Vol. XII & Issue No. 3 March - 2019
INDUSTRIAL ENGINEERING JOURNAL

PREDICTION OF REMAINING USEFUL LIFE, RELIABILITY AND HAZARD RATE OF A TOOL

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ABSTRACT

In general, leftover materials come out from industries and are disposed-off in landfill areas which causes environmental hazard. Outcome of the remaining useful life of tool is an example of reuse in green manufacturing. Tools are discarded much prior using its full potential. Such rejected tools have some remaining potential which can be used for further production. The basic principle of finding remaining useful life is to find out reuse potential of the tool. Prediction of tool life which is also known as predicted tool life (L_P) is determined by regression model developed in methodology by using experimental data. To determine experimental data Taguchi method is used as it reduces number of trial. Remaining useful life is determined by predicted life and consumed life (L_C). Reliability provides the potential of the tool to perform its function in given time for some set of condition. As tool is used its reliability goes on decreasing. Hazard rate is the depreciation of tool w.r.t. to time. Weibull model is developed to determine reliability and hazard rate. By using experimental data weibull constants are determined which gives an equation for calculating reliability and hazard rate. The basic purpose of the work is to determine RUL in line with reliability and hazard rate.

KEYWORDS: *Remaining useful life (RUL), consumed life, regression model, reliability, hazard rate, Weibull distribution etc.*

1. INDRODUCTION

Environment friendly manufacturing is the main focus of the manufacturing companies. In order to attain sustainable development, in many countries, industries are necessary to fulfill government legislation of reducing material waste to a maximum of 5% by the year 2015 (kanari, 2003). RUL is determined by using consumed life of the tool and this is the foremost purpose of the research. Reliability and hazard rate is also found out with the help of experimental data like consumed life of the tool. Regression analysis is used for predicting the tool life which is used to govern remaining useful life. Remaining useful life is used to access the reuse potential of the tool, thus decreasing the leftover tool or material. Reliability is the measure of performance of the tool for specified period of time in a given conditions. It basically provides the idea of quality over time. A product that "works" for a long period of time is a consistent one. Since all units of a product fail at different times, reliability is a probability. As time of action increases reliability goes on decreasing. Hazard rate is the rate of decease of an item for a given period. It is also known as failure rate and determined by hazard function. Based on its survival to an earlier time hazard function analysis the possibility of an item that it will persist to a given time period. Hazard rate is only applied to an element that cannot be restored.

2. LITERATURE REVIEW

Many works have been done in past in exploration for remaining useful life of the tool. But there is less to catch the work for reliability and hazard rate. So there is lot of room for research work in the field of reliability and hazard rate.

Vikas B. Magdum etal. [1]. He studied on turningEN8 steel on lathe machine. His work was focused on optimization of the process parameters. He also made the appraisal for the process parameters. He worked on evaluation of maximum performance characteristics. Vinod Kumar et al. [2]. His work was focused on optimal design of end mill cutters. His detailed study was on verifying the cutting tool forces and stress for milling Titanium alloy Ti-6AI-4V. Pravin Kumar S. et al. [3]. He worked on process failure mode effect and analysis. For his study, he picked up number of work pieces and tools to check out the potential failures and defects. MiroslavZetek et al. [4]. He studied Inconel 718 and found that high temperature and pressure generated, while machining, only at small area of tool tip. Gavin H.P. et al. [5]. His study was on structural reliability and safety. For this purpose he executed the high order limit functions.

Tvedt et al. [6]. He studied the failure probability on structural reliability and second-order approximations. This section of research helped us to find out the reliability of the tool. Wager, J.G., Barash, M.M., et al. [7]. Study for sharing of the life of HSS tools, Journal of Engineering for Industry-Transaction of the ASME 73/4. This research work calculated the life extent of the HSS tool. Choi, S.K., Grandi, R.V.,et al. [8]. Reliability-Based Structural Design, Springer-Verlag. It studied the reliability of the structure castoff in springe design which help us to understand the idea of reliability and its uses.

