Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 6 (2023)

Multi Objective Optimization Using Vikor Approach During Turning Of Ti6Al4V-ELI

[1]Suresh R. Nipanikar, [2] Gaurav D. Sonawane, [3] Vikas G. Sargade, [4]Niket V. Malvade

[1] Assistant Professor, Department of Mechanical Engineering, Karmaveer Bhaurao Patil College of Engineering, Satara 415001, Maharashtra, India.
sureshnipanikar@rediffmail.com
[2] Assistant Professor, Department of Mechanical Engineering, Sandip Foundation's SITRC, Nashik, Maharashtra 422006, India.
[3] Professor, Department of Mechanical Engineering, Dr. Babasaheb Ambedkar Technological University, Lonere-402103, Maharashtra, India.
[4] Assistant Professor, Department of Mechanical Engineering, Karmaveer Bhaurao Patil College of Engineering, Satara 415001, Maharashtra, India.

Abstract: This paper investigates the influence of cutting process parameters on the surface roughness and average flank wear of tool insert during turning of titanium alloy Ti-6Al-4V ELI (Extra Low Interstitial) in dry environment by using PVD AlTiN insert and uncoated insert. L18 orthogonal array design of experiment was used. Turning parameters were selected for machining such as cutting speed (80, 125, 170 m/min), feed (0.08, 0.15, 0.2 mm/rev) and depth of cut 0.5 mm constant. PVD AlTiN insert and uncoated K313 insert were used for turning of Ti6al4V ELI. Experimental data were analyzed and determined VIKOR index. Lowest VIKOR index gives the optimal parameters. Optimum parameters are *Vc*: 125 m/min; *f*: 0.08 mm/rev; Tool insert: PVD AlTiN.
Keywords: Ti6Al4V ELI, surface roughness, Average flank wear, PVD AlTiN, VIKOR

Corresponding Author: Suresh R. Nipanikar,
Research Scholar, Mechanical Engineering Department, Dr. Babasaheb Ambedkar Technological University, Lonere-402103, Maharashtra, India. sureshnipanikar15@gmail.com

NOMENCLATURE:

Vc : Cutting Speed (m/min)
f : Feed (mm/rev)
a_p : Depth of cut (mm)
Ra : Surface roughness (µm)
Vb_{avg} : Average flank wear (µm)

1 INTRODUCTION

Ti6Al4V Extra Low Interstitial is a high purity grade of Ti6Al4V alloy. Ti6Al4V alloy has low oxygen, iron and carbon. Because of its good fatigue strength and low modulus it is used in biomedical applications, i.e. joint replacements, bone fixation devices, surgical clips and cryogenic vessels also it is used in the marine and aerospace applications.

Surface roughness influences the performance of mechanical components and their cost of production because it affects factors, such as geometrical tolerances, ease of handling, friction, electrical and thermal conductivity etc. Workpiece and tool insert material properties and machining conditions influencing on surface roughness.

Various literatures have mentioned on the poor machining behavior of Titanium alloys. In contravention of the extended usage of titanium alloy in numerous fields, it possess assorted machining problems and consider as a difficult to cut material [1]. Generally temperature generated gets transmitted to the tool insert in the machining of titanium alloys owing to low thermal conductivity property of titanium alloy, hence temperature concentration at the edge of tool insert, so rapid tool failure was observed[2]. Accelerates the tool wear because of high temperature generated during the machining of titanium alloys, so tool life decreases [3]. The wear was observed during the high speed dry turning of titanium alloy when turning process carried out by different coated tool inserts, feed rate was the dominant factor influencing on cutting forces and surface roughness [4]. Tool wear can be described with wear types and wear mechanisms. Tool wear influences the rate of material removal, surface roughness of the machined component [5]. Tool wear is found near the cutting edge of the rake and flank faces of the cutting tool insert. The main cause of tool damage is related to the adhesive, mechanical and thermal wear increases exponentially due to diffusion and becomes the main contributor to tool wear [6]. The feed was the most dominant factor for surface roughness having 97.34% contribution during turning of Ti6Al4V ELI with using PVD TiAlN insert in dry environment [7, 8]. Diffusion and dissolution are one of the main problems when cutting metals, due to the fact that material from the cutting tools tends to dissolute into the workpiece [9].

