International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 5,May 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

DIAMOND COATING IMPACT INVESTIGATION ON TOOL LIFE FOR HSS END MILL CUTTER USED IN POCKET MILLING OF MATERIAL AISI 4028H

Chandni A. Patel*, Hardik J. Patel2, Nilesh M. Vora3

[1]*M.E. student, Sardar Patel Institute of Technology, Piludara, Mehsana, chandnipatel249@gmail.com*
[2]*Asst. Professor, Sardar Patel Institute of Technology, Piludara, Mehsana*
[3]*Design Engineer, Ingersoll Rand Ltd., Ahmedabad*

Abstract: The aim of work is to improve the tool life without affecting machine parameter likes MRR and also without investment for new tool. The experiment is based on Taguchi method including suitable orthogonal array. The experiment was conducted twice on material AISI 4820H Alloy steel on CNC vertical milling machine. The ANOVA technique will apply to study significance of each machining parameter on the TOOL LIFE and MRR. There are total nine set of variety taken for a study of tool life by varying the depth of cut, Spindle Speed, Feed, Cutting Velocity and same were repeated again for Diamond coated End mill cutter. The change in life observed was positive varying from minimum of 12.61 % to the maximum increased of tool life 16.69%.

Keywords: CNC vertical milling, AISI 4820H alloy steel, MRR, Tool life, Taguchi method, ANOVA, Diamond coating

I. INTRODUCTION

Machining parameter tables provided by the machine tool manufacturers often do not meet the operator requirements and sometimes even do not provide efficient guidelines to manufacturing engineers. This may lead to the act of adjustment in the customer's requirements, which may result in poor quality, and ultimately rejection of the final product by them. Hence, a suitable Selection of machining parameters of CNC milling machine process is necessary.

Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed. In industries or shop floor it is defined as: The length of time of satisfactory service or amount of acceptable output provided by a fresh tool prior to it is required to replace or recondition. Prior to the start of any tool life improvement activities, it is most important to have a clear view of the actual tool life. Since tool life reacts rather sensitive to the influence of various process parameters, a comprehensive analysis of the circumstances of tool failure starting from development phase to production phase is highly recommended.

AISI 4820H is an H-Steel grade Alloy Steel widely used for machining purpose to manufacture no. of load bearing units like shaft. The machining of AISI 4820H can be achieved via no of processes. The main intent of work is to figure out the tool life for material AISI 4820 with and without coating. The end milling cutter used for pocketing operation is having manufacturer standard material as HSS with standard tool life with standard cutting parameters, but in real life the cutting parameters may vary based on requires and complexity of the work. So in such cases the stander tool life may not be applicable. Hence to improve the life of cutter we should apply some coating on it. Such kind of research work is scope of area to work.

There are total nine set of variety taken for a study of tool life by varying the depth of cut, Spindle Speed, Feed, Cutting Velocity and same were repeated again for Diamond coated End mill cutter. The change in life observed was positive varying from minimum of 12.61 % to the maximum increased of tool life 16.69%. The pattern of tool life Vs case no. is shown in Graph in conclusion of paper which clearly indicated with increased in depth of cut from 2 to 2.5 and 3 tool life is constantly increasing by keeping feed and cutting speed as constant i.e. 32 and 1.3 M / Min. through this work we can conclude that the time require for change over of tool in case of failure of tool due to burn out or wear can be reduce by applying diamond coating which is having significant average improvement of tool life of 102 Min for same cutting parameters.

II. LITERATURESURVEY

Ishan B. Shah and Kishore. R. Gawande[9] demonstrate that the cutting speed and depth of cut are the main parameters that influences the tool life of end mill cutters of CNC milling machine while milling of stainless steel 304. They indicate that the tool life can be improved simultaneous through DOE approach instead of using Engineering judgment. Low depth of cut, low cutting speed and high feed rate are recommended to obtain better tool life for specific rang. They increased tool life up to 28%[9].

S.R.Das, R.P. Nayak and D. dhupal[17] indicate in their paper that Depth of cut and cutting speed are the most important parameter influencing the Tool wear while dry turning of AISI D2 steel. The minimum tool wear found at cutting speed of 150 m/min ,depth of cut of 0.5 mm and feed rate of 0.25 mm/rev.The percentage contribution of depth of cut (60.85%) and cutting speed (33.24%) in affecting the variation of tool wear significantly larger as compared to the contribution of the feed(5.70%).The predicted optimal range of tool wear is in between 0.21 and 0.31[17].

