

Reliability Analysis of Single Point Cutting Tool on Al6063 Alloy

K. Udayani^{1*}, S. Gajanana², P. Laxminarayana³

Submitted: 25/01/2024 Revised: 05/03/2024 Accepted: 12/03/2024

Abstract: This study aims to investigate the Al6063 alloy machining reliability of a single point cutting tool. Because of its well-known advantageous mechanical qualities, Al6063 can be used in a wide range of applications. The machining results are highly impacted by tool wear, such as flank wear, which makes prompt tool replacement necessary to preserve component quality and production efficiency. To assess tool performance, the experiment used High-Speed Steel (HSS) tools under various cutting conditions, such as speed, feed, depth of cut, and rake angle. Using image processing methods, flank wear was assessed, and experimental data was used to simulate its distribution as a normal distribution. The probability that the cutting tool would function satisfactorily for the designated amount of time before needing to be replaced was ascertained using reliability analysis. The findings show that increased cutting forces improve tool reliability; in fact, some experiments had reliability percentages above 75%. The results highlight how crucial it is to maximize machining parameter optimization to extend tool life and reduce operational disturbances. To increase manufacturing productivity and quality assurance in Al6063 alloy applications, future research might concentrate on further optimizing these parameters and confirming the findings across various tool materials and machining environments.

Keywords - DOE, Flank wear, HSS tool, Process parameters, Reliability, Resultant Force

1. Introduction

Al 6063 is an alloy composed of aluminium, silicon, and magnesium as alloying elements. It could be heat treated and welded, and its mechanical characteristics are generally good. Numerous studies have examined the machinability and material characterization of Al6063. Tool wear, such as crater formation, built-up edges, and flank and nose wear, can negatively impact the surface quality of produced components and require costly rework.

Many life studies by J.G. Wager et al. [1] utilizing HSS tools for low carbon steel machining reveal that tool life values follow a statistical distribution that deviates from the normal distribution by about 0.3 of a coefficient of variation. The distribution patterns of normal and accelerated exams are similar, indicating a potential wider use for accelerated exams. It is important to remember that the commonly accepted concepts of "constant" and "exponent" tool life are merely statistical mean values and cannot be used to predict the life of any

specific tool used in the field. Estimates of the probabilistic tool life are proposed, and the planned direction for further work is emphasized. The study by K Hitomi et al. [2] concentrated on the tool life's dependability analysis.

Moreover, based on machining parameters and tool-wear limitations, it was shown that the reliability function may be utilized to swiftly compute the reliability of cutting tools in specific time. W.S. Lin [3] conducted multiple trials to evaluate the dependability variance of the cutting tool. Along with tool life and wear distribution, the trial data yields the dependability function and tool wear distribution of cutting tools. In addition, the reliability of the cutting tools at any given moment and the tool wear limit and cutting parameters for high-speed machining (HSM) may be easily ascertained with the help of the derived reliability function. A stochastic model is presented by El Wardany et al. [4] to forecast the tool failure rate while using ceramic tools to convert hardened steel. This model is predicated on the idea that the primary causes of the tool life ending are chemical wear, progressive wear, and early failure (such as chipping and breaking). Each reason for "tool failure" is believed to have a statistical distribution. The failure rate, reliability function, and tool-life distribution are then represented by general equations. Next, an experimental verification of the assumed distributions is made. The coefficients of these equations are found using the experimental data. Researchers Konstantinos Salonitis et al. [5] looked at how the overall manufacturing efficiency is affected by

1Research Scholar, Department of Mechanical Engineering, Osmania University, Hyderabad, India Email:

udhu28@gmail.com

2Department of Mechanical Engineering, MVSREC, Hyderabad, 501510, India

3Department of Mechanical Engineering, Osmania University, Hyderabad, India

**Corresponding Author: - K Udayani*

*1*Research Scholar, Department of Mechanical Engineering, Osmania University, Hyderabad, India Email:*