MCDM is a part of quantitative techniques, regarding designing mathematical and computational tools for supportive the particular assessment of performance criteria. MCDM is the procedure of finding the best feasible solution from various alternatives. Linear normalization is generally used to remove the units of criterion functions in VIKOR optimization technique. VIKOR optimization technique is a ranking technique used for multi criteria decision making to optimize the process parameters [10]. The compromise solution is the nearest to the ideal solution which is the feasible solution [11]. Various output parameters optimized using polynomial regression models [12]. Linear programming approach and multiple regression technique is used for to optimize the multiple process parameters using Taguchi experiments [13].

A number of times have been made to optimum the input parameters during turning of Ti6Al4V ELI, but not any type of experimental analysis have been made earlier by using VIKOR method coupled with signal to noise ratio method.

It is evident from the literature survey and to the best perception of the author that no study has been conducted regarding machining analysis of Ti6Al4V ELI with PVD AlTiN and Uncoated inserts and optimization by VIKOR method coupled with signal to noise ratio.

VIKOR approach coupled with signal to noise ratio method is extensively used optimization method discovers valid and unbiased conclusions. Consequently, the key goal of this study is the parameter optimization of the turning Titanium alloy Ti6Al4V ELI in dry environment with PVD AlTiN coated insert and uncoated insert for surface roughness and average flank wear. Experimental observations analyzed by using VIKOR approach coupled with signal to noise ratio process. Henceforth, the use of above mentioned optimization methods for machining of Ti6Al4V ELI in the present work is quite innovative.

Therefore, the major interest of this study is to explore the influence of machining conditions on surface roughness and average flank wear in turning of Ti6Al4V ELI in dry environment and compare the performance with PVD AlTiN coated insert and K313 uncoated insert Kennametal make at various machining parameters and multi criterion decision making by using VIKOR approach.

DESIGN OF EXPERIMENT

There are various ways in which design of experiments may be designed and it always based on the number of factors and levels of each factors.

L18 orthogonal array design of experiment was designed in the presented work considering two machining parameters such as cutting speed and feed with three levels and one parameter (i.e. cutting tool) with two different inserts and the response variables are surface roughness of machined surface and average flank wear of tool insert.

1.1 VIKOR method:

The MCDM technique is very well-known procedure extensively useful for to finding the best solution amongst numerous experiments having several features. The VIKOR optimization technique was established for multi optimization of difficult systems. VIKOR technique emphases on ranking and select from all alternatives. VIKOR is useful tool in MCDM. Compromise solution provides a lowest of the individual regret of the opponent and a highest group utility of the majority so decision maker might accept the compromise solution. The distance from the ideal solution representing by an aggregating function in VIKOR technique. VIKOR ranking index is an aggregation of all criteria. Experiment having highest ranked VOKOR index is close to the best solution. Decision matrix shown in equation (1) can be denoted for MCDM problem.

$$\begin{matrix} A_1 \\ A_2 \\ . \\ . \\ A_m \end{matrix} \quad \begin{bmatrix} Cx_1 & Cx_2 & Cx_3 & . & . & Cx_n \\ x_{11} & x_{12} & x_{13} & . & . & x_{1n} \\ x_{21} & x_{22} & x_{23} & . & . & x_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ x_{m1} & x_{m2} & x_{m3} & . & . & x_{mn} \end{bmatrix} \quad \text{-----(1)}$$

where, A_1 denotes i^{th} alternative, i =1,2,3 . . , m. Cx_j denotes the j^{th} criterion, j = 1,2,3 . . , n. Individual performance of an alternative is denoted by x_{ij} .

In MCDM problem comprise calculating the utilities of an alternatives and assign rank to each alternative for assessing the best solution. The highest utility is presumed to be the optimal solution. VIKOR method involves following stages.

Stage 1: Normalized decision matrix representation

Equation (2) can be used for to express the normalized decision matrix.

$$F= \left\lfloor f_{ij} \right\rfloor_{mxn} \qquad \text{-----(2)}$$

where, $f_{ij} = \dfrac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x2_{ij}}}$, i= 1, 2, 3, . . , m; and performance of alternative A_i is denoted by x_{ij} with respect to the j^{th} criterion.

