Tool Life Analysis by using FEA of Multilayer Coated Carbide Insert

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Abstract- Mathematical models of tool life have been developed for turning austenitic stainless steel AISI 304 material with multilayer coated tungsten carbide inserts. Process parameters (cutting speed, feed rate, depth of cut, tool nose radius and tool hardness) are used as inputs to the developed mach inability models. Data of 9 experiments when turning austenitic stainless AISI 304 material have been used to generate, compare and evaluate the proposed models of tool life for the considered material. Also, the numerical methodology used here is ANSYS R14.5 to calculate the tool life of coated cemented carbide cutting tool. A three dimensional Finite Element Model was also developed and the predicted results were compared with those measured. The above thesis presents the experimental work carried out on lathe machine in turning of austenitic stainless AISI 304 material using CVD multilayer (MTCVD-TiN-TiCN-Al2O3-TiN) coated cemented carbide insert, Simulation work and parametric correlation between the different variables. The turning test were conducted at three different cutting speeds (112, 180 and 280 m/min) while feed rate (0.2, 0.315 and 0.4 mm/rev) and depth of cut (1, 1.5 and 2 mm) respectively. The influences of all cutting parameters were investigated on the machined surface roughness and cutting forces; temperature at tool and work piece contact and also modelling of tool life was done. The worn parts of the cutting tools were also examined under microscope. Above new multilayer coating provides better wear resistance, proven seating due to smooth and secures seating surfaces and new violet coating easily identifies flank wear. Multilayer coating synergizes the advantage of different coating materials in the layered structure and has particular edge over monolayer coated tool. Also Post-coat treatment which improves edge toughness, long and predictable tool life, reduces depth-of-cut notching. Improved edge toughness provides smooth outer surface to reduce forces, friction, and work piece sticking. Post-coat grinding provides secure seating surface. Alpha alumina layer (MTCVD-TiN-TiCN-Al2O3-TiN) provides coating integrity at elevated speeds. However, low thermal conductivity and work hardening characteristics have made it difficult to machine with conventional cutting tools under normal operating condition. The study clearly indicates as the tool life was also found to be maximum for Vc = 280 m/min while rapid progression of tool wear was observed for dry machining of Vc = 112 m/min. The tool's performance was evaluated based on its tool life. In this study, a carbide tool with MTCVD-TiN-TiCN-Al2O3-TiN coating with 4P geometry at the cutting edge is proposed for performing medium machining of Austenitic stainless steel AISI 304 material.

Keywords: Turning, Multilayer Coated carbide tool; medium machining; AISI 304 Austenitic stainless steel; Surface roughness; Tool life.

Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy.

The AISI 300 series of austenitic stainless steels represent the largest group of steels in use of total. [2] However these steels have very high corrosion resistance, it is more difficult to machine these materials because of their low heat conductivity, built – up edge tendency and high work hardening properties than carbon and low alloy steels.Poor surface finish and high tool wear are the common problems [1]. Since turning is the primary operation in most of the production processes in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and work piece setup, chatter, and use of cutting fluids.

The aim of our present experimental investigation is to study the effect of multilayer coated tool on surface roughness, flank wear, tool life while machining on austenitic stainless steel AISI 304 material by employing Taguchi's orthogonal array design and Taguchi's Design of Experiments approach (DOE) is used to analyse the effect of process parameters on surface roughness. This paper deals the analysis of tool life of given insert model by using FEA while turning on AISI 304 austenitic stainless steel material. Following are the some important fundamentals related with our investigation.

a. Tool Wear

It has been recognized widely that tool life can be divided into three phases characterized by three different flank wear processes.

(i) Break-in.
(ii) Normal wear.
(iii) Abnormal or catastrophic wear.

b. Tool life (Taylor's Equation)

$$VC*T^n = C$$

Vc = Cutting speed (m/min)
T = Tool life (min)
n & C = constants determined by the work material, tool material, tool design, etc. (7) .

c. Factor affecting Cutting speed

The following factors influence on the cutting speed permitted by the tool (8).

- Physio-mechanical properties of the metal being machined.
- Material of the cutting tool.
- Rate of feed and depth of cut.
- Tool geometry.
- Size of the tool flank.
- Cutting fluid used.
- Maximum permissible amount of tool wear.
- Type of machining being performed.

d. Effect of the metal being machined.