udhu28@gmail.com

the dependability of cutting tools. It is challenging to determine a cutting tool's exact remaining life as, in most circumstances, it can be utilized for several operations with various processing conditions. Based on sophisticated approximation techniques, the current study suggests a novel approach to cutting tool dependability estimate. A widely used technique for structural reliability issues is reliability-based design/operation, which evaluates essential infrastructure performance under stochastic design parameters. The life of the cutting tools used in the machining processes has a significant impact on the components' quality. Chipping from tool damage may lead to the component being machined being trashed. As Carmen Elena Patino Rodriguez et al. [6] showed, it was expected that a normal distribution might be utilized to represent tool's life. Finding the machining technique's operations sequence will allow you to determine how long each tool will run during the procedure. An algorithm is provided to determine when the cutting tool should be replaced. The proposed method is used to evaluate a turning and drilling manufacturing process's reliability. S. Ajmal Hussain et al. conducted an experimental analysis and comparison between silicon carbide and aluminum (6063) [7]. Aluminum and its component parts are a great alternative to steel because of their low weight and resistance to corrosion, making them useful in both commercial and domestic contexts. Steel is a well-known commodity that is used extensively in industries, and its price is always rising, which has an impact on manufacturing costs for both the home and automotive sectors. Because of this, it is imperative to swap out steel with a material that maintains the right weight ratio while being extremely robust and lightweight. Al6063 is therefore utilized in this situation due to its strong tensile properties, good toughness, medium strength, moderate ductility, and resistance to corrosion. Siva Bhaskar et al.'s [8] approach for calculating the optimal time for replacement of tool is based on the tool performance determined by the dependability function. Oussama Zerti et al. [9] provided a method for determining the optimal machining parameters that yield a minimum of 23 surface roughness using the Taguchi approach. The mechanical properties of the heat-treated 6063 aluminum alloy were examined by researchers Montasser S. Tahat et al. [10]. Aluminum alloy is appropriate for a variety of industrial applications due to its stable mechanical properties and structural integrity. In addition to summarizing current patents, the study focused on the mechanical properties of the alloy in question following age hardening treatment. Abdalla Hassan Mihdy Jassim, et al. [11] looked into the effects

of heat treatments on the aluminum alloy 6063's tensile behavior and toughness. After two hours of homogenization at 560°C, the alloy samples underwent a one-hour solution heat treatment at 500, 530, and 560°C, and then they were quickly quenched in room-temperature water. The yield stress and tensile strength maximum values are 288.6 and 264.5 MPa, respectively. U. Lakshminarayana, et al. [12] used the dependability function to calculate a tool's performance in order to identify when it should be replaced. The results of the study by Nithin M. Mali et al. [13] include shorter cycle times, adaptable procedures, compatible surface roughness, higher rates of material removal, and less environmental issues because cutting fluid is not required. However, it significantly increased tool wear and changed the quality and performance of the product due to the increased mechanical stress and heat generation. Additionally, utilizing a CNC machine for dry machining, an examination and comparison of the performance of uncoated and multilayer coated (Al₂O₃+TiC+TiAlCrN) ceramic tools have been carried out. A model for estimating tool wear and an experimental study on cutting tool wear were published by Vishal S. Sharma et al. [14]. We recode and analyze the variations in cutting force, vibration, and acoustic emission values with cutting tool wear. Adaptive Neuro fuzzy Inference system (ANFIS) is used to construct a model for tool wear estimation in turning operations based on experimental data. The model has been developed using acoustic emission (Ring down count), vibrations (acceleration), and cutting forces in conjunction with time. The cutting tool's wear rate can be estimated by this model. The model's wear estimation findings are compared with the actual outcomes and displayed. When comparing the actual and anticipated tool wear values, the model produced results that were quite excellent. The model can also be used to estimate tool wear online, although its accuracy is dependent on appropriate training and data point selection. The addition of WC and group IV carbides to Ti(C,N)—was examined by Kwon et al. in [15]. Ni Cermets alters the microstructure, which modifies the material's properties.

2. Experimentation

2.1 Work material preparation

From the experimental investigation, the following table 5 has been developed.

This involves preparation of the cylindrical rod of Al6063 alloy material for the experimentation on Lathe machine. The work piece measures 240 mm in length and 25.4 mm in diameter.



Figure 1. Workpiece after machining

2.2 Optimum composition of Al6063

Al6063 material of the following composition were used based on strength criteria, and the same material is used for this experimentation. This is the optimum

composition of Al6063 alloy having highest tensile strength.

Table 1: Weight percentage of metals in Al6063

Metal	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
Wt %	0.45	0.2	0.3	0.1	0.1	0.05	0.05	0.1	98.65

All the machining parameters considered, and the levels of each parameter are represented in table 2 along with the units considered.

Table 2: Input parameters with test levels

Factors	Units	Designation		Test levels	
		Actual form	Coded form	Low	High
Cutting speed	rpm	v	X1	150	445
Feed	mm/rev	f	X2	0.21	0.421
Depth of cut	mm	d	X3	0.2	0.5
Rake angle	degrees (°)	r	X4	15	20

2.3 Selection of tool material

Tool material used is HSS tool (High Speed Steel) for the machining purpose.

Table 3: Chemical composition of Miranda HSS ZEDD Tool

Tool Grade	Material Grade	Approximate % of metals					
		C	Cr	Mo	W	Co	V
ZEDD	M2	0.9	4.1	5.0	6.4	-	1.8

2.4 Design of Experiments (DOE):

To solve the problem with the necessary precision, as indicated in Table 4, the DOE involves choosing the appropriate number of trials and conditions under which to conduct them.

