially modified tools, comparison of cutting force, temperature, power usage, and surface polish was carried out. Magnified photographs from the scanning electron microscope were used to test tool wear in various locations. The enhanced tool greatly reduced average cutting force, Temperature, and power usage during the experiments.

I. INTRODUCTION

In the conventional machining process, chips are produced by removal of material by tool. In dry turning, apart from the wear tool, the machined surface may also be distorted due to a temperature rise and overall deterioration in machining. To enhance the tribological characteristics of the tool surface, EDM and Laser Assisted Machining are utilised. These methods can create microstructures on the tool surface that improve lubricant retention, reducing friction and, consequently, wear during the machining process. Nowadays, one of the important objectives in modern manufacturing involves prolonging tool life to increase efficiency in operations, reduce downtime, and lower overall costs. The wear of a tool during a machining process, such as turning, immediately contributes to the quality and economic viability of the production. Micro-texturing of tool is a new approach for increasing tool life by changing the surface properties through the introduction of geometrical features on the tool surface, which provides better lubrication and lowers friction, wear, and tear.

Traditionally, tool life estimation has been done based on empirical models and expertise, which hardly capture the complex dynamics arising from tool wear under different operating conditions. On the other hand, machine learning now promises a new direction for developing improved tool life prediction with data-driven insights coupled with computational modelling. In the conventional machining process, chips are formed due to the removal of metals from the work material. During dry turning, besides tool wear, the increase in temperature can further lead to distortion of the work piece material and deterioration of the machining. Various cutting fluids and lubricants have been tried to solve these problems; new ways of application and usage during machining have been pursued. Another variant is the MQL use in the operation, whereby only a small quantity of lubricant is applied to the cutting zone or some other agency. This could cool and lubricate effectively enough, with less consumption of fluid to reduce the risk of environmental contamination. Advanced machining processes such as EDM and LAM are also employed to improve the tool surface. These processes are capable of developing microstructures on the tool surface that enhance the retention of lubricants, hence reducing friction and wear during the machining process.

To eliminate this problem, new studies on various cutting fluids, lubricants, and application techniques besides advanced machining processes for enhancing the tool surface qualities are under investigation. These investigations would lead to better quality on the machined surface, reduced wear of the tool, and higher efficiency in general machining [2–4]. Its surface was perforated, whereby it gave better performance. This perforation indeed and reduced wear to a greater extent. In order to establish feasible tool wear reduction and friction, the surface texturing on the tools and its behaviour throughout the machining process were explored. The experimental investigation of the tool comparison with and without roughness in mild steel machining has been done by Lei [5]. It was observed that a 30% reduction in cutting force and improvement of the machining process was observed. A finite element approach has been followed and showed the temperature and stress induced on the tooltip of the textured tool was reduced. The works of Kawasegi [6] on aluminium samples are in line with the improvement in the machining process. It was concluded that the microgrooves parallel to the machined surface texture showed better performance than other textures. The textured tools showed increased cutting force and better adhesion between tool and workpiece as compared to the standard tools. Obikawa [7] has studied the cutting of aluminium alloys with a cemented carbide texturing tool. The machining process resulted in an improved texture for the parallel type tool, which was because of improved lubrication conditions.

On the other hand, various publications cited include those on aerial textures [8,9], dimple textures [10], channel textures [11] that are assisting to reduce the cutting process and tool wear. Many of the researchers [9,11,12] have observed that micro holes have a positive effect. Therefore, a deep understanding of the effective use of other kinds of textures for optimization in the machining process is required. This researcher done to see the texture parameters vary with machining process. Study of normal stainless steel was taken as the work material.