Hongzhou Wang (2002) et al. [9].Relatedseveralprevailing maintenance policies for both single unit and multi-unit systems. The stress was on single unit systems. He also discussed connection between different maintenance policies. ISO 3685 (1993) et al. [10]. Tool life testing with single point turning tools, 2nd edition, International Organization for Standards, Geneva discussed the idea of tool life in different circumstances and different cutting constraints. Erry Yulian T Adesta, Muataz AI Hazza, Muhammad Riza, Delvis Agusman and roschan et al. [11]. In this research work tool life assessment model based on simulated flank wear for the duration of high speed hard turning was discussed. Idea of measuring flank wear and determination of response tool life which can be found practically, generated from this research work. Enrico Zio and

Francesco Di Maio et al. [12]. This research discussed the fuzzy tactic for predicting the remaining useful life in dynamic failure scenario of a nuclear system and gave the idea of using Fuzzy logic to determine the remaining useful life of the tool. Fatida Rugrungruang et al. [13]. Developed methodologies that improve in predicting the remaining life time and reuse potential of used works. This research work generated the idea that reuse potential of a tool can be found out which add in green manufacturing concept. Ali RizaMotorcu et al. [14]. In his work on optimization of machining parameter for surface roughness of AISI 8660 hardened alloy steel conversed the effective parameters and nose radius on the surface roughness. The result indicated that the feed is the leading factor followed by depth of cut and tool's nose radius. However the cutting speed revealed the insignificant effect. Bom Soon Lee, Han Sub Chung et al. [15]. This study work conferred the method of predicting remaining useful life by using operating data and information on mechanisms. R. K. Suresh et al. [16]. This study envisaged the optimal setting of process parameters which influences the surface roughness in the course of the machining operation (Placeholder1) of En41B alloy steel with cermet tool. From the results the feed and speed are identified as the most significant course parameters on work piece surface roughness. Gaurav Sharma and Prof P.C. Tewari et al. [17] studied the operational reliability of a crusher of a sugar plant in which he mentioned the availability, repair rate and failure rate of the crusher unit. Shreyas Lakhe, Rohit Mariwalla and Chaityanya Reddy et al. [18] developed a linear model based on regression analysis in which they used regression analysis as a data mining to predict the price of the stock market. A sunny kumar, V. Jaya Prasad and VVK Lakshmi et al. [19] presented the study on working capital management on liquidity and profitability of Indian firms. They applied regression analysis to set the relationship between profitability variables, liquidity and other variables.

3. EXPERIMENTAL DATA COLLECTION

The experimental statistics is composed from the central institute of plastic engineering and technology (CIPET) Bhopal. CIPET Centre in the state of Madhya Pradesh was recognized at Bhopal in the year 1988 is situated nearby BHEL in Industrial Govindpura Area on J.K. Road. CIPET: center for skilling and technical support(CSTS) - Bhopal is providing training, technical and consultancy services in Design, CAD/CAM/CAE, Tool Room, Plastic Processing and Testing. CIPET: CSTS - Bhopal is an ISO 9001:2008 certified and Plastic Testing Centre is recognized by NABL, ISO/IEC 17025-2005.Following tables show the different experimental data collected from the experiment. Table 3.1 shows the specification of vertical milling machine, cutting tool and work piece.

Table 3.1 Description of vertical milling machine, cutting tool and work piece

S. No	Parameter	Value
Machine		
1	Power of spindle motor	4 HP
2	Speed range of spindle motor	45-2000 rpm
3	Power of feed motor	0.75 HP
4	Feed (X and Y direction)	16-800 mm/min
Cutting Tool		
1	Cutting tool material	Uncoated tungsten carbide insert (P 30 grade triangular shape)
2	Number of insert	5
3	Diameter of insert holder	80 mm
Work Piece		
1	Work piece material	IS2062 steel
2	Hardness	25 HRC
3	Size of work piece	50×200×550 mm

Table 3.2 shows the values of response tool life. It is the total life of the tool under-going the operation. Total life (L_T) of the tool is generally measured up to the flank wear of 0.6 mm after that tool is either through away or used for some other purposes.

Table 3.2Response tool life (Total life)

Trial No	Spindle speed rpm	Feed mm/min	Depth of cut mm	Measured cutting time up to flank wear of			Responses (L_T) (Total life)
				0.0-0.2 mm	0.2-0.4 mm	0.4-0.6 mm	Tool life min
1	250	50	0.1	25	27	28	80
2	250	80	0.15	24	26	24	74
3	250	125	0.2	21	20	21	62
4	500	50	0.1	18	16	17	51
5	500	80	0.15	14	15	14	43
6	500	125	0.2	12	11	10	33
7	1000	50	0.15	10	9	10	29
8	1000	80	0.2	6	5	7	18
9	1000	125	0.1	5	6	5	16
10	250	50	0.2	30	29	28	87
11	250	80	0.1	24	23	26	73
12	250	125	0.15	21	20	22	63
13	500	50	0.15	16	16	19	51
14	500	80	0.2	15	14	15	44
15	500	125	0.1	10	10	11	31
16	1000	50	0.2	9	10	8	27
17	1000	80	0.1	7	6	7	20
18	1000	125	0.15	5	5	5	15

Table 3.3 shows the values of consumed life (L_C) of the tool. Consumed life of the tool is measured up to the flank wear of 0.4 mm after that tool is either required grinding or used for some other purposes or through away.