Table 4: Design Matrix

Trial №	v (rpm)	f (mm/rev)	d (mm)	r (°)
1	150	0.21	0.2	15
2	445	0.21	0.2	15
3	150	0.421	0.2	15
4	445	0.421	0.2	15
5	150	0.21	0.5	15
6	445	0.21	0.5	15
7	150	0.421	0.5	15
8	445	0.421	0.5	15
9	150	0.21	0.2	20

10	445	0.21	0.2	20
11	150	0.421	0.2	20
12	445	0.421	0.2	20
13	150	0.21	0.5	20
14	445	0.21	0.5	20
15	150	0.421	0.5	20
16	445	0.421	0.5	20

3. Observation Of Flank Wear (VB)

For all the 16 trials flank wear is observed after each trial and are shown below in figures 1 to 16



Figure 2. Tool-1 geometry before and after experiment

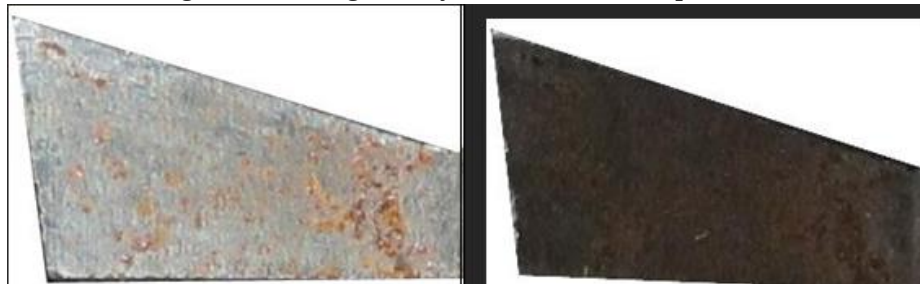


Figure 3. Tool-2 geometry before and after experiment

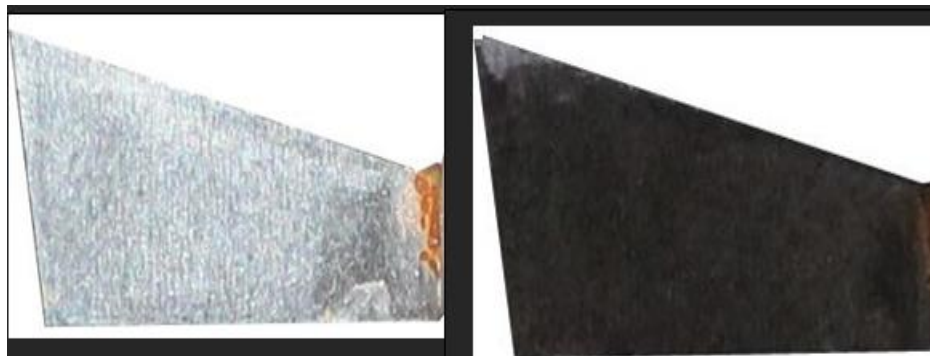


Figure 4. Tool-3 geometry before and after experiment



Figure 5. Tool-4 geometry before and after experiment

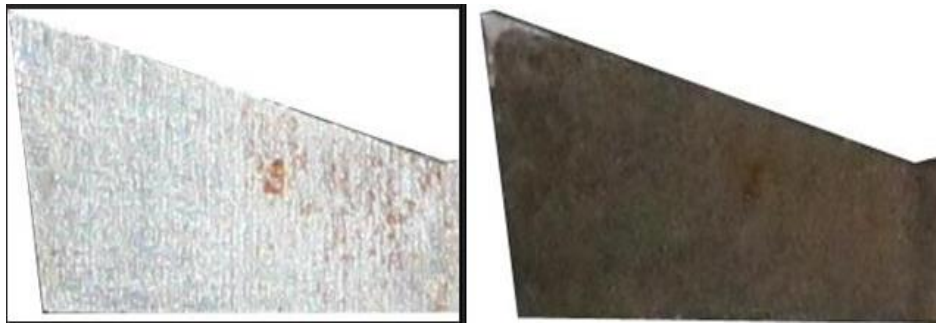


Figure 6. Tool-5 geometry before and after experiment