Stage 2: To find an ideal solution and negative ideal solution

Equation (3) is used for to find the ideal solution A^* and equation (4) is used for to find the negative ideal solution A^{-} :

$$A^* = (\max f_{ij} \mid j \in J) \text{ or } (\min f_{ij} \mid j \in JK^1),\ i = 1, 2, 3, . . . , m$$

$$= \{ f_1^*, f_2^*, f_3^* ..., f_n^* \} \qquad \text{------ (3)}$$

$$A^{-} = (\min f_{ij} \mid j \in J) \text{ or } (\max f_{ij} \mid j \in JK^1),\ i = 1, 2, 3. . . m$$

$$= \{ f_1^{-}, f_2^{-}, f_3^{-}, ..., f_n^{-} \} \qquad \text{------ (4)}$$

where, J = { j = 1, 2, 3, ..., n\f_{ij}, if desired output is larger},

JK^1 = { j = 1, 2, 3, ..., n\f_{ij}, if desired output is smaller},

Stage 3: Computation of regret and utility measure

Equation (5) is used for to determine the utility measure and equation (6) is used for to determine the regret measure.

$$S_i = \sum_{j=1}^{n} w_j \frac{(f_j^* - f_{ij})}{(f_j^* - f_j^{-})} \qquad \text{----- (5)}$$

$$R_i = \text{Max} \left[w_j (f_j^* - f_{ij}) / (f_j^* - f_j^{-}) \right] \qquad \text{----- (6)}$$

where, utility measure represented by S_i and the regret measure represented by R_i and weight of the j^{th} criterion is represented by w_j .

Step 4: Calculation of VIKOR index

Equation (7) can be used for the computation of VIKOR index

$$Q_i = v \left[\frac{S_i - S^*}{S^{-} - S^*} \right] + (1-v) \left[\frac{R_i - R^*}{R^{-} - R^*} \right] \qquad \text{----- (7)}$$

where, VIKOR value represented by Q_i ,

i = 1, 2, 3. . . m; S^* = Min(utility measure value, S_i); S^{-} = Max (utility measure value, S_i);

R^* = Min (Regret measure value, R_i); R^- = Max (Regret measure value, R_i) and weight of the largest i group utility is represented by v. Smallest VIKOR value suggests the best solution.

1.1.1 Optimization technique implemented

Stage 1: Computation of quality loss

Quality loss computation for output parameters using smaller the better criterion is given below.

(a) For lower the better response

$$L_{ij} = k_1 \times \frac{1}{r}\sum_{k=1}^{r}\frac{1}{y_{ijk}^2} \quad \text{----- (8)}$$

where, quality loss related with the j^{th} output in the i^{th} experimental run is represented by L_{ij} ; k^{th} replication datum for the j^{th} output in the i^{th} experimental run is represented by Y_{ijk} ; the number of replication for each experimental run is represented by r . Quality loss coefficients is represented by K_1 , i = 1, 2, 3, . . , m; j = 1, 2, 3, . . , n; k = 1, 2, 3, . . , r.

Stage 2: Computation of normalized quality loss for all output parameters in all experimental run. Equation (9) is used for the normalized quality loss computation.

$$f_{ij} = \frac{L_{ij}}{\sqrt{\sum_{i=1}^{m} L_{ij}^2}}, \ i = 1, 2, 3, \ldots, m; \ j = 1, 2, 3, \ldots, n. \quad \text{----- (9)}$$

where, normalized quality loss of the j^{th} output in the i^{th} experimental run is represented by F_{ij} .

Stage 3: Computation of ideal solution and negative ideal solution.

$$A^* = \{\min f_{ij} \mid i = 1, 2, 3, \ldots, m\} = \{ f_1^*, f_2^*, f_3^* \ldots, f_n^* \}, \quad \text{----- (10)}$$

$$A^- = \{\max f_{ij} \mid i = 1, 2, 3, \ldots, m\} = \{ f_1^-, f_2^-, f_3^- \ldots, f_n^- \}, \quad \text{----- (11)}$$

Equation (10) is used for to find ideal solution whereas the equation (11) is used for to find negative ideal solution. The ideal solution represents the minimum normalized quality loss whereas the maximum normalized quality loss of all experimental runs represents negative ideal solutions, so a smaller normalized quality loss is desired.

Stage 4: equations (5) is used for computation of the utility measure and equation (6) is used for computation of regret measures for each output in all experimental run.

Stage 5: Computation of VIKOR index of the i^{th} experimental run. A smaller VIKOR index value close to the best ideal solution.

Stage 6: Determine optimum set of input parameters.

Equation (7) is used for computation of VIKOR index, and the influence of the parameters can be found from the computed VIKOR values. A smaller value of VIKOR index indicates a better quality.