Piyush Pandey , Prabhat sinha,Vijay kumar and Manas Tiwari[11] perform their practical two output parameter such as MRR and surface roughness. The result shows that Cutting speed and feed rate are the powerful control parameters for the material removal rate and depth of cut and feed rate calculated as powerful factors for controlling the surface finish of Mild Steels[11].

Kamal Hassana, Anish Kumar, M.P.Garg[11] investigates the effects of process parameters on Material Removal Rate (MRR) in turning of C34000. Feed rate is found to be the most significant factor & its contribution to material removal rate is 42.77 %. The interaction between cutting speed and feed rate is found to be significant which contributes 7.75%.The best results for Material removal rate (lower is better) would be achieved when C34000 work piece is machined at cutting speed of 55 mm/min, depth of cut of 0.2 mm, feed rate of 0.35 mm/rev[11].

K.B. Ahsan, A.M. Mazid, R.E. Clegg, G.K.H. Pang[12] said in their paper that Cutting speed is a significant factor in assessing the tool life and it is true for both of coated and uncoated carbide inserts. As the cutting speed increases, the tool life decreases very sharply. At lower cutting speeds, the uncoated carbide tool life is better in comparison with the tool life of coated ones while machining by using cutting fluid. Tool life is highly dependent on the application of proper cutting fluid. If the flow of cutting fluid is stopped, the tool fails very shortly. Hence wet machining is safer as compared with the dry machining and it is more sustainable[12].

Assistant Prof. Abrar A. Arshi, Assistant Prof. Atish Dighewar[1] investigate that Tin coated tool perform better as compared to uncoated cutting tool. The effect of cutting is to reduce wear and tear of tool tip point as well as more heat dissipation to surrounding hence the increase in tool life[1].

B. Sahoo, A K Chattopadhyay and A B Chattopadhyay[3] investigate that coolant flow with the contribution of 60.69% is the most important parameter in controlling the surface roughness and it also affect the tool life while machining the1040 MS material. The optimal parameters obtained as spindle speed of 2500 rpm, feed rate of 800 mm/min, 0.8 mm depth of cut, 30 lit/min coolant flow[3].

M. Narasimha, K. Sridhar, R. Reji Kumar, Achamyeleh Aemro Kassie[10] use coatings on tungsten based cemented carbide cutting tool to improve tool life. Coatings like TiN,Al2O3,TiC/Al2O3/TiN are used. For comparison, uncoated tungsten carbides are also tested under the same cutting conditions. The coated tools produces lower surface roughness compared to the uncoated too. The wear of the TiN coated tool was around 12% lower than the wear observed on the uncoated tool. TiN/Al2O3 coated tool showed a decrease of around 65% compared to the uncoated tool. The decrease in wear was due to the wear resistance properties of the TiN and Al2O3 materials and the high chemical stability of the Al2O3 layer[10].

Rama Rao. S's Statistical results (at a 95% confidence level) show that the voltage (A), feed rate (B), and electrolyte concentration (C) affects the metal removal rate by 34.04%, 58.09% and 7.57% in the electrochemical machining of LM6 Al/5%SiC composites, respectively. The maximum metal removal rate is calculated as 0.131 g/min by Taguchi's optimization method. Metal removal rate increases with voltage, feed rate and electrolyte concentration in electrochemical machining of LM6 Al/5%SiC composites[12].

III METHODOLOGY

3.1 Design of Experiment

Design of experiments (DOE) is a statistical technique introduced by Sir R. A. Fisher in England in the early 1920s. Design of Experiment (DOE) is a structured and organized method that is used to determine the relationship between the different factors of input variables that affects a process and the output or response of that process. Design of Experiment involves designing a set of experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal conditions, the factors that most influence the results, and those that do not, as well as details such as the existence of interactions and synergies between factors. When applied to product or process design, the technique helps to seek out the best design among the alternatives. Here the problem is to find out the effect of three input parameters:

(i) Depth of Cut
(ii) Cutting Speed
(iii) Feed

On two output parameters:

(i) Tool life
(ii) Material Removal Rate

There is 3-level parameter design considered here. So there are three different value of every input parameter is taken into account for investigating its effect on output parameters.