Fig 1: CNC Lathe for Turning Process

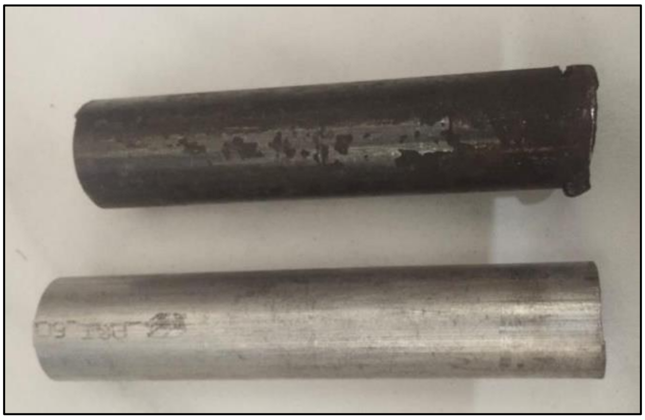

Fig 2: Aluminium and EN-8 Material before Turning Operation

Fig 3: Tool Tip

Fig 4: Aluminium and EN-8 Material After Turning Operation

II. OBJECTIVES

- **Effect of Cutting Force and Tooltip:** Durning machining process mechanical energy generate heat at the tool material and work piece material. Heat is generated on the cutting force, rotating speed and friction generated by the tooltip.
- **Effect of Power and Surface Roughness:** The maximum power is utilized in dry turning and cutting process, due to increase in speed revolution generate more friction in cutting process.
- **Effect of Chip Formation and Tool Wear:** The turning process performance different chips formed, where the speed irregular. The continuous chips are formed at constant speed of the machining process. The lubricant reduces friction wear to the tooltip.

III. IMPLEMENTATION

Collecting the data of aluminium and EN-8 material, then refer the data values from standard data book or textbook. Now analyse the data value in Kennametal using standard data value of material. In Kennametal change the material configuration in metric and Brinell hardness value according to the aluminium and EN-8 material. Make a Kennametal tabular data for prediction of tool life using Taylor's tool life equation.

$VT^n = C$

V is in cutting velocity m/min, **T** is time in minute, n is the exponent of material and **C** is the constant.

$\pi * D * N$

Cutting velocity formula is V = 1000

D = Diameter and N = speed (rpm)

Now collect the data of Aluminium and EN-8 material to perform the experiment in CNC lathe machine. Similar make experimental tabular data for prediction of tool life using Taylor's tool life equation $VT^n = C$.

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In the cases of EN-8 (P1/P10) material, high friction is generated at the tooltip during the turning process, because of material hardness. A greater cutting force will be needed to shear off chips from the workpieces. Problems in tool penetration into the workpiece, mainly due to some wobbling, found to be associated with a lower cutting speed. Represent the tooltip temperature for different cutting conditions.

Use Co-lab to represent the tabular data into graphical form using polynomial algorithm. The graph representation shows the tool life variation through the curve with different diameter of spindle speed and cutting speed. Tool life was pointed with dots and the polynomial curve indicates the tool life in increasing and decreasing form as tabular data.