Table 3.3 Consumed life of the tool

Trial No	Speed rpm	Feed mm/min	Depth of cut mm	Consumed life of the tool (L_C) (Measured up to 0.4 mm flank wear) min
1	250	50	0.1	52
2	250	80	0.15	50
3	250	125	0.2	41
4	500	50	0.1	34
5	500	80	0.15	29
6	500	125	0.2	23
7	1000	50	0.15	19
8	1000	80	0.2	11
9	1000	125	0.1	11
10	250	50	0.2	59
11	250	80	0.1	47
12	250	125	0.15	41
13	500	50	0.15	32
14	500	80	0.2	29
15	500	125	0.1	20
16	1000	50	0.2	19
17	1000	80	0.1	13
18	1000	125	0.15	10

Table 3.4 shows the values of the actual remaining useful life (RUL) of the tool. These values of the RUL is based on experiment. Here, RUL is obtained by response tool life (L_T) and consumed life (L_c) of the tool by using Mazhar's model.

Table 3.4 RULof the tool (Experimentally)

Trial No	Response (L_T) (Total life) (Measured up to 0.6 mm flank wear) min	Consumed tool life (L_C) (Measured cutting time up to flank wear of 0.4 mm) min	Remaining useful life (RUL) = L_T– L_C(Experimental values) min
1	80	52	28
2	74	50	24
3	62	41	21
4	51	34	17
5	43	29	14
6	33	23	10
7	29	19	10
8	18	11	7
9	16	11	5
10	87	59	28
11	73	47	26
12	63	41	22
13	51	32	19
14	44	29	15
15	31	20	11
16	27	19	8
17	20	13	7
18	15	10	5

4. METHODOLOGY

This section consist of three methodologies, first method is used to predict tool life (Section 4.1) by using regression analysis, second method is the modification of Mazhar's model to predict RUL (Section 4.2) and third method is used to predict reliability and hazard rate (Section 4.3) by using weibull distribution.

4.1 Prediction of Tool Life

Data compelled technique such as regression analysis is used for estimation of total life of the tool. This response tool life with the consumed life forms the basis of RUL model. In this analysis regression analysis is used to develop a model equation for determining the total tool life.

4.1.1 Regression Technique

Regression technique is commonly employed to establish the relationship between response variables and set of predictor variables. Here, Regression technique is used to set the relationship between tool life and the process parameter (speed, feed, depth of cut). Tool life can be represented by the following equation-

$$TL(Tool\ Life) = C\ (v^l f^m d^n)\ (4.1)$$

Where TL is the response tool life, v f and d is process parameters, l m and n are model parameters, C is the model constant. The above equation can be represented in linear form as

$$\ln(TL) = \ln C + l \ln v + m \ln f + n \ln d\ (4.2)$$

The above equation can further be expressed as,

$$Y = B_0 + B_1 X_1 + B_2 X_2 + B_3 X_3\ \ (4.3)$$

Where,

$$B_0 = \ln C, B_1 = l, B_2 = m, B_3 = n,$$

$$X_1 = \ln v, X_2 = \ln f, X_3 = \ln d$$

4.1.2 Determination of Coefficients

The affiliations between these independent variables and dependent variables are acknowledged by developing a regression centered mathematical model. This regression model is established by determining coefficients of regression after developing an equation based on it. These coefficients are determined with the assistance of Minitab software by using experimental data. The less important coefficients can be excluded along with the responses they are accompanied with, without upsetting the exactness of the model. The coefficients are given as follows:

$$\ln c = 11.7,\ \ c = 120571$$

$$l = -0.924, m = -0.49, n = 0.0679$$

These values of coefficients are used in evolving a mathematical model based on the regression analysis for predicting tool life.