1.2 Signal to noise ratio

In this paper signal to noise ratio is calculated considering smaller is better model for surface roughness of machined surface and average flank wear of tool insert.

1.2.1 Smaller is better model

Data for surface roughness of machined surface and average flank wear of tool insert, which are lower the better performance model are preprocessed as per equation (12).

$$S/N = -10 \log ((1/n) (\sum y^2) \quad \text{----- (12)}$$

where, y^2 is average of observed data y and n is the number of observations.

2 EXPERIMENTAL PROCEDURES

2.1 Workpiece material:

The workpiece material used during the turning process was in the form of a cylindrical bar of alpha-beta titanium alloy Ti6Al4V ELI. The chemical composition of the Ti6Al4V ELI (in wt. %) is given in Table 1.

Table 1 Chemical composition of Ti6Al4V ELI

The Ti6Al4V ELI has a microstructure, which consisted of elongated alpha phase surrounded by fine, dark etching of beta matrix. Ti6Al4V ELI material offers high strength and depth hardenability (32 HRC). Figure 1 shows the photographic view of experimental setup.

Figure 1 Photographic view of (a) experimental setup

2.2 Cutting tool material

A cutting tool insert with ISO designation CNMG 120408FF KC5010 PVD AlTiN and CNMG 120408MS K313 WC/Co uncoated insert Kennametal make were selected for turning of Ti6Al4V ELI.

2.3 Machining tests

All the machining experiments were conducted on a ACE CNC LATHE JOBBER XL, which FANUC Oi Mate- TC as a controller. PCLNL 2525M12 tool holder is used. During the experiments, the combinations of the machining process parameter values were designed by using L18 orthogonal array design of experiment. The cutting speeds were set at 80, 125 and 170 m/min, and feed rate were set at 0.08, 0.15 and 0.20 mm/rev. The depth of cut was 0.5 mm is constant during the turning of Ti6Al4V ELI. The machining experiments were carried out in dry environment. Experimental design and measured response values are shown in Table 2.

Table 2 Experimental design and measured response values

3 RESULTS AND DISCUSSION

3.1 Surface roughness, *Ra (μm)*

Surface finish is the significant machinability index as the service life and performance of the finished part are frequently affected by its surface roughness, nature of residual stresses and existence of surface or subsurface micro cracks, mostly under dynamic loading the part is to be used. Surface roughness decreases abruptly with the increase in cutting speed for a given value of feed. This is owing to the fact that, as cutting speed increases, the temperature increases at the cutting zone that leads to the tempering of material and thus reduces the surface roughness.

It was realized that surface roughness increases with an increase in the feed. The surface roughness is observed to be minimum at 170 m/min cutting speed with 0.08 mm/rev feed rate. Due to increase in feed, generating more heat and vibration consequently contributing to a poor surface finish. Surface roughness is more when machining performed with uncoated insert as compared to PVD AlTiN coated insert because hot hardness of coated insert is more as compared to uncoated insert. Main effects plot for surface roughness, Ra is shown in Figure 2. It is observed from Figure 2 as cutting speed increases from 80 m/min to 170 m/min surface roughness decreases. As feed increases from 0.08 mm/rev to 0.2 mm/rev surface roughness increases. Surface roughness is low when machining is done with the PVD AlTiN as compared to K313 uncoated insert.

Figure 2 Main effects plot for surface roughness, Ra (μm)

3.2 Average flank wear, Vb_{avg} (μm)

The performance of a tool insert is generally evaluated in the terms of tool life on the basis of wear criterion i.e. flank wear that mostly effects on the strength of the cutting tool insert and subsequently the dimensional accuracy of the Ti6Al4V ELI turned surface. During machining of Ti6Al4V ELI, the tool coating quickly delaminates, mainly due to high friction and temperature generates between tool and chip coating.

As cutting speed and feed increases average flank wear increases. At low cutting speed and low feed rate the minimum average flank wear is found. As feed rate increases generating more heat and vibration consequently to a high flank wear. Ti6Al4V ELI having low thermal conductivity (6.7 W/m-K) so the temperature increases as cutting speed increases during machining consequently the cutting tool insert loose its strength.

Figure 3 shows the main effects plot for average flank wear, Vb_{avg}. As cutting speed (Vc) increases from 80 m/min to 170 m/min and feed increases from 0.08 mm/rev to 0.20 mm/rev average flank wear (Vb_{avg}) increases and which is shown in Figure 3. Average flank wear (Vb_{avg}) is low when machining is done with the PVD AlTiN insert as compared to K313 uncoated insert. Tool wear pattern is shown in Figure 4.