A. *Design Methodology*

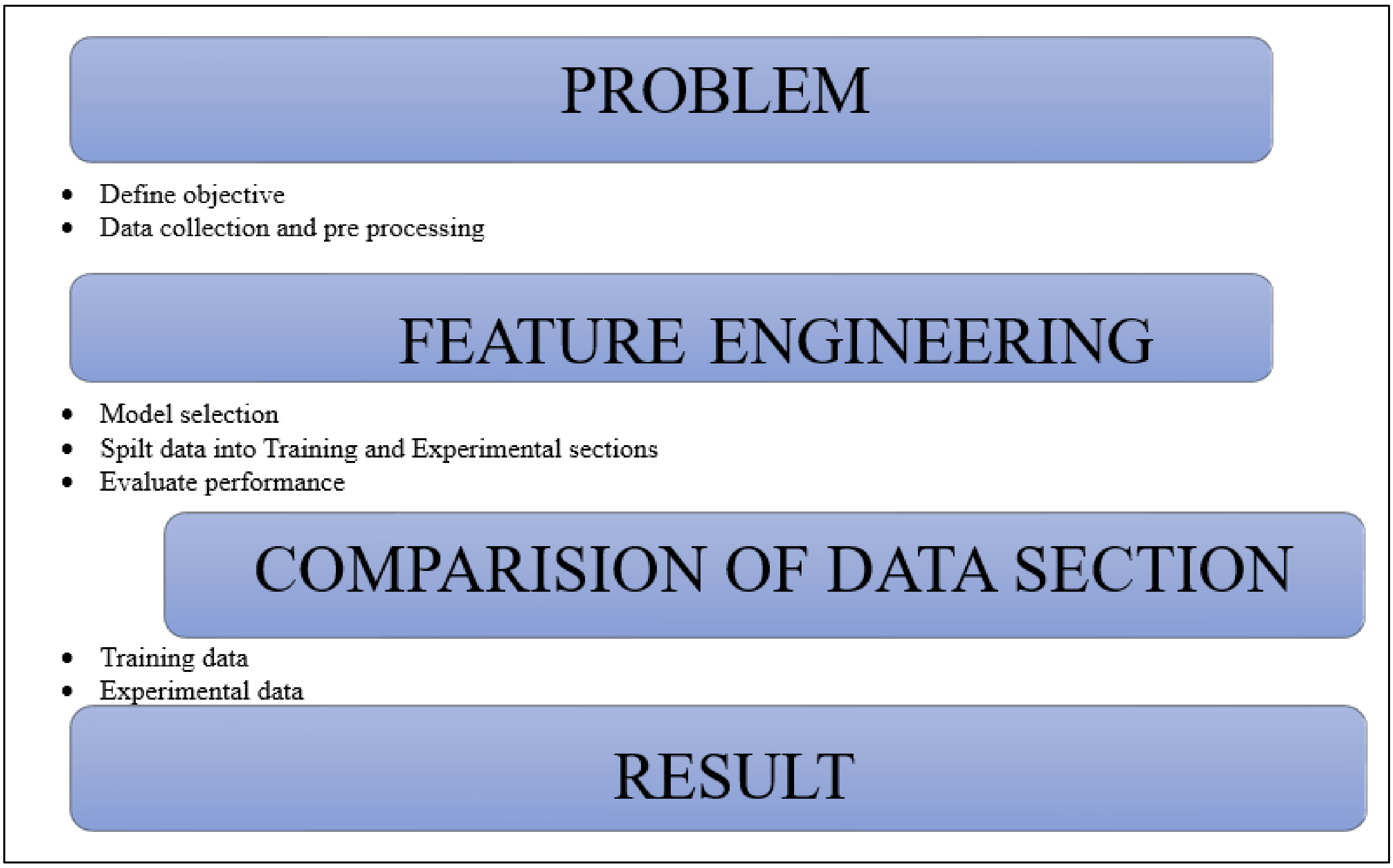

Fig 5: Flow Chart

B. *Surface Roughness Measurement:*

- **Purpose:** Profilometers quantify the texture of a surface by measuring parameters such as Ra (average roughness), Rz (average maximum height), Rq (root mean square roughness), and others defined by ISO standards.
- **Process:** The instrument uses a stylus or non-contact method to traverse the surface, recording deviations in height over a specified length. This data is then analysed to determine the roughness profile

Reference from P.N Rao Manufacturing Technology Volume-2 Text book Cemented carbide tool material speed exponent, n from 0.20 to 0.49. Taylor's tool life equation is given by $VT^n = C$

V is in cutting velocity m/min & T is time in minute in turning operation.

Cutting velocity formula is $V = \frac{\pi * D * N}{1000}$

Modified Taylors equation is $VTnfn^1 d^{n_2} = C$
$n_1 = feed$, $n_2 = depth\ of\ cut$ & C = constant

For P1, P10 tool material n = 0.38 & 0.4, $n_1 = 0.10$, $n_2 = 0.06$ & C = 500 & 350

Table 1: Cutting Parameters and Tool Materials

	EN – 8	**Aluminium**
Tool	Cemented carbide	Cemented carbide
Cutting speed (V)	200 (M/min)	200-1000 (M/min)
Feed rate	0.1-0.3 (mm/rev)	0.2-0.5 (mm/rev)
Depth of cut	0.5-2 mm	0.5-2 mm

- **Tool Geometry:** Tool radius, rake angle, relief angle, and micro-texture pattern including density, shape, and dimensions. Tool Material composition greatly influences its wear resistance and thermal conductivity.
- **Coating:** Coatings like Tin, Titan, or DLC can increase tool life by reducing friction and wear.
- **Tool Shape:** It includes tool nose radius, cutting edge angle, and clearance angles.
- **Micro-Texture:** Texture pattern, e.g., dimples, grooves, density, depth, and distribution on the

➢ *Surface Roughness:*

- **Initial Surface Condition**: The initial roughness of the tool surface may affect frictional forces and the progress of wear in machining. Coolant and Lubrication.
- **Type of Coolant:** Water, oil, and other coolants that may be used have an influence on the tool temperature and wear rate.
- **Lubrication:** Lubricants decrease friction and heat, resulting longer tool life.