The physio-mechanical properties of the work metal have a large influence on the cutting speed permitted by the tool. This influence is predetermined, by the heat generated in cutting and the heat distribution between the chip, work, tool and the surrounding medium (8).

e. Effect of the feed and depth of cutting

Since the rate of feed and depth of cutting have an influence on the cutting forces and temperature, they strongly affect on the speed permitted by the tool. Increased cutting speed and depth of cut result in increased temperatures at the cutting zone. At elevated temperatures chemical wear becomes a leading wear mechanism and often accelerates weakening of cutting edge; resulting in premature tool failure (chipping), namely edge breakage of the cutting tool. In addition, it is noticed that when feed rate is increased, residual stresses change from compressive to tensile (10). An investigation showed that hardness greatly influences the material properties accounting for high variation in flow stress properties. Residual stresses become more compressive as work piece hardness increases.

f. Experimental set up

The cutting tests have been carried out on an (SN 40B-50B) lathe.
The machine specifications are listed below.
•Type and model: Center lathe SN 40B-50B.
•Manufacturer: Czechoslovakia, Tos Trencin.
• Total power of machine without extra equipment:
6.6 KW for 50Hz.
• Spindle speed (22.4-2000) r.p.m
• Feed rate (0.1-0.4) mm/rev.
• Center length 1500 mm.

g. Work Piece Material

Austenitic stainless steel AISI 304 material work pieces with hardness of 35 to 38 HRC are used; the chemical compositions are given in Table (A).Fig. (A) Illustrate the work piece photograph and dimension. Solid bar of AISI 304 steel with 32 mm diameter, 300mm long was used as work piece.

Figure 1.Work piece

Table 1. Chemical composition of AISI 304

Elements	Composition(%wt)
C	0.051
Si	0.412
Mn	1.351
Cr	18.275
Ni	8.473
Mo	0.301
Cu	0.318
Ti	0.005
V	0.049
W	0.003
Co	0.019
Nb	0.020
Fe	Balance

Table 2.Mechanical Properties of work material

Grade	304
Tensile Strength (MPa) min	515
Yield Strength (MPa) min	205
Elongation (% in 50mm) min	40
Rockwell B (HR B) max	92
Brinell (HB) max	201

h. Cutting Tool

Coated cemented carbide:

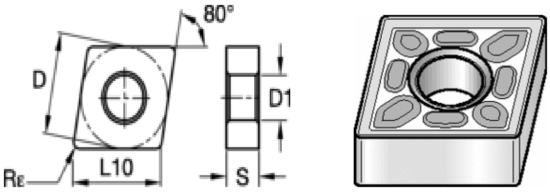


Figure 2: Insert Geometry

Table 3: Insert Specification

ISO Catalogue No.	D	L10	S	Rε	D1
	Mm	mm	mm	mm	mm
CNMG1204044P	12.70	12.90	4.76	0.4	5.16
CNMG1204084P	12.70	12.90	4.76	0.8	5.16
CNMG1204124P	12.70	12.90	4.76	1.2	5.16

Coated cemented carbide currently represents 80-90% of all cutting tool inserts. Its success as a tool material is due to its unique combination of wear resistance and toughness, and its ability to be formed in complex shapes. Coated cemented carbide combines cemented carbide with a coating. Together they form a grade which is customized for its application.

Single High hardness Tungsten Carbide Coated cutting tool is used to perform turning process. Each experiment was carried out with new sharp tool in order to keep the cutting conditions unchanged. The cutting-test were conducted without coolant and, as result, totally 09 experiments were performed.

Cutting tool materials have different combinations of hardness, toughness and wear resistance, and are divided into numerous grades with specific properties. Generally, a cutting tool material that is successful in its application should be:

- Hard, to resist flank wear and deformation
- Tough, to resist bulk breakage
- Non-reactive with the work piece material
- Chemically stable, to resist oxidation and diffusion
- Resistant to sudden thermal changes.