Figure 3 Main effects plot for average flank wear, Vb_{avg} (μm)

Figure 4 Tool wear pattern of (a) Uncoated insert (b) PVD AlTiN insert at *Vc*: 125 m/min; *f*: 0.08 mm/rev

3.3 Multi Criterion decision making using VIKOR approach

Estimation of quality loss for each output parameter have been computed by using equation (8) and provided in Table 3.

Table 3 Estimation of quality loss for each experiment

Lower the better characteristic have been selected for surface roughness, (Ra) and average flank wear (Vb_{avg}). Estimation of normalized quality loss have been computed by using equation (9) and shown in Table 4.

Table 4 Estimation of normalized quality loss for each experiment

Utility measure of each output for all experiments and that is shown in Table 5.

Table 5 Utility measure of individual response for all experiments

It has been assumed that the weightage of all output parameters are equally significant. So, 50% weightage has been allocated to surface roughness and average tool flank wear. Utility and regret measure for every experiment have been computed and that is shown in Table 6.

Table 6 Utility measure (S_i) and regret measure (R_i) of individual alternatives

Table 7 shows VIKOR index of each experiment.

Table 7 VIKOR index of individual experiments

VIKOR index analyzed by using S/N ratio. The ideal solution represents minimum normalized quality loss and negative ideal solutions represents the maximum normalized quality loss of all experimental runs. These are calculated by using equation (3) and equation (4) are as follows:

$A^* = \{\min f_{ij} \mid i = 1, 2,\} = \{ f_1^*, f_2^* \} = \{0.07936, 0.03143\}$

$A^- = \{\max f_{ij} \mid i = 1, 2,\} = \{ f_1^-, f_2^- \} = \{0.43724, 0.79777\}$

The signal to noise ratio for VIKOR index has been calculated using equation (12) considering lower the better model and that is shown in Table 8.

Table 8 Signal to noise ratio for VIKOR index

The optimal condition denotes the combination of input factor levels that is expected to give the best performance. The average signal to noise ratio indicates the relative effects of the different input parameters on response parameters like surface roughness and average flank wear during machining of Ti6Al4V ELI. Higher value of signal to noise ratio indicates better quality characteristics. Therefore, on the basis of signal to noise ratio for each input process parameter and its level is shown in Figure 5. The optimum machining parameters for both surface roughness and average flank wear were obtained at level 2 of cutting speed (125 m/min), level 1 of feed (0.08 mm/rev), level 2 of cutting tool insert (PVD AlTiN).

Figure 5 Average signal to noise ratio by control factor for VIKOR index

The response table for signal to noise ratio for VIKOR index is shown in Table 9. The feed rate has the maximum effect on VIKOR index.

Table 9 Response table for S/N ratio for VIKOR index

The stages of measurement and evaluation is shown in Figure 6.

Figure 6 Stages of measurement and evaluation

4. CONCLUSIONS

In this article, multi objective optimization has been done by detection of an optimum combinations of parameters, capable of producing desired quality turned part. Three process parameters (cutting speed, feed, tool insert) has been optimized using VIKOR optimization technique coupled with S/N ratio. The VIKOR optimization technique introduces the ranking index depends on the specific measure of closeness to the ideal solution. Feed rate has the highest influence on the surface roughness. Cutting speed has the maximum effect on the average flank wear as compared to feed. Feed rate has the maximum effect on VIKOR index followed by cutting speed and type of tool insert. From the VIKOR optimization technique optimum combination of process parameters are as *Vc*: 125 m/min, *f*: 0.08 mm/rev., *Cutting tool*: PVD AlTiN.

REFERENCES

[1] Escamilla-Salazar, I. G., Torres-Treviño, L. M., González-Ortíz, B., & Zambrano, P. C. (2013). Machining optimization using swarm intelligence in titanium (6Al 4V) alloy. *The International Journal of Advanced Manufacturing Technology*, *67*(1-4), 535-544.

[2] Khanna, N., & Davim, J. P. (2015). Design-of-experiments application in machining titanium alloys for aerospace structural components. *Measurement*, *61*, 280-290.