➢ *Cutting Parameters:*

- **Cutting Speed** - The relative surface speed of motion between the workpiece and tooltip.
- **Feep Rate** - The rate of advance of the tool per workpiece revolution.
- **Depth of Cut** - Thickness of the material is removed.

➢ *Environmental Conditions:*

- **Ambient Temperature:** The temperature of the environment where the machining operation is being performed will have an impact on tool wear.
- **Humidity and Contaminants:** The presence of humidity and contaminants can affect certain wear mechanisms.

C. Polynomial Algorithm for Tool Life Material

➢ *Define the Problem*

- **Objective:** Predict tool life based on various material properties (e.g., hardness, tensile strength).
- **Data Required:** A dataset containing measurements of tool life and corresponding material properties.

➢ *Data Collection*

- Collect data that includes:
- Tool Life (y): Dependent variable (e.g., hours, cycles).
- Material Properties (X): Independent variables (e.g., hardness, tensile strength, thermal conductivity).

➢ *Data Preprocessing*

- Clean the Data: Handle missing values and remove outliers.
- Feature Engineering: Consider transforming categorical variables if necessary.
- Normalization: Normalize or standardize features if they vary significantly in scale.

➢ *Generate Polynomial Features*

- Use polynomial transformations to create higher-degree features from the original data.

➢ *Split the Data*

- Divide your data into training and testing sets to evaluate performance.

➢ *Training*

- A polynomial regression model using linear regression on the polynomial features.

➢ *Evaluation*

- Evaluate the performance using metrics like R-squared, Mean Absolute Error (MAE), and Mean Squared Error (MSE).

➢ *Visualization*

- Visualize the training values vs. predicted tool life values to assess the fit.

➢ *Analyze Coefficients*

Look at the coefficients of the polynomial model to interpret the impact of each material property on tool life.

```
print ("Coefficients:", model. coef_)
```

➢ *Optimization and Tuning*

- Experiment with different polynomial degrees to find the best fit for your data.
- Consider using regularization techniques (e.g., Ridge or Lasso regression) to prevent overfitting.

IV. RESULT

Table 2: Experimentation table for Turning Process-Training Data by Kennametal

S.N0	Cutting speed (m/min)	Diameter (D)	Depth Of Cut (mm)	Feed Mm/ min	Metal removal rate(Q) Cm^3/Min	Cutting Time (min)	Cutting power (kw)	Motor power (kw)	Spindle speed (rpm)	Tool life
1.	100	30	0.01	0.06	0.6	1.57	0.02	0.02	1061	69
2.	125	30	0.01	0.06	0.75	1.26	0.02	0.02	1326	38
3.	150	30	0.01	0.06	0.9	1.05	0.03	0.03	1591	23
4.	200	30	0.01	0.06	1.2	0.79	0.03	0.03	2122	11
5.	225	30	0.01	0.06	1.35	0.7	0.04	0.04	2387	8
6.	100	40	2	0.08	16	1.57	0.46	0.51	795	22
7.	125	40	2	0.08	20	1.26	0.57	0.63	994	13
8.	150	40	2	0.08	24	1.05	0.69	0.77	1193	8
9.	200	40	2	0.08	32	0.79	0.92	1.02	1591	4
10.	225	40	2	0.08	36	0.7	1.03	1.14	1790	2.9

Reference from Prince Dabreo et al 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1070 012101 research paper and from P.N. Rao text book n = 0.38, c = 500 for 30mm diameter and n = 0.4 & C = 350 for 40mm diameter, EN-8 Material using cemented carbide tool.