4.1.3 Mathematical Model for Predicting Tool Life

This regression model is created on experimental data. Here, the first order polynomial model is used to formulize a mathematical model.

$$\ln(TL) = 11.7 - 0.924 \ln v - 0.49 \ln f + 0.0679 \ln d\ (4.4)$$

This equation can be written in the form of tool life as

$$TL = 120571(\ v^{-0.924} f^{-0.49} d^{0.0679}\ )\ (4.5)$$

Above equation 4.5 is used for determining the value of tool life for different process parameters.

4.2 Remaining Useful Life (RUL)

(Modification of Mazhar's model)

The remaining useful life is sculpted as a function of the component's overall life and the actual (used) life under the working conditions of use (Mazhar's et al, 2001). Mathematically it can be written as

$$L_{RUL} = L_M - L_A\ (4.6)$$

Where, L_{RUL} = Remaining useful life

L_M = Mean life

L_A= Actual life

L_M, basically denotes the component's total functional life under specified conditions of use. It is assessed by analyzing the time-to failure records of a family of components functioned under the same circumstances of use. Here, weibull analysis is employed to approximate the mean life of the specific class of components under-attention. L_A Actual life (used) of components is assessed by engaging condition monitoring data. Here, observed data is used by employing regression analysis. Thereafter, the actual life of the component is assessed by picking an appropriate procedure. The above can be simplified by equation (4.7) as under:

$$L_{RUL} = L_T - L_C\ \ (4.7)$$

Where, L_{RUL} =remaining useful life

L_T = Tool life (overall life)

L_C = Consumed life (actual usage time)

Here, total life of the components is projected using regression technique under the customary of use. Consumed life is usually attained based on usage condition. The above equation (4.7) can also be expressed as:

$$L_{RUL} = L_P - L_C\ (4.8)$$

Where, L_P = predicted life

L_C = Consumed life

As every component experiences numerous operating environment, discrete assessment of the used potential of every single component is essential. Consumed life is determined by analysing the condition monitoring of the logged data during their usage time.

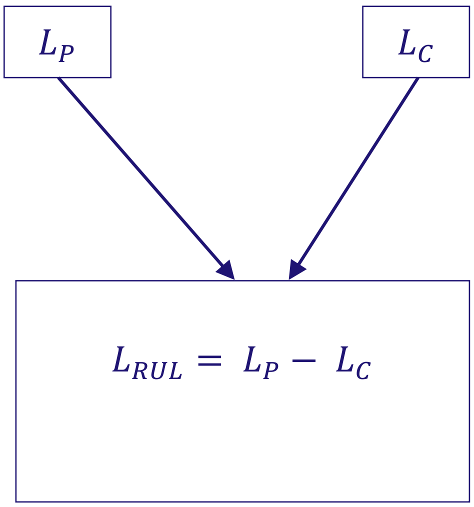


Figure 4.1 Method for remaining life valuation of components

4.3 Reliability and Hazard Rate

Reliability is the measure of how long a component can work without failure in given environment. Hazard rate tells about the extent of depreciation occurs in given time. Both are the important parameters used to measure life of the tool. In this research work weibull distribution is used to determine both the parameters.

4.3.1 Weibull Distribution

Weibull distribution is the vital equation of determining the reliability and hazard rate of the tool. It is mainly used in bath tub curve for finding failure rate. Weibull failure probability density function $f(t_i)$ is given by

$$f(t_i) = \frac{\beta}{\eta}(\frac{t_i}{\eta})^{\beta-1} e^{(-\frac{t_i}{\eta})^{\beta}} \quad (4.9)$$

Reliability $R(t_i)$ of Weibull distribution is given by

$$R(t_i) = e^{-(\frac{t_i}{\eta})^{\beta}} \quad (4.10)$$

Hazard rate $h(t_i)$ (instantaneous failure rate) of Weibull distribution is given by

$$h(t_i) = \frac{\beta}{\eta}(\frac{t_i}{\eta})^{\beta-1} \quad (4.11)$$

Where β = Weibull shape parameter

η = Weibull scale parameter

t_i = Consumed life of the tool

4.3.2 Determination of Coefficients

Coefficients of the weibull distribution are determined by using regression analysis technique. The purpose of the research is to design the model equation for reliability and hazard rate. The value of β and η are determined by regression analysis with the help of experimental data of consumed life. Failure probability (cumulative density function) is given by