3.2 Test Setup

3.2.1 Specification of CNC Milling

Figure 1 - CNC machine

Table 1: Specification of CNC milling machine

Model no: BMW 60	Controller system: PLC based	Main spindle drive: DC Drive
Spindle power: 7.5 kW	Interpolation: circular, linear,	Code used: G, M
X-axis travel: 1050mm	Y-axis travel: 610mm	Z-axis travel: 610mm

3.2.2 Specification of Material

Table 2: Chemical composition

Iron(Fe):94.495-95.88%	Nickel(Ni):3.20-3.80%	Manganese(Mn):0.400-0.800%
Molybdenum(Mo):0.200-0.300%	Carbone(C):0.170-0.320%	Silicon(si):0.150-0.300%

Table 3: Mechanical Properties

Tensile strength: 685Mpa	Yield strength: 460Mpa	Elastic modulus: 190-210Gpa	Bulk modulus: 140Gpa
Shear modulus:80Gpa	Poisson ratio:0.27-0.30	Hardness,Brinell:197	Machinability:50

Thermal conductivity: 44.5W/mK

Density: 7.85g/cm3

3.3 Level Factor Selection

Table 4: Level factor

Factor	unit	Level 1	Level 2	Level 3
Cutting speed	m/min	2	2.5	3
Feed rate	mm/rev	30	32	34
Depth of cut	mm	1.3	1.4	1.5

IV RESULT AND DISCUSSION

4.1 Experimental Design:

Two different combination of design of experiment are:

Table 5: Experimental design

	TOOL MATERIAL	MACHINING MATERIAL
Case I	High Speed Steel	AISI 4048H
Case II	High Speed Steel with Diamond Coating	AISI 4028H

4.2 Case I: Normal HSS Tool

Here in this case, we have taken AISI 4028h as work material and HSS as tool material. And Depth of cut, Feed and cutting speed are taken as input parameters and tool wear rate and material removal rate are taken as output parameters. The design of this experiment is as represented by the table given below. Same exercise was repeated for tool having Diamond coating with all the parameter similar to case one to verify the impact of coating on tool life.

Table 6: L9 Orthogonal Array

Sr. No.	Cutting Depth [MM]	Feed Per Revolution	Cutting Speed [M/Min]

1	2	30	1.3
2	2	32	1.4
3	2	34	1.5
4	2.5	30	1.4
5	2.5	32	1.5
6	2.5	34	1.3
7	3	30	1.5
8	3	32	1.3
9	3	34	1.4

4.2.1 Calculation of MRR

Symbol	Designation	Unit Of Measure									
ae	Working engagement	mm	20	20	20	20	20	20	20	20	20
AP	Cutting depth	mm	2	2	2	3	3	3	4	4	4
DCap	Cutting diameter at cutting depth AP	mm	100	100	100	100	100	100	100	100	100
Dm	Machined diameter (component diameter)	mm	100	100	100	100	100	100	100	100	100
fz	Feed per tooth	mm	32.00	50	60	40	50	60	40	50	60
fn	Feed per revolution	mm/r	30	32	34	30	35	40	30	35	40
n	Spindle speed	rpm	1800	1800	1800	1900	1900	1900	2000	2000	2000
vc	Cutting speed	m/min	1.25	1.3	1.35	2	2	2	2	2	2
vf	Table feed	mm/min	1200	1200	1200	1200	1200	1200	1200	1200	1200
ZEFF	Number of effective teeth	pcs	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
hex	Maximum chip thickness	mm	4	4	4	4.3	4.3	4.3	4	4.2	4.1
hm	Average chip thickness	mm	3.75	3.8	3.71	3.8	3.75	3.82	3.6	3.8	3.68
kc	Specific cutting force	N/mm2	1	3.5	4	3	3	3	3	3	3
Pc	Net power	kW	0.027	0.1008	0.1224	0.12825	0.14963	0.171	0.18	0.21	0.24
Mc	Torque	Nm	0.01475	0.05508	0.06689	0.06639	0.07746	0.08852	0.08852	0.10328	0.11803
Q	Metal removal rate	cm3/min	1620	1728	1836	2565	2992.5	3420	3600	4200	4800
Table Feed	vf = fz × n × ZEFF	*mm / Min*	40500.00	43200.00	45900.00	42750.00	49875.00	57000.00	45000.00	52500.00	60000.00
Cutting speed,	vc = π × DCap × n / 1000	*m/min*	565.47	565.47	565.47	596.89	596.89	596.89	628.30	628.30	628.30
Spindle speed,	n = vc × 1000/ π × DCap	*r/min*	3.98	4.14	4.30	6.37	6.37	6.37	6.37	6.37	6.37
Feed per tooth,	*fz* = *v*f / *n* × ZEFF	*mm*	7633.85	7829.58	8010.83	5036.22	5875.59	6714.96	5301.28	6184.83	40.00
Feed per revolution,	*f*n = *v*f / *n*	*mm/rev*	30.00	32.00	34.00	30.00	35.00	40.00	30.00	35.00	40.00
Metal removal rate,	Q = AP × *ae* × *v*f / 1000	*cm3/min*	1620.00	1728.00	1836.00	2565.00	2992.50	3420.00	3600.00	4200.00	4800.00
Net power,	*P*c = *ae* × AP × *v*f × *k*c / 60 × 106	*kW*	0.03	0.10	0.12	0.13	0.15	0.17	0.18	0.21	0.24
Torque	*Mc = Pc × 30 × 103 / 3.1415 × n*	*Nm*	0.0148	0.0551	0.0669	0.0664	0.0775	0.0885	0.0885	0.1033	0.1180