Figure 7. Tool-6 geometry before and after experiment

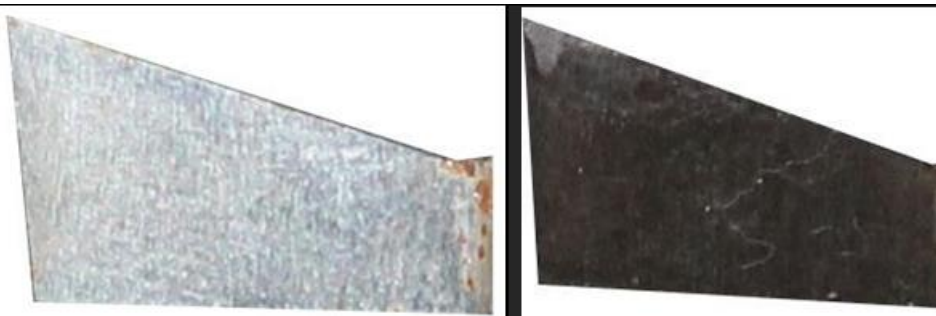


Figure 8. Tool-7 geometry before and after experiment



Figure 9. Tool-8 geometry before and after experiment



Figure 10. Tool-9 geometry before and after experiment



Figure 11. Tool-10 geometry before and after experiment



Figure 12. Tool-11 geometry before and after experiment

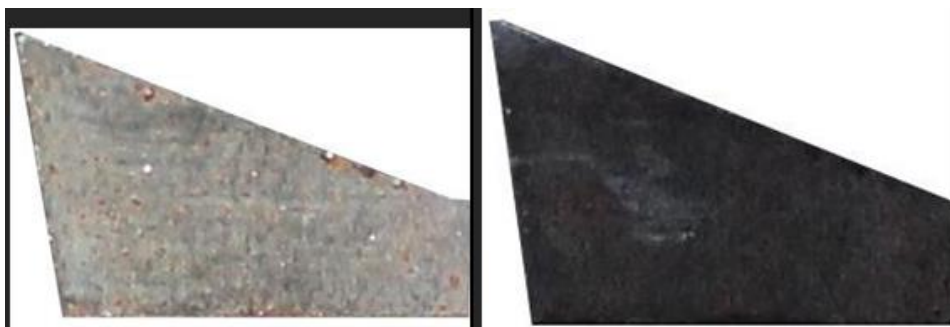


Figure 13. Tool-12 geometry before and after experiment

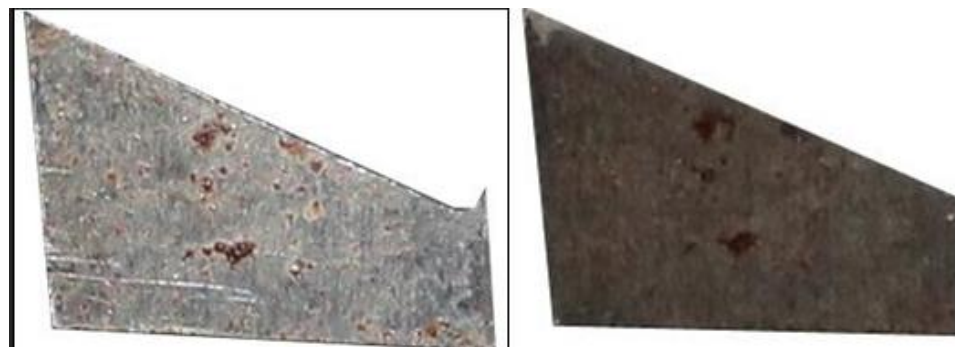


Figure 14. Tool-13 geometry before and after experiment

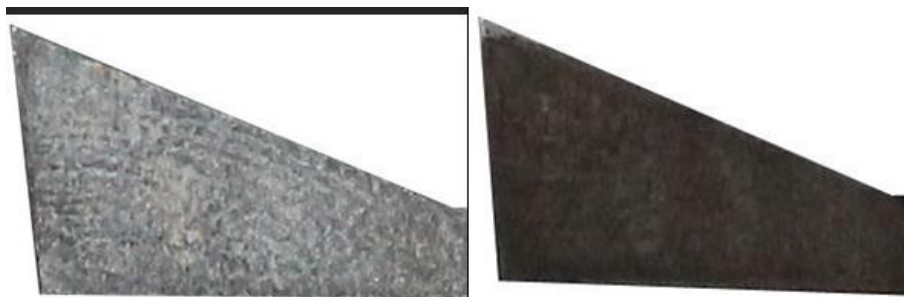


Figure 15. Tool-14 geometry before and after experiment



Figure 16. Tool-15 geometry before and after experiment

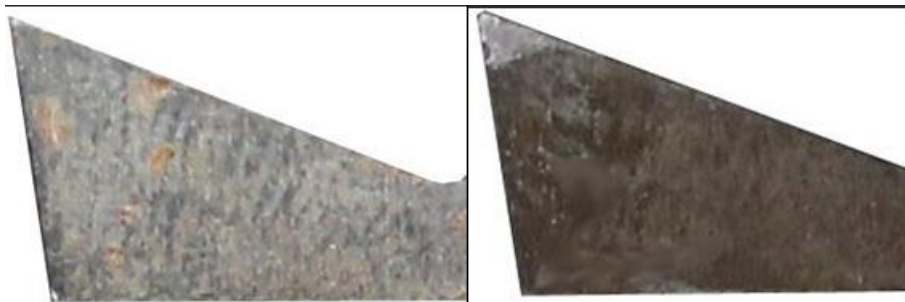


Figure 17. Tool-16 geometry before and after experiment

3.1 Calculation of flank wear using Image processing

Flank wear detection using MATLAB is shown in below figure 18.