Three types of Cutting inserts are used for this kind of experimental investigation namely.
Where,
C=Insert shape
N=Insert clearance angle
M=Tolerance class
G=insert features
12=size
04=thickness
04, 08, 12=corner radius
4P=chip breaker (optional)

i. Tool Holder

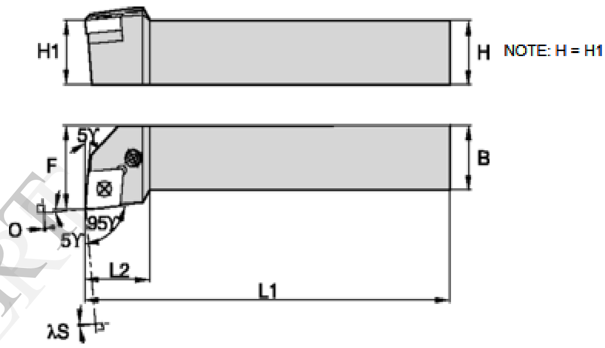


Figure 3: Tool-holder of Clamping System P

Table 4: Tool Holder Description

H	B	F	L1	L2	λS°	γO°
16	16	20	100	26	-6	-6

Table 5.Properties of cutting inserts

Coating method and layers/substrate	ISO grade	Geometric form	Manufacturer and code
MTCVD (TiN-TiCN-Al2O3-TiN) Cemented carbide	M30	CNMG 120404 TN30M 4P	WIDIA™ Value
MTCVD (TiN-TiCN-Al2O3-TiN)	M30	CNMG 120408 TN30M 4P	WIDIA™ Value

Cemented carbide			
MTCVD (TiN-TiCN-Al2O3-TiN) Cemented carbide	M30	CNMG 120412 TN30M 4P	WIDIA™ Value

Table 6.Cutting parameters levels

parameters	Levels		
	1	2	3
Cutting speed (m/min)	112	180	280
Feed (mm/rev)	0.2	0.315	0.4
Depth of cut (mm)	1	1.5	2
Nose radius(mm)	0.4	0.8	1.2

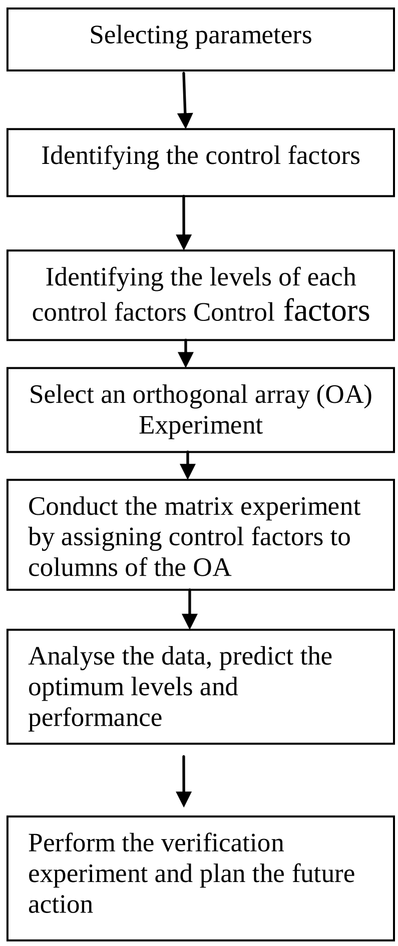
1. Taguchi Method

Taguchi parametric design is an effective tool for robust design. It offers a simple and systematic qualitative optimal design at a relatively cost. [1]

Taguchi method is a powerful statistical tool used for the design of experiments (DOE) can be effectively utilized to optimize process / product, which involves various steps of planning, conducting and evaluating results of orthogonal array experiments to determine the optimum levels of usage parameters under very noisy environment. The major goal is to maintain the variance in the results very minimal even in the presence of noise inputs to make robust process against all variations. It focuses on optimizing quality characteristic most economically for a process.

DOE is a powerful statistical technique to study the effect of many usage parameters and for determining the optimal parameter settings of a process and thereby achieving improved process performance with reduced process variability. Taguchi's methodology involves use of specially constructed tables called "Orthogonal Array" (OA) which requires very less number of experimental runs in designing which are consistent and very easy. It is successfully used in the various areas of manufacturing industries. We have taken L9"Orthogonal Array" (OA)

1.1 Taguchi methodology



2. Experimental Procedure

Turning is a widely used material removal process from the surface of a rotating cylindrical work piece. The present experimental investigation was carried out according to the conditions given in Table 6. Taguchi specified L9 mixed level design. The machining tests are carried out on the material in cylindrical form, 300mm long and 32 mm diameter by cutting inserts separately with three different nose radii on a WIDIA CNMG insert lathe. These work pieces cleaned prior to the experiments by removing 0.5 mm thickness of the top surface from each work piece in order to eliminate any surface defects and wobbling, and also actual turning Length is 300mm. The surface of machined surfaces has been measured by a Talysurf (Taylor Hobson, Surtronic 3+, UK) surface roughness tester.