Fig 2: Print screen of calculation of MRR

	TOOL LIFE WITH OUT COATIING IN MIN								
T = (k^1/n)/(V^1/n x f^n1/n x d^n2/n)									
WhereT = Tool life in min,									
f = feed in mm per revolution	32.0	30.0	34.0	32.0	30.0	34.0	32.0	30.0	34.0
d = depth of cut in mm	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0
n = Tool constant 0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
n1= feed exponent constant – 0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
n2 =depth of cut exponent constant- 0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
k= constant- 47	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00
v = cutting speeds (m /min)	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4
1/n	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
n1/n	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
n2/n	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
(k^1/n)	4879681.0	4879681.0	4879681.0	4879681.0	4879681.0	4879681.0	4879681.0	4879681.0	4879681.0
V^1/n	2.4	5.1	3.3	2.4	5.1	3.3	2.4	5.1	3.3
f^n1/n	1024.0	900.0	1156.0	1024.0	900.0	1156.0	1024.0	900.0	1156.0
d^n2/n	1.7	1.7	1.7	2.1	2.1	2.1	2.4	2.4	2.4
(V^1/n x f^n1/n x d^n2/n)	4352.8	7932.9	6685.2	5203.5	9483.3	7991.8	6020.6	10972.5	9246.8
T MIN	1121.1	615.1	729.9	937.8	514.6	610.6	810.5	444.7	527.7

Fig 3: Print screen of calculation of tool life

4.2.2 Calculation of Tool life

The relation between 3 inputs and 2 Output are shown in below table. Where we can see the result of MRR and Tool Life against each case. The similar case for diamond coating was also conducted as all the cutting parameters were same there was not a change in MRR but we can see the improvement of tool life.

Table 7: Set of results

Sr. No.	Cutting Depth [MM]	Feed Per Revolution [MM/ Rev]	Cutting Speed [M/Min]	MRR [CM³/Min]	Toll Life [Min]
1	2	30	1.3	1620	1121.06
2	2	32	1.4	1728	615.12
3	2	34	1.5	1836	729.92
4	2.5	30	1.4	2565	937.78
5	2.5	32	1.5	2992.5	514.56
6	2.5	34	1.3	3420	610.59
7	3	30	1.5	3600	810.50
8	3	32	1.3	4200	444.72

9	3	34	1.4	4800	527.72

4.3 ANOVA Technique

The technique of analysis of variance is an indispensable tool in the scientific and industrial research for the analysis of experimental data involving quantitative measurements and is particularly helpful when several independent sources of variation are present in the data such as the results obtained at different temperatures. The source of variation in the data may be due to various causes, assignable or chance. Using the analysis of variance techniques it is possible to estimate how much of the total variation in a set of data can be attributed to one or more assignable causes of variation being classed as due to chance causes which produces the residual or error variation. For this design, the ANOVA carried out with Minitab 16 software and ANOVA table given below:

Table 8: ANOVA Technique for MRR

MRR						
Source	**SS**	**df**	**MS**	**F**	**P**	**% Contrib**
DEPTH OF CUT	9167800.50	2	4583900.25	73.56	0.01	89.21%
FEED	859573.50	2	429786.75	6.90	0.13	8.36%
CUTTING SPEED	124633.50	2	62316.75	1.00	0.50	1.21%
Error	124633.50	2	62316.75			1.21%
Total	10276641.00	8				

Table 9: ANOVA technique for tool life

TOOL LIFE						
Source	**SS**	**df**	**MS**	**F**	**P**	**% Contrib**
DEPTH OF CUT	78626.65	2	39313.33	28.81	0.03	20.09%
FEED	307270.31	2	153635.16	112.60	0.01	78.51%
CUTTING SPEED	2728.82	2	1364.41	1.00	0.50	0.70%
Error	2728.82	2	1364.41			0.70%
Total	391354.61	8				

The ANOVAs table shows the impact of Depth of Cut is having significant impact (89.21%) on MRR and Feed is having highest impact (78.51%) on Tool Life. In all the Output the Cutting speed is having least impact.