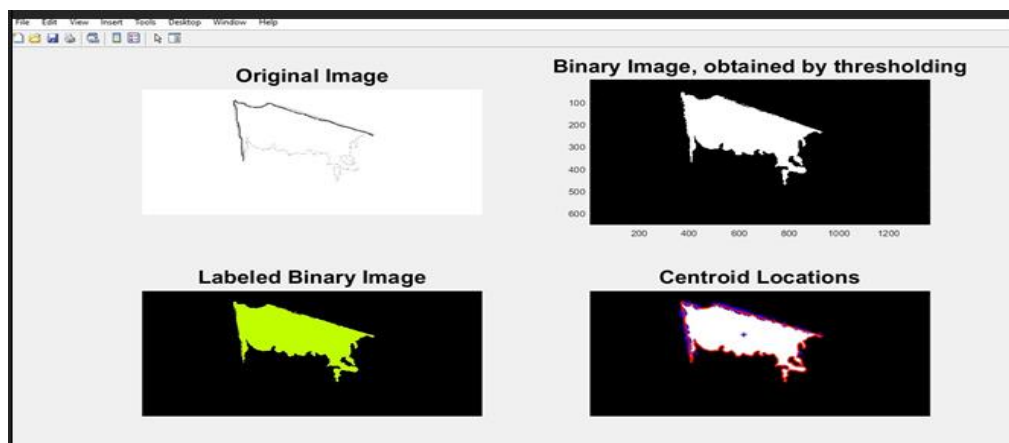


Figure 18. Flank Wear detection in MATLAB

Flank wear detection of each trial specimen using image processing is shown below from figure 19 to figure 26