$$F(t_i) = 1 - e^{-(\frac{t_i}{\eta})^{\beta}} \quad (4.12)$$

The above equation can be written as

$$\ln[1 - F(t_i)] = -(\frac{t_i}{\eta})^{\beta}$$

$$\ln\{-\ln[1 - F(t_i)]\} = \beta \ln(\frac{t_i}{\eta})$$

$$\ln\{-\ln[1 - F(t_i)]\} = \beta \ln(t_i) - \beta \ln(\eta)$$

$$Y_i = a + bX_i \quad (4.13)$$

Where,

$$Y_i = \ln\{-\ln[1 - F(t_i)]\}$$

$$X_i = \ln(t_i)$$

$$a = -\beta \ln(\eta)$$

$$b = \beta$$

Where the constants in the equation (4.13) is determined as follows

$$a = \frac{\sum_{i=1}^{N} Y_i}{N} - b\frac{\sum_{i=1}^{N} X_i}{N}$$

$$b = \frac{\sum_{i=1}^{N} X_i Y_i - \sum_{i=1}^{N} X_i \sum_{i=1}^{N} Y_i / N}{\sum_{i=1}^{N} X_i^2 - (\sum_{i=1}^{N} X_i)^2 / N}$$

Median Rank Method is used to determine $F(t_i)$ which is given by

$$F(t_i) = \frac{i - 0.3}{N + 0.4}$$

Where, $i = 1,2,3 \ldots \ldots N$

$$N = 18$$

To determine the value of constants we have to construct a table in which consumed tool life (t_i) is arranged in ascending order. Table 4.1 shows the different values of the variables

Table 4.1 Values of the variables

Serial No (i)	t_i min	X_i	Y_i	X_i^2	X_iY_i
1	10	2.30	-3.25	5.29	-7.48
2	11	2.40	-2.34	5.75	-5.61
3	11	2.40	-1.84	5.75	-4.41
4	13	2.57	-1.50	6.60	-3.86
5	19	2.95	-1.22	8.70	-3.60
6	19	2.95	-0.99	8.70	-2.92
7	20	3.00	-0.79	9.00	-2.37

8	23	3.14	-0.61	9.86	-1.92
9	29	3.37	-0.45	11.36	-1.52
10	29	3.37	-0.28	11.36	-0.94
11	32	3.47	-0.14	12.04	-0.49
12	34	3.53	0.01	12.46	0.04
13	41	3.71	0.16	13.76	0.59
14	41	3.71	0.31	13.76	1.15
15	47	3.85	0.47	14.82	1.81
16	50	3.91	0.65	15.29	2.54
17	52	3.95	0.87	15.60	3.44
18	59	4.08	1.18	16.65	4.81
		$\sum_{i=1}^{N} X_i$= 58.66	$\sum_{i=1}^{N} Y_i$= -9.76	$\sum_{i=1}^{N} {X_i}^2$= 196.75	$\sum_{i=1}^{N} X_i Y_i$= -20.74

The value of the shape parameter and scale parameter is determined by using data available in Table 4.1 are given as follows:

$\beta = 1.982$

$\eta = 34.208$ min

These values of the coefficients are used to determine the model equation for predicting reliability and hazard rate.

4.3.3 Mathematical Model to Determine Reliability and Hazard Rate

The final model equation used to determine reliability and hazard rate is designed by using values of coefficients. Final equation of the reliability and hazard rate becomes

$$R(t_i) = e^{-\left(\frac{t_i}{34.208}\right)^{1.982}} \quad (4.14)$$

And

$$h(t_i) = 1.805 \times 10^{-3} (t_i)^{0.982} \quad (4.15)$$

Reliability and hazard rate are determined by using above equation with the help experimental data. These equation are based on the consumed life of the tool.

5. RESULT

Remaining useful life of the tool is lastly determined by predicting tool life (by regression analysis) and consumed life of the tool which is determined experimentally (measure to .4 mm flank wear). The following table shows RUL of the tool