2.1Temperature Measurement

The interface temperature values that are obtained with infrared thermometer when machining AISI 304 austenitic stainless steel related to the cutting speed and feed rate parameters with a varying depth of cut and nose radius. With increasing the cutting speed, the interface temperature decreased. The exploration of this phenomenon is, most of the heat generated in machining is removed from the cutting zone by the chip .So the chip speed flow in the cutting zone tending to increase with cutting speed, leading to a greater heat evacuation. Taking into consideration of the temperature as a function of friction, the contact length decreased with increasing cutting speed. An increasing value of feed rate leads to an augmentation of the cutting and feed forces. However, the energy consumption is higher and the temperature rise increasing.

2.2The Influence of Machining Parameters on Tool Flank Wear and Surface Roughness

With increasing the cutting speed, tool flank wear was decreased. Due to the austenitic stainless steel AISI 304 has low thermal conductivity; this material cannot evacuate the heat rapidly. So at the lower cutting speed, the tool performance is seen very poor. Also indicated the poor tool performance at the lower cutting speed because of the longer contact time on the rake face as the chips moved slowly when compared to the higher cutting speeds. In the same paper, the authors have also reported that the tool flank wear has increased at the 280 m/min. Cutting tests were carried out on lathe machine under dry conditions. The machining process on lathe is programmed by speed, feed, and depth of cut and nose radius. In total 9 work pieces (Φ32 mm x 300mm) are prepared. These work pieces cleaned prior to the experiments by removing 0.5mm thickness of the top surface from each work piece in order to eliminate any surface defects and wobbling. Three different nose radii of CVD coated inserts have been taken to study the effect of tool geometry. The surface roughnesses of machined surfaces are measured by a Mitutoyo SJ-201 surface roughness tester and measurements were repeated 3 times.

Table 7. Experimental Result

Speed (m/min)	Feed (mm/rev)	DOC (mm)	NR (mm)	Fc (N)	Ft (N)	Temp. (°C)	Chip Thickness (mm)	Chip Thickness Ratio	Chip Contraction Ratio	Shear Plane Angle (°)	Flank Wear (mm)	Surface Roughness (µm)	MRR (mm^3/min)
112	0.2	1	0.4	567.9	156.67	289.9	0.32	0.625	1.6	29	0.182	2.348	2577.618
112	0.315	1.5	0.8	1059.48	367.45	292.5	0.4	0.7875	1.269841	35	0.189	2.674	3745.743
112	0.4	2	1.2	1599.03	476.62	293.3	0.49	0.816327	1.225	36	0.193	2.876	3967.495
180	0.2	1.5	1.2	1032.98	376.85	295.2	0.31	0.645161	1.55	30	0.145	2.569	3573.698
180	0.315	2	0.4	892.76	314.98	298.1	0.37	0.851351	1.174603	37	0.169	2.552	4122.96
180	0.4	1	0.8	1137.96	417.09	296.4	0.45	0.888889	1.125	38	0.178	2.675	3735.294
280	0.2	2	0.8	765	286.46	297.7	0.3	0.666667	1.5	31	0.169	2.435	4362.955
280	0.315	1	1.2	717.8	278.72	296.2	0.37	0.851351	1.174603	37	0.171	2.532	3967.254
280	0.4	1.5	0.4	698.7	235.89	298.9	0.43	0.930233	1.075	39	0.178	2.457	4739.011

3. Modelling:

Modelling is the initial step for any simulation work. It basically is the modelling of the 3D geometry according to the requirement of the simulation. This is done in CAD software available viz. CATIA.

For the analysis the software used in this particular case is ANSYS 14.5.For this case material property are to be produced by some means like experimental data or engineering data as in this case various engineering data sources are explored for the material properties. So for material properties a stand-alone system is prepared for engineering data by daring and dropping engineering data in stand-alone box. Then it is modified with the following materials:

TiN
TiCN
Al2O3

The analysis is to be done for all the different coating materials.