VB of tool 1 = 0.1, VB of tool 2= 0.07

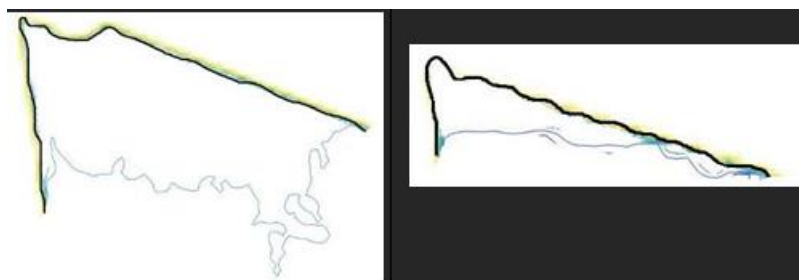


Figure 19. Flank wear of tool 1 & tool 2

VB of tool 3 = 1.45, VB of tool 4= 0.36

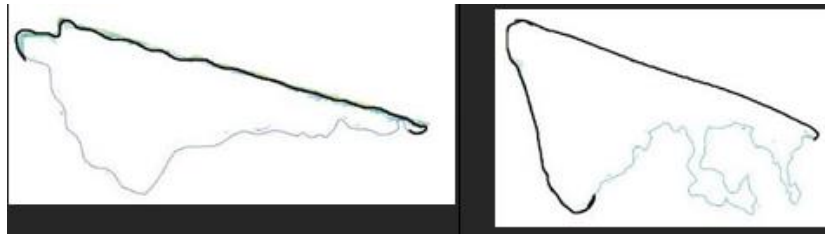


Figure 20. Flank wear of tool 3 & tool 4

VB of tool 5 = 0.29, VB of tool 6= 0.07

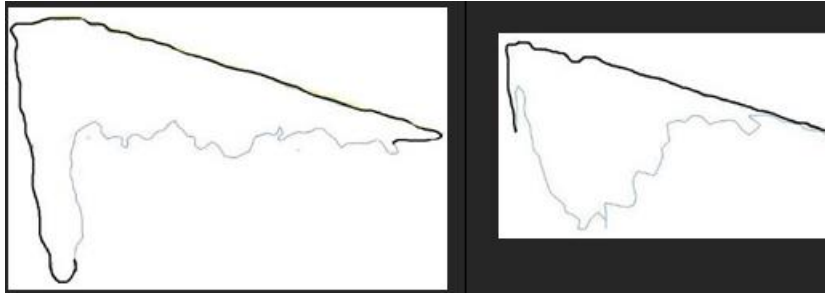


Figure 21. Flank wear of tool 5 & tool 6

VB of tool 7 = 0.19, VB of tool 8= 0.25

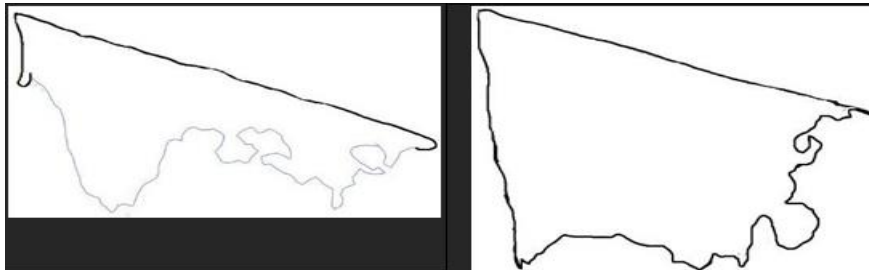


Figure 22. Flank wear of tool 7 & tool 8

VB of tool 9 = 0.22, VB of tool 10= 0.24

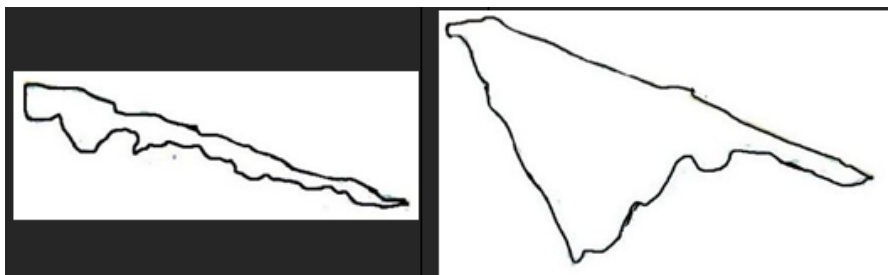


Figure 23. Flank wear of tool 9 & tool 10

VB of tool 11= 0.45 VB of tool 12= 0.06

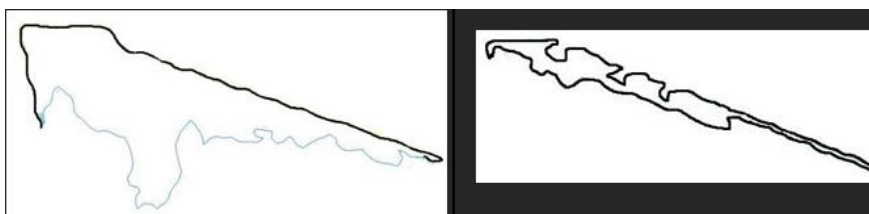


Figure 24. Flank wear of tool 11 & tool 12

VB of tool 13= 0.28, VB of tool 14= 0.1

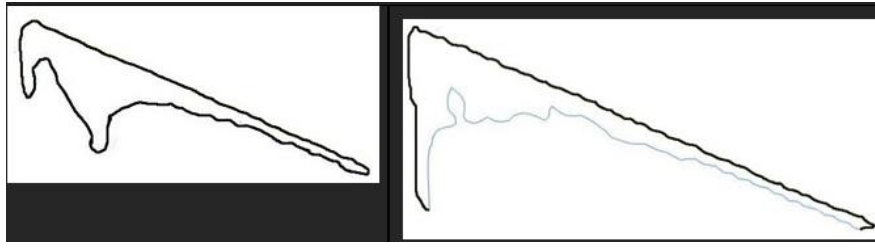


Figure 25. Flank wear of tool 13 & tool 14

VB of tool 15= 0.18, VB of tool 16= 0.26

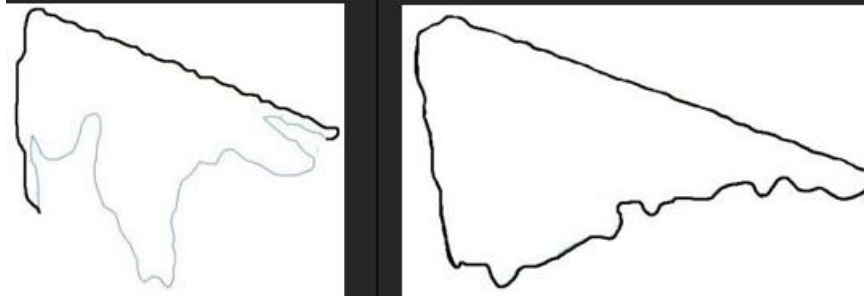


Figure 26. Flank wear of tool 15 & tool 16

3.2 Calculation of Reliability

The tool life model assumes that flank wear follows a normal distribution.