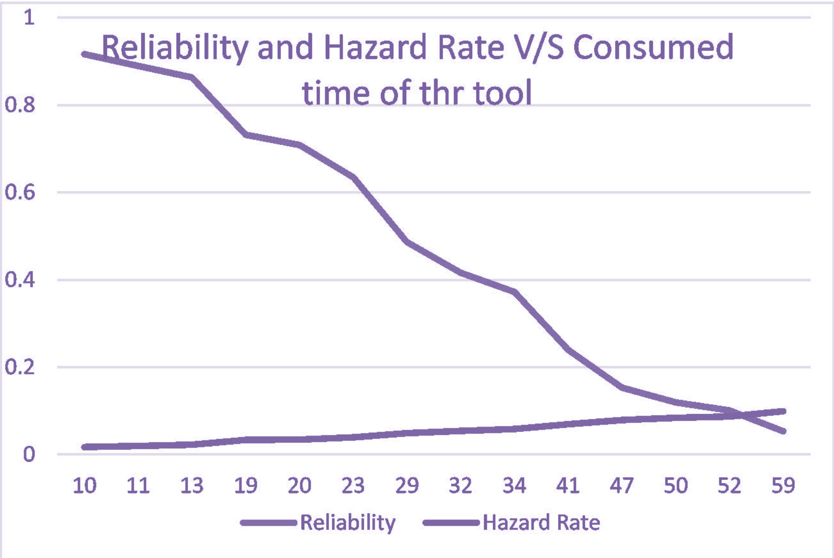
Table 5.1 RUL of the Tool (by regression Analysis)

Trial No	Predicted Life (L_P)min	Consumed Life (L_C) min	Remaining Useful Life min
1	93.98	52	41.98
2	76.49	50	26.49
3	62.38	41	21.38
4	47.12	34	13.12
5	38.51	29	9.51
6	31.40	23	8.4
7	24.96	19	5.96
8	20.10	11	9.1
9	14.49	11	3.49
10	102.13	59	43.13
11	72.68	47	25.68
12	60.16	41	19.16
13	49.59	32	17.59
14	39.93	29	10.93
15	28.78	20	8.78
16	25.89	19	6.89
17	18.42	13	5.42
18	15.25	10	5.25

Reliability and hazard rate of the tool is determined by the relation we found on methodology. According to the theoretical concept of reliability, it must be decreased w.r.t consumed time. In the same manner hazard rate must be increased w.r.t the tool consumed time. The following table shows the reliability and hazard rate

Table 5.2 Reliability and Hazard Rate

Serial No (i)	Speed rpm	Feed mm/min	Depth of cut mm	Consumed Life (t_i) min	Reliability $R(t_i)$	Hazard Rate $h(t_i)$/min
1	1000	125	0.15	10	0.916	0.017
2	1000	80	0.2	11	0.899	0.019
3	1000	125	0.1	11	0.899	0.019
4	1000	80	0.1	13	0.863	0.022
5	1000	50	0.15	19	0.732	0.033
6	1000	50	0.2	19	0.732	0.033
7	500	125	0.1	20	0.708	0.034
8	500	125	0.2	23	0.634	0.039
9	500	80	0.15	29	0.486	0.049
10	500	80	0.2	29	0.486	0.049
11	500	50	0.15	32	0.416	0.054
12	500	50	0.1	34	0.372	0.058
13	250	125	0.2	41	0.239	0.069
14	250	125	0.15	41	0.239	0.069
15	250	80	0.1	47	0.153	0.079
16	250	80	0.15	50	0.119	0.084
17	250	50	0.1	52	0.101	0.087
18	250	50	0.2	59	0.053	0.099



6. CONCLUSION

This research on tungsten carbide tipped tool comes out with four most speculated conclusion:

- Maximum RUL is 43.13 min and this RUL exists when speed, feed and depth of cut is 250 rpm, 50 mm/min and 0.2 mm respectively. On the other hand minimum RUL is 3.49 min at the speed of 1000 rpm, feed of 125 mm/min and depth of cut is 0.1 mm.
- From the above data we can conclude that speed has the highest effect on tool depreciation whereas depth

of cut has the lowest.

- Reliability is maximum at the early phase and goes on decreasing as the consumed life of the tool increases. Hazard rate is minimum at the early phase and goes on increasing as the consumed life of the tool increases.

On analysing results, it can be concluded that this research is very helpful in analyzing RUL, reliability and hazard rate in various industrial sector as well as for further research work. This study can be extended to analyse different material of tool and work piece like HSS, ceramics etc. Further industrial system like machine tool, workshop etc. can be taken as our study point. This study is limited to only 18 trial but it can be extended to more number of trial to generalize the idea. In this study regression analysis is used to determine RUL, other methods like fuzzy technique, artificial neural network technique, support vector regression etc. can be employed for further study. If applied in any industry, it will improve the effectiveness and also improve the green manufacturing system of the industry.

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