[3] Wu, H., & Guo, L. (2014). Machinability of titanium alloy TC21 under orthogonal turning process. *Materials and Manufacturing Processes*, *29*(11-12), 1441-1445.

[4] Liu, Z., An, Q., Xu, J., Chen, M., & Han, S. (2013). Wear performance of (nc-AlTiN)/(a-Si 3 N 4) coating and (nc-AlCrN)/(a-Si 3 N 4) coating in high-speed machining of titanium alloys under dry and minimum quantity lubrication (MQL) conditions. *Wear*, *305*(1), 249-259.

[5] Sandvik Coromant. Modern metal cutting – A practical handbook. First north American ed. Fair Lawn, NJ: (1996). Sandvik Coromant, Technical Editorial dept;. p. 2–IV-27.

[6] Maekawa, K., & Obikawa, T. (2000). Metal Machining: Theory and Applications. Oxford: Elsevier Ltd; 2000. p. 1–19.

[7] Sargade, V., Nipanikar, S., & Meshram, S. (2016). Analysis of surface roughness and cutting force during turning of Ti6Al4V ELI in dry environment. *International Journal of Industrial Engineering Computations*, *7*(2), 257-266.

[8] Nipanikar, S., Sargade, V., & Guttedar, R. (2018). Optimization of process parameters through GRA, TOPSIS and RSA models. *International Journal of Industrial Engineering Computations*, *9*(1), 137-154.

[9] Kramer BM, Von Turkovich BF (1986). A comprehensive tool wear model. CIRP Ann. 35(1),67–70.

[10] Mardani, A., Jusoh, A., MD Nor, K., Khalifah, Z., Zakwan, N., & Valipour, A. (2015). Multiple criteria decision-making techniques and their applications–a review of the literature from 2000 to 2014. *Economic Research-Ekonomska Istraživanja*, *28*(1), 516-571.

[11] Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European journal of operational research*, *156*(2), 445-455.

[12] Khuri, A. I., & Conlon, M. (1981). Simultaneous optimization of multiple responses represented by polynomial regression functions. *Technometrics*,*23*(4), 363-375.

[13] Logothetis, N., & Haigh, A. (1988). Characterizing and optimizing multi-response processes by the Taguchi method. *Quality and Reliability Engineering International*, *4*(2), 159-169.

Table 1 Chemical composition of Ti6Al4V ELI

Composition	C	Si	Fe	Al	N	V	S	O	H	Ti
Wt %	0.08	0.03	0.22	6.1	0.006	3.8	0.003	0.12	0.003	Balance

Table 2 Experimental design and measured response values

Expt. No.	Cutting speed (m/min)	Feed (mm/rev)	Cutting Tool Insert	Surface Roughness, Ra (µm)	Average tool flank Wear, Vb (µm)
1	80	0.08	PVD AlTiN	0.81	29.11
2	80	0.15	PVD AlTiN	1.24	32.58
3	80	0.2	PVD AlTiN	1.31	37.36
4	125	0.08	PVD AlTiN	0.73	33.22
5	125	0.15	PVD AlTiN	1.21	43.01
6	125	0.2	PVD AlTiN	1.29	58.72
7	170	0.08	PVD AlTiN	0.72	49.74
8	170	0.15	PVD AlTiN	0.85	78.02
9	170	0.2	PVD AlTiN	1.00	82.65
10	80	0.08	Uncoated	0.96	34.89
11	80	0.15	Uncoated	1.45	38.48
12	80	0.2	Uncoated	1.69	46.87
13	125	0.08	Uncoated	0.94	37.36
14	125	0.15	Uncoated	1.35	45.72
15	125	0.2	Uncoated	1.52	71.06
16	170	0.08	Uncoated	0.92	55.01
17	170	0.15	Uncoated	1.14	101.16
18	170	0.2	Uncoated	1.47	146.67

Table 3 Estimation of quality loss for each experiment

Expt. No.	Quality loss estimates Surface roughness,	Average tool flank wear, Vb_{avg}	Expt. No.	Quality loss estimates Surface roughness, Ra	Average tool flank wear, Vb_{avg}
1	0.6561	847.3921	10	0.9216	1217.3121
2	1.5376	1061.4564	11	2.1025	1480.7104
3	1.7161	1395.7696	12	2.8561	2196.7969
4	0.5329	1103.5684	13	0.8836	1395.7696
5	1.4641	1849.8601	14	1.8225	2090.3184
6	1.6641	3448.0384	15	2.3104	5049.5236
7	0.5184	2474.0676	16	0.8464	3026.1001
8	0.7225	6087.1204	17	1.2996	10233.3456
9	1.0000	6831.0225	18	2.1609	21512.0889