4.4 Pareto Analysis

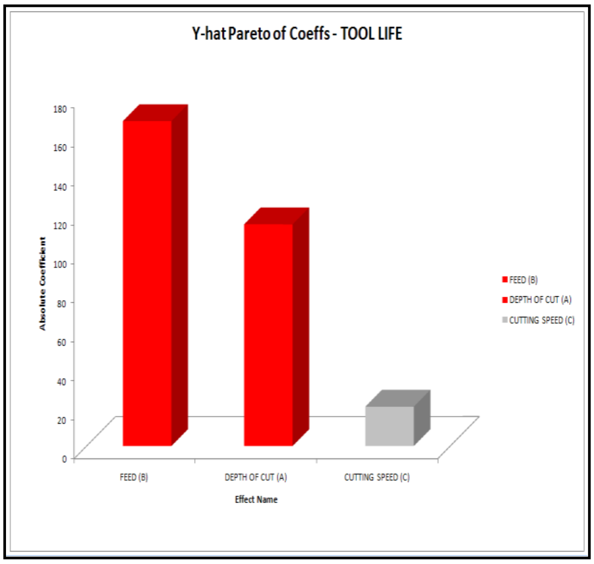

Fig 4: Pareto graph for tool life

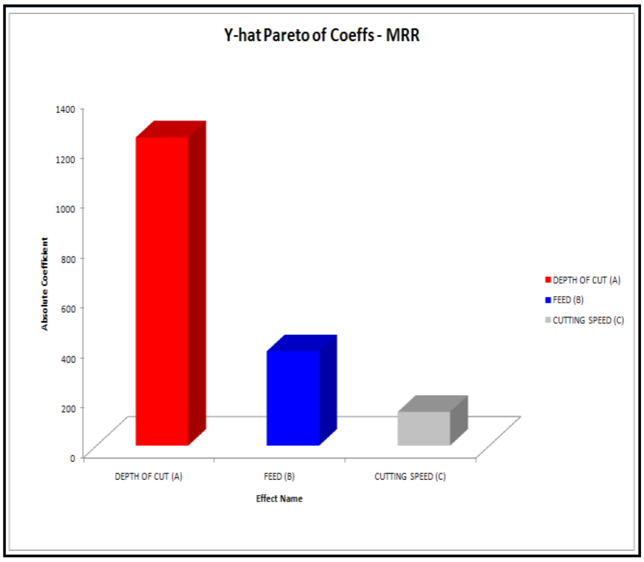

Fig 5: Pareto graph for MRR

The Pareto analysis shows the impact of Feed, Depth of cut and cutting speed on Tool Life (fig 4) which is in line with ANOVAs table. Same kind of analysis for MRR is also shown in fig 5. From this analysis we can conclude that the Feed selection is having prime impact on tool life while Depth of cut play major role for MRR. The Cutting speed is having lower impact on Tool life with respect to Feed, and Depth of Cut and same is true in case of MRR also.

4.5 CASE II: Diamond coated HSS Tool

Calculation of tool life for diamond coated HSS Tool

f = feed in mm per revolution	32.0	30.0	34.0	32.0	30.0	34.0	32.0	30.0	34.0
d = depth of cut in mm	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0
n = Tool constant for Diamond coating	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
n1= feed exponent constant – 0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
n2 =depth of cut exponent constant- 0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
k= constant- 52(frm tool manufacturer	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
v = cutting speeds (m /min)	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4
T MIN	1262.4	708.9	835.6	1063.3	597.1	703.8	924.2	518.9	611.7

Fig 6: Print screen of calculation of tool life without coating

IV CONCLUSION

We have conducted two experiments one is with Coating and one is without coating. In both the cases we have kept cutting parameter same to check the impact of coating on toll life. There were total 09 cases we simulated on machine with and without coating. The details of cases are shown in below table.