Fig 6: Tool Life and Cutting Speed of n = 0.38

Fig 7: Tool Life and Cutting Speed of n = 0.4

Table 3: Reference from C.J. Rao et al. / Procedia Engineering 97 (2014) 241 – 250 and P.N Rao text book n = 0.33, c = 80 for 30 mm diameter and n = 0.4, c = 80 for 40 mm diameter, Aluminium material using cemented carbide tool

S.N0	Cutting speed (m/min)	Diameter (D)	Depth Of Cut (mm)	Feed Mm/ min	Metal removal rate(Q) Cm^3/Min	Cutting Time (min)	Cutting power (kw)	Motor power (kw)	Spindle speed (rpm)	Tool life
1.	50	30	2	0.8	80	0.24	1.09	1.21	530	35
2.	60	30	2	0.8	96	0.2	1.31	1.46	636	22
3.	70	30	2	0.8	112	0.17	1.53	1.7	742	16
4.	80	30	2	0.8	128	0.15	1.75	1.94	848	12
5.	100	30	2	0.8	160	0.12	2.18	2.42	1061	7
6.	50	40	1	0.4	20	0.63	0.27	0.3	397	21
7.	60	40	1	0.4	24	0.52	0.33	0.37	477	14
8.	70	40	1	0.4	28	0.45	0.38	0.42	557	10
9.	80	40	1	0.4	32	0.39	0.44	0.49	636	7
10.	100	40	1	0.4	40	0.31	0.55	0.61	795	5

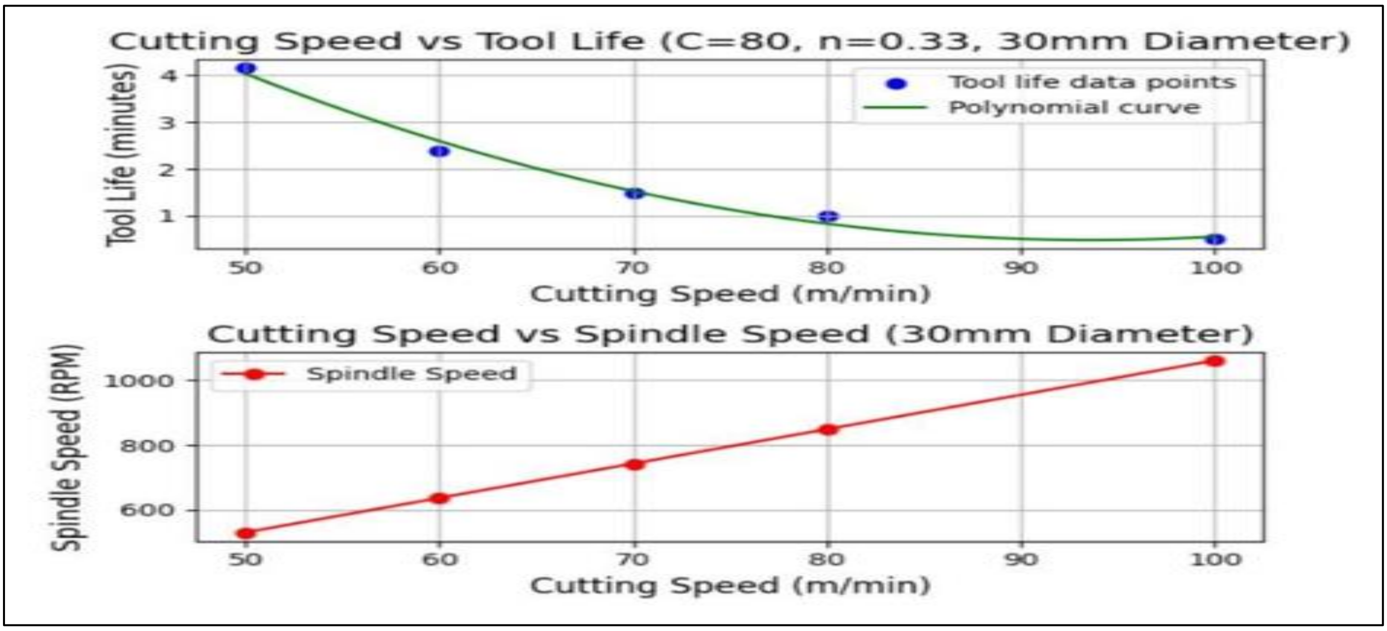

Fig 8: Tool Life and Cutting Speed of n = 0.33

Fig 9: Tool Life and Cutting Speed of n = 0.33

- *Calculation for EN-8 Material 30 mm Diameter:*

n = 0.38, C = 500 & V = 100

V = $\frac{\pi*30*N}{1000} \Rightarrow \boldsymbol{V} = \frac{100*1000}{\pi*30} \Rightarrow$ N = 1061 rpm