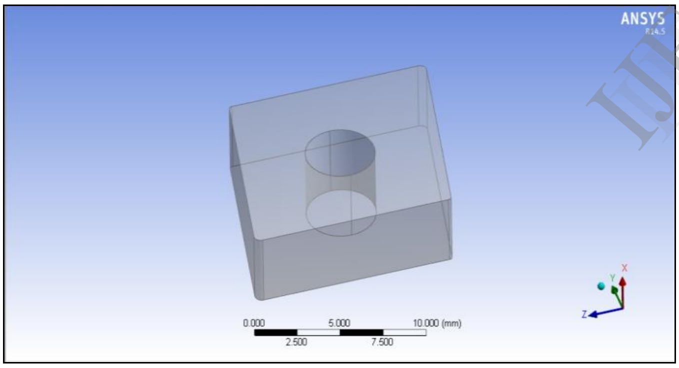


Figure 4.Model developed by ANSYS

3.2Material Selection:

The material is selected in 5 different types and mixed in a following manner:

Layer	Material
(+Z)	
5	TiN
4	TiCN
3	Al2O3
2	TiN
1	Carbide
(-Z)	

3.3Meshing:

In this part the various elements are selected for meshing the modelling.

3.4Boundary Conditions:

They are defined for bounding the setup in the right manner. Different boundary conditions used in this case are as below:

- Fixed support
- Force

Force is applied on the cutting edge in negative x direction as 1599.03 and on y direction as 476.62N from table 1.

Case 1:

Table 8.Process Parameters of Trial 1

Speed	Feed	DOC	NR	Fv	Ff	Temp.
112	0.4	2	0.4	1599.03	476.62	293.3

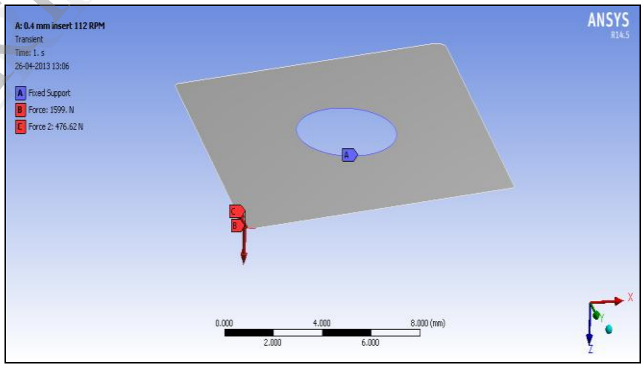


Figure 5(a).Force conditions for the tool

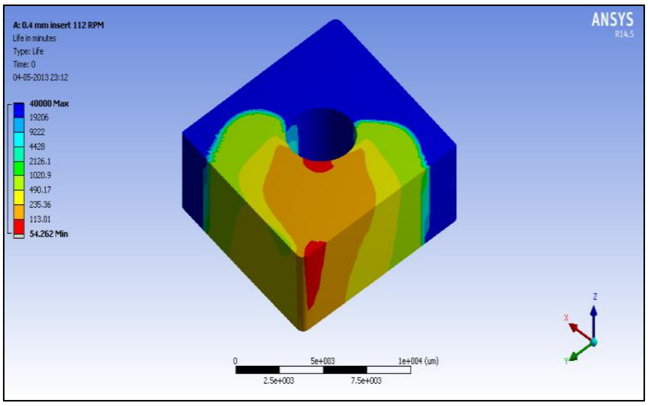


Figure 6. Tool Life of 0.4mm Nose Radius insert at 112rpm

Case 2:

Table 9.Process Parameters of Trial 2

Speed	Feed	DOC	NR	Fv	Ff	Temp.
180	0.4	1	0.4	1137.96	417.09	296.4

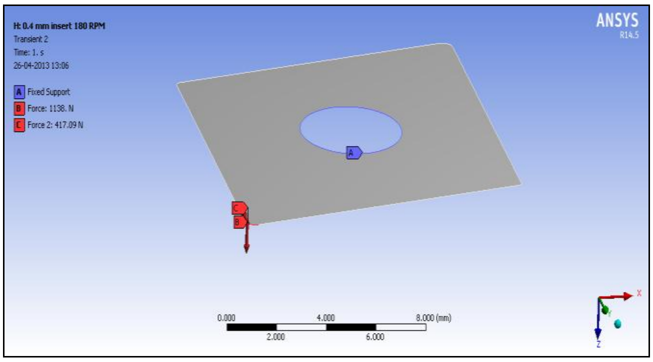


Figure 5(a).Force conditions for the tool

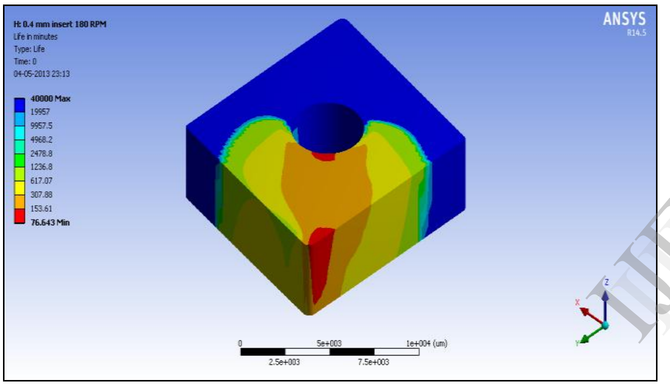


Figure 7.Tool Life of 0.4mm Nose Radius insert at 180rpm

Case 3:

Table 10.Process Parameters of Trial 3

Speed	Feed	DOC	NR	Fv	Ff	Temp.
280	0.2	2	0.4	765	286.46	297.7

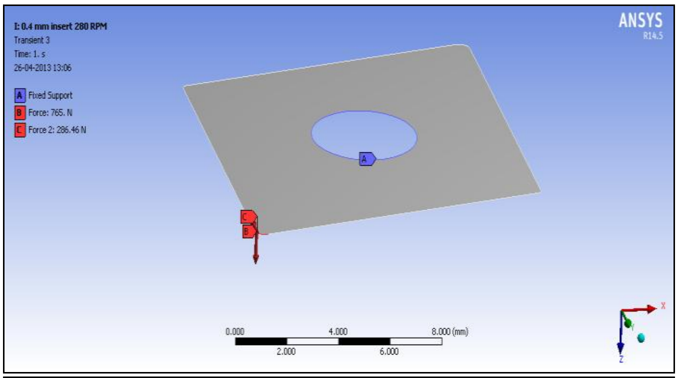


Figure 5(a).Force conditions for the tool

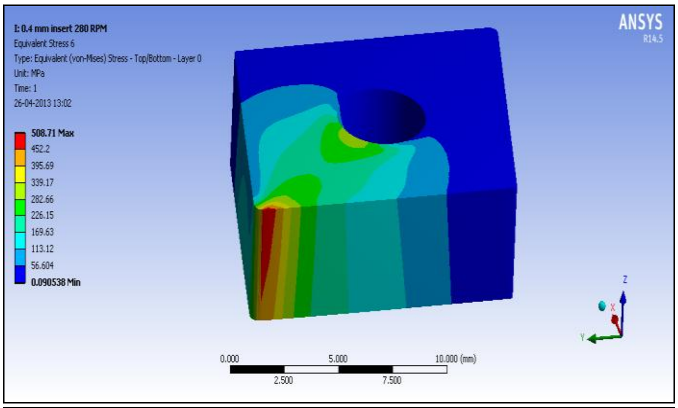


Figure 8.Tool Life of 0.4mm Nose Radius insert at 280rpm

Following table shows the tool life in minutes of 0.4 mm nose radius insert with different process parameters and forces.

Table 11.Tool Life Result

(V)	(f)	DOC (mm)	NR (mm)	Fv (N)	Ff (N)	Tool Life (min)
112	0.4	2	0.4	1599.03	476.62	54.262
180	0.4	1	0.4	1137.96	417.09	76.643
280	0.2	2	0.4	765	286.46	130.98

4. Conclusion

The present work has been conducted up to the nine trials to study the tool life by using FEA of multilayer coated carbide insert material on AISI 304 austenitic stainless steel using CVD Coated cutting inserts. Taguchi technique is employed to determine the optimal levels of process parameters. The conclusions of the investigation can be drawn as Follows:

1. According to the coating types, the best surface finish is obtained for cutting by insert coated with MTCVD-TiN-TiCN-Al2O3-TiN by CVD technique.
2. The present work may be extended to study the influence of coating thickness on other responses like tool wear, tool vibration.
3. The present work is carried out under dry environment. This work may be carried out under different cutting fluids.
4. CNC machines can be used for the experimentation to have the better control of the process variables and also parameters can be set to the desired accuracy.

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