	DEPTH OF CUT	FEED	CUTTING SPEED	% INCREASE IN LIFE
CASE :01	2	32	1.3	12.61%

CASSE:02	2	30	1.5	15.24%
CASE: 03	2	34	1.4	14.48%
CASE :04	2.5	32	1.3	13.39%
CASE :05	2.5	30	1.5	16.03%
CASE: 06	2.5	34	1.4	15.27%
CASE :07	3	32	1.3	14.02%
CASE :08	3	30	1.5	16.69%
CASE: 09	3	34	1.4	15.92%

Table 10: Detail of increase in tool life

The min improvement in Tool Life was observed as 12.61 % with Depth of cut as 2 MM and feed 32 mm/rev, Cutting speed of 1.3 M / Min. While the maximum increased of tool life 16.69% in case no 08 with cutting parameter DOC as 3mm, Feed 34 m/rev and Cutting speed of 1.4 M / Min. The pattern of tool life Vs case no is shown in Graph which clearly indicated with increased in depth of cut from 2 to 2.5 and 3 tool life is constantly increasing by keeping feed and cutting speed as constant i.e. 32 mm/rev and 1.3 M / Min.

f = feed in mm per revolution	32.0	30.0	34.0	32.0	30.0	34.0	32.0	30.0	34.0
d = depth of cut in mm	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0
n = Tool constant 0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
n1= feed exponent constant – 0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
n2 =depth of cut exponent constant- 0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
k= constant- 47	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00	47.00
v = cutting speeds (m /min)	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4
T MIN	1121.1	615.1	729.9	937.8	514.6	610.6	810.5	444.7	527.7

Fig 7: print screen of calculation of tool life without coating

The minimum tool life observed in case 01 is 444.7 Min and Maximum tool life is 1121.1 Min. The average tool life based on case 01 to case 09 was observed as 701.33 Min. By doing diamond coating the tool life was observed as 518.9 min as minimum and 1262.4 Min as a maximum tool life. The average life of tool was also increased to 802.878 Min from 701.328 which is equivalent to 102 Min which is equal to 14.85 %. we can see that by doing coating we can have increased of tool life near about 15% which itself is justified for the cost involvement of coating and increased in tool life of 102 min can be also help is to reduce loading and unloading of tool for Pocket milling operation.

f = feed in mm per revolution	32.0	30.0	34.0	32.0	30.0	34.0	32.0	30.0	34.0
d = depth of cut in mm	2.0	2.0	2.0	2.5	2.5	2.5	3.0	3.0	3.0
n = Tool constant for Diamond coating	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
n1= feed exponent constant – 0.49	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
n2 =depth of cut exponent constant- 0	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
k= constant- 52(frm tool manufacturer	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
v = cutting speeds (m /min)	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4
T MIN	1262.4	708.9	835.6	1063.3	597.1	703.8	924.2	518.9	611.7

Fig 8: Tool life with Coating

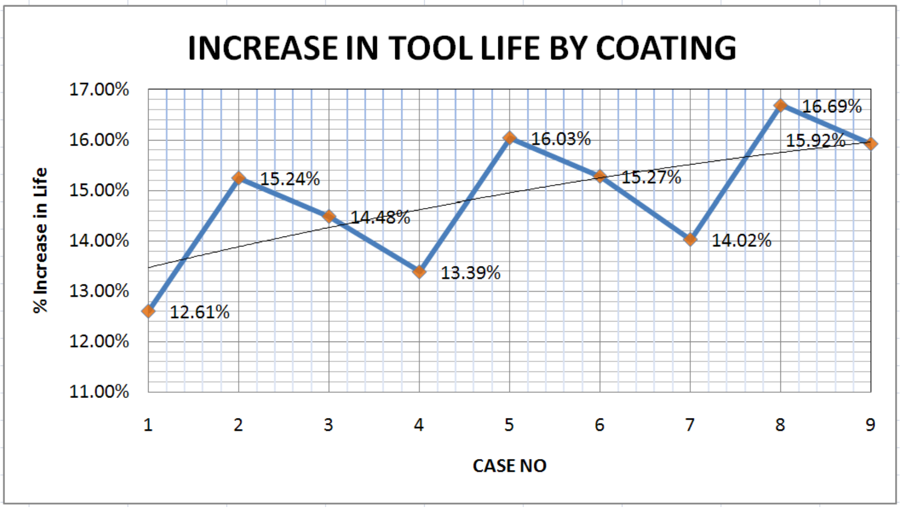

Fig 9: Graph of increase in tool life

So by both the criteria i.e. cost investment and time consumption for coating purpose it is justified to have Diamond coating as better option. Also if we are buying new Diamond based tool which is not cost effective solution with respect to HSS with diamond coating.

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