Based on the extrapolation of Wager and Barash [1971], Hitomi et al. [1979], and W.S. Lin [2008], the flank wear distribution's probability density function ($f(VB)$) can be expressed by the following formula:

$$f(VB) = \frac{1}{[\sqrt{2\pi}] \sigma} \exp \left(-\frac{(VB - \mu)^2}{2\sigma^2} \right) \quad (1)$$

If the average VB is the function of (f), (d), (v) and (r) then,

$$VB = \emptyset(v, f, d, r)$$

$$\mu = E[VB] = E[\emptyset(v, f, d, r)]$$

$$\sigma = \text{Var}[VB] = E[(VB - \mu)^2]$$

There is an exponential relationship between VB and cutting parameters, thus the flank wear is expressed by

$$VB = C v^{b1} f^{b2} d^{b3} r^{b4}$$

where C , $b1$, $b2$, $b3$ are constants which can be obtained from experimentation. Now, the probability function of flank wear is given by,

$$f(VB) = \frac{1}{[\sqrt{2\pi}] \sigma} \exp \left(-\frac{(VB - C v^{b1} f^{b2} d^{b3} r^{b4})^2}{2\sigma^2} \right) \quad (2)$$

Damage probability of turning tool occurred before time t :

$$P(\tau < t) = \left[\int_0^t f(\tau) d\tau \right] \quad (3)$$

If the flank wear when the tool life end is VB^* , then, the probability of flank wear reach life limit at time t is:

$$P(VB \geq VB^*) = 1 - \left[\int_0^{VB^*} f(VB) dVB \right] \quad (4)$$

Then,

$$\left[\int_0^t f(\tau) d\tau \right] = \left[\int_0^{VB^*} f(VB) dVB \right] \quad (5)$$

On substituting $f(VB)$, into equation (5), rearranging and differentiating with respect to t , probability density function of tool life $f(t)$ is

$$f(t) = \frac{1}{[\sqrt{2\pi}] \sigma} \exp \left[-\left(\frac{T_v - t}{\sqrt{2}\sigma} \right)^2 \right]$$

The time T_v is reached when the average value of flank wear reaches VB^* . The following equation can be used to get the reliability function $R(t)$.

$$R(t) = 1 - P(\tau < t)$$

$$= 1 - \int_{-\infty}^t \frac{1}{[\sqrt{2\pi}] \sigma} \exp \left[-\frac{1}{2} \left(\frac{x - \mu}{\sigma} \right)^2 \right] dx$$

However, there is no closed form of solution to this integral, then the transformation Z is given by,

$$Z = \frac{T_v - \mu}{\sigma}$$

As a result, the general cutting tool reliability equation based on the failure event is provided by,

$$R(t) = 1 - \emptyset \left[\frac{T_v - \mu}{\sigma} \right]$$

Thus, $R(t) = 1 - \emptyset(Z)$

Where $\emptyset(Z)$ is the probability of failure of the tool,

Hence, $R(t) = 1 - P(t)$

Value of Z is chosen from normal distribution table.

3.3 Metal Removal Rate (MRR)

The amount of material removed in millimeters per minute (mm^3) during turning operations is known as the MRR. Each turning of the work piece results in the removal of a ring-shaped layer of material.

$$MRR = \frac{W_b - W_a}{\rho \cdot t} \frac{\text{mm}^3}{\text{min}}$$

where ρ is the material's density (gm/mm³), t is the machining time (min), W_b is the workpiece's weight before machining, and W_a is the workpiece's weight after machining (gm).

From the experimental investigation, the following table 5 has been developed.

Table 5: Result table

Trial No.	v (rpm)	f (mm/rev)	d (mm)	r (°)	Machiningtime t (min)	Flank Wear VB (mm)	Resultant Force (kgf)
1	150	0.21	0.2	15	3.11	0.1	22.95
2	445	0.21	0.2	15	1.05	0.07	71.48
3	150	0.421	0.2	15	1.55	1.45	99.08
4	445	0.421	0.2	15	0.53	0.36	70.93
5	150	0.21	0.5	15	3.1	0.29	8.60
6	445	0.21	0.5	15	1.05	0.07	14.56
7	150	0.421	0.5	15	1.54	0.19	34.67
8	445	0.421	0.5	15	0.52	0.25	43.60
9	150	0.21	0.2	20	3.08	0.22	70
10	445	0.21	0.2	20	1.04	0.24	47.09
11	150	0.421	0.2	20	1.56	0.45	23.17
12	445	0.421	0.2	20	0.52	0.06	6.72
13	150	0.21	0.5	20	1.02	0.28	11.88
14	445	0.21	0.5	20	1.04	0.1	13.07
15	150	0.421	0.5	20	1.54	0.18	17.03
16	445	0.421	0.5	20	0.52	0.26	15.76

Table 6: Calculation of normal variate(Z)

Trial No	Flank wear VB (mm)	t (min)	T _v	Z
1	0.1	3.11	1.86	4.95
2	0.07	1.05	0.9	1.93
3	1.45	1.54	0.06	-0.707
4	0.36	0.53	0.08	0.644
5	0.29	3.1	0.64	1.116
6	0.07	1.05	0.9	1.933
7	0.19	1.54	0.48	0.613
8	0.25	0.52	0.12	-0.518
9	0.22	3.08	0.04	-0.770
10	0.24	1.04	0.26	-0.078
11	0.45	1.56	0.20	-0.267
12	0.06	0.52	0.52	0.738
13	0.28	1.02	0.21	-0.235
14	0.1	1.04	0.62	1.053
15	0.18	1.54	0.51	0.707
16	0.26	0.52	0.12	-0.518