Table 4 Estimation of normalized quality loss for each experiment

Expt. No.	Normalized quality loss estimates Surface roughness,	Average tool flank wear, Vb_{avg}	Expt. No.	Normalized quality loss estimates Surface roughness, Ra	Average tool flank wear, Vb_{avg}
1	0.10044	0.03143	10	0.14109	0.04514
2	0.23539	0.03936	11	0.32187	0.05491
3	0.26271	0.05176	12	0.43724	0.08147
4	0.08158	0.04093	13	0.13527	0.05176
5	0.22414	0.06860	14	0.27900	0.07752
6	0.25475	0.12787	15	0.35369	0.18726
7	0.07936	0.09175	16	0.12957	0.11222
8	0.11061	0.22574	17	0.19895	0.37950
9	0.15309	0.25333	18	0.33081	0.79777

Table 5 Utility measure of individual response for all experiments

Expt. No.	Utility measure of each response: Surface roughness, Ra	Utility measure of each response: Average tool flank wear, Vb_{avg}	Expt. No.	Utility measure of each response: Surface roughness, Ra	Utility measure of each response: Average tool flank wear, Vb_{avg}
1	0.05890	-5.59498E-10	10	0.17248	1.79011E-02
2	0.43598	1.03589E-02	11	0.67763	3.06474E-02
3	0.51234	2.65369E-02	12	1.00000	6.53000E-02
4	0.00620	1.23968E-02	13	0.15622	2.65369E-02
5	0.40454	4.85111E-02	14	0.55786	6.01473E-02
6	0.49010	1.25850E-01	15	0.76657	2.03348E-01
7	0.00000	7.87176E-02	16	0.14031	1.05431E-01
8	0.08731	2.53559E-01	17	0.33417	4.54202E-01
9	0.20601	2.89558E-01	18	0.70261	1.00000E+00

Table 6 Utility measure (S_i) and regret measure (R_i) of individual alternatives

Expt. No.	Utility measure of each criterion: Utility measure (S_i)	Utility measure of each criterion: Regret measure (R_i)	Expt. No.	Utility measure of each criterion: Utility measure (S_i)	Utility measure of each criterion: Regret measure (R_i)
1	0.05890	0.05890	10	0.19038	0.17248
2	0.44634	0.43598	11	0.70828	0.67763
3	0.53888	0.51234	12	1.06530	1.00000
4	0.01860	0.01240	13	0.18276	0.15622
5	0.45305	0.40454	14	0.61800	0.55786
6	0.61595	0.49010	15	0.96991	0.76657
7	0.07872	0.07872	16	0.24574	0.14031
8	0.34087	0.25356	17	0.78838	0.45420
9	0.49557	0.28956	18	1.70261	1.00000

Table 7 VIKOR index of individual experiments

Expt. No.	VIKOR Index	Rank	Expt. No.	VIKOR Index	Rank
1	0.035512323618	2	10	0.132047680524	5
2	0.341453329421	10	11	0.541565220623	15
3	0.407585671783	11	12	0.810775443851	17
4	0.000000000121	**1**	13	0.121555730026	4
5	0.327527991142	9	14	0.454121783496	14
6	0.419206460736	12	15	0.664271978891	16
7	0.051426290721	3	16	0.132199101578	6
8	0.217779341525	7	17	0.452229953345	13
9	0.281938059521	8	18	0.999999999716	**18**

Table 8 Signal to noise ratio for VIKOR index

Expt. No.	S/N ratio	Expt. No.	S/N ratio
1	28.99242	10	17.58538
2	9.33337	11	5.32698
3	7.79562	12	1.82199
4	**198.35885**	13	18.30449
5	9.69503	14	6.85655
6	7.55144	15	3.55308
7	25.77630	16	17.57543
8	13.23967	17	6.89281
9	10.99693	18	0.00000

Table 9 Response table for S/N ratio for VIKOR index

Level	Cutting speed	Feed	Cutting tool insert
1	11.8093	51.0988	34.6377
2	40.7199	8.5574	8.6574
3	12.4135	5.2865	--
Delta	28.9106	45.8123	25.9803
Rank	2	1	3

Figure 1 Photographic view of (a) experimental setup