VT^n = C

100*$T^{0.38}$ = 500 ⇒ $T^{0\cdot 38} = \frac{500}{100} \Rightarrow$ T = $50^{\frac{1}{38.}} \Rightarrow$ 69 min

Similarly for V = 125, 150, 200 & 225

- *Calculation for EN-8 Material 40 mm Diameter:*

n = 0.4, C = 350 & V = 100

V = $\frac{\pi*40*N}{1000} \Rightarrow \boldsymbol{V} = \frac{100*1000}{\pi*40} \Rightarrow$ N = 795 rpm

VT^n = C

100*$T^{0.4}$ = 500 ⇒ $T^{0\cdot 4} = \frac{500}{100} \Rightarrow$ T = $5^{\frac{1}{0.4}} \Rightarrow$ 22 min

Similarly for V = 125, 150, 200 & 225

- *Calculation for Aluminium material 30 mm diameter:*

n = 0.33, C = 80 & V = 50

V = $\frac{\pi*30*N}{1000} \Rightarrow \boldsymbol{V} = \frac{50*1000}{\pi*30} \Rightarrow$ N = 530 rpm

VT^n = C

50*$T^{0.33}$ = 80 ⇒ $T^{0\cdot 33} = \frac{80}{50} \Rightarrow$ T = $5^{\frac{1}{0.33}} \Rightarrow$ 35 min

Similarly for V = 60, 70, 80 & 100

- *Calculation for Aluminium material 40 mm diameter:*

n = 0.4, C = 80 & V = 50

V = $\frac{\pi*40*N}{1000} \Rightarrow \boldsymbol{V} = \frac{50*1000}{\pi*30} \Rightarrow$ N = 397 rpm

VT^n = C

50*$T^{0.4}$ = 80 ⇒ $T^{0\cdot 4} = \frac{80}{50} \Rightarrow$ T = $5^{\frac{1}{0.4}} \Rightarrow$ 21 min

Similarly for V = 60, 70, 80 & 100

Reference from Prince Dabreo et al 2021 IOP Conf. Ser.: Mater. Sci.research paper of c = 350 in EN-8, c=80 in aluminium and from P.N. Rao text book n = 0.38,0.4 for 30mm and 40mm diameter. Taylors tool life equation is VT^n = C

Table 4: Experimental Data for Turning Operation in CNC Lathe Machine

S.N0	Cutting speed (m/min)	Diameter (D)	Depth Of Cut (mm)	Feed rate Mm/ min	Cutting Time (min)	Dry run F (mm/min)	Spindle speed (rpm)	Tool life
EN-8 Material								
1.	60	32	2	6	38	10	600	102
2.	79	42	2	4	42	13	600	40
Aluminium								
3.	50	30	2	10	35	23	500	4.7
4.	75	40	2	15	31	28	600	1.5

V. CONCLUSION

A. *Cutting Parameters:*

- **Cutting Speed:** Tool life decreases exponentially with increasing cutting speed due to higher temperatures causing accelerated wear.
- **Feed Rate:** Higher feed rates generally reduce tool life, but the effect is less pronounced than cutting speed
- **Depth of Cut:** Larger depths of cut increase cutting forces, leading to faster tool wear.

B. *Tool Wear Mechanisms:*

Cemented carbide tools like Kennametal experience various wear mechanisms like flank wear, crater wear, and chipping, influenced by cutting conditions. Tool wear affects surface finish, dimensional accuracy, and ultimately the tool life.

C. *Practical Implications:*

Understanding the relation of material cutting parameters and tool life allows for optimization machining processes, minimizing costs related to tool replacement and downtime.

D. *Predictive Accuracy:*

Experimental validation is essential for refining the predictive models, as real-world conditions can introduce complexities not captured in theoretical equations.

The outcomes of Kennametal data and experimental data is analyzed and compared for the prediction of tool life. These experiments make to understand about the property of material and tool life prediction. Polynomial algorithm is utilised for graphical presentation from the tabular data.

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