Mean of flank wear (μ) = 0.285,

Standard deviation of flank wear (σ) = 0.3181

Table 6: Calculation of Reliability

Trial No.	Normal Variate (Z)	Probability of failure (%)	Reliability (%)
1	4.95	-	-
2	1.93	97.32	2.68
3	-0.707	24.20	75.8
4	0.644	73.89	26.11
5	1.116	86.65	13.35
6	1.933	97.32	2.68

7	0.613	72.91	27.09
8	-0.518	30.5	69.5
9	-0.770	22.06	77.94
10	-0.078	47.21	52.79
11	-0.267	39.74	60.26
12	0.738	76.73	23.27
13	-0.235	40.9	59.1
14	1.053	85.31	14.69
15	0.707	75.8	24.2
16	-0.518	30.5	69.5

4. Conclusions

According to the obtained data, for trial-9, with machining inputs of $v = 150$ rpm, $f = 0.21$ mm/rev, $d = 0.2$ mm at $r = 200$ and observed cutting force of 70 kgf, exhibited the maximum reliability of 77.94%. The force of 70 kgf corresponds to MRR of 0.763 cm³/min.

This concludes that high cutting force is required for the tool to be more reliable. The tool replacement time is suggested as 3minutes, which is indicated for minimum MRR.

5. References

- [1] Abdullah Hassan Mihdy Jassim, (2015) "Effect of Heat Treatments on the Tensile Properties and Impact Toughness of 6063 Aluminium Alloy", ResearchGate.
- [2] A. Siva Bhaskar, Venkata Ramesh Mamilla, (2013) "A Reliability Based Approach for Predicting Optimal Tool Replacement Time," International Journal of Scientific Research in Knowledge.
- [3] Carmen Elena Patino Rodriguez, Gilberto Francisco Martha de Souza, (2013) "Reliability concepts applied to cutting tool change time", IJSRK.
- [4] El Wardany, T. I., & Elbestawi, M. A. (1997). Prediction of tool failure rate in turning hardened steels. The International Journal of Advanced Manufacturing Technology, 13(1), 1–16. doi:10.1007/bf01179225
- [5] J.G. Wager, M.M. Barash, (1971) "Study for distribution of the life of HSS tools", Journal of Engineering for Industry, ASME 73/4 295-299.
- [6] K. Hitomi, N. Nakamura, S. Inoue, (1979) "Reliability analysis of cutting tools", Journal of Engineering for Industry 101 185-190.
- [7] Konstantinos Salonitis, Athanasios Koliosb, (2013) "Reliability assessment of cutting tools life based on advanced approximation methods", ScienceDirect.
- [8] Kwon, W. T., Park, J. S., & Kang, S. (2005) "Effect of group IV elements on the cutting characteristics of Ti (C, N) cermet tools and reliability analysis", Journal of Materials Processing Technology, 166(1), 9–14.
- [9] Montasser S. Tahat, Nadim A. Emira, Hamzeh T. Mohamad, (2010) "Study of the Mechanical Properties of Heat Treated 6063 Aluminium Alloy", ResearchGate.
- [10] Nithin M Mali, T. Mahender, (2015) "Wear Analysis of Single Point Cutting Tool with And Without Coating", International Journal of Research in Engineering and Advanced Technology, Volume 3, Issue 3.
- [11] Oussama Zerti, Athmane Yallese, Salim Belhadi, Lakhdar Bouzid, (2014) "Taguchi Design of Experiments for Optimization and Modeling of Surface Roughness When Dry Turning X210Cr12 Steel", ResearchGate.
- [12] S. Ajmal Hussain, Rajaneesh R, Hashim Nizam, Jithin K (2019) "Experimental Analysis on Aluminum alloy (6063) with Silicon Carbide: An Experimental Investigation", Volume: 06, IRJET.
- [13] U. Lakshminarayana, B. Sri Harsha Vardhan Reddy, K. Srinu, B. SurBabu, Akula Siva Bhaskar, (2015) "Predicting Optimal Tool Replacement Time in Turning of Super Alloy Using Reliability Testing", Journal of Material Science and Mechanical Engineering, Volume 2, Number 5.
- [14] Vishal S. Sharma, S. K. Sharma, Ajay K. Sharma, (2007) "Cutting Tool Wear Estimation for Turning." Springer.
- [15] W.S. Lin, (2008) "The reliability analysis of cutting tools in the HSM processes", International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering, Volume 30 Issue 2 Pages 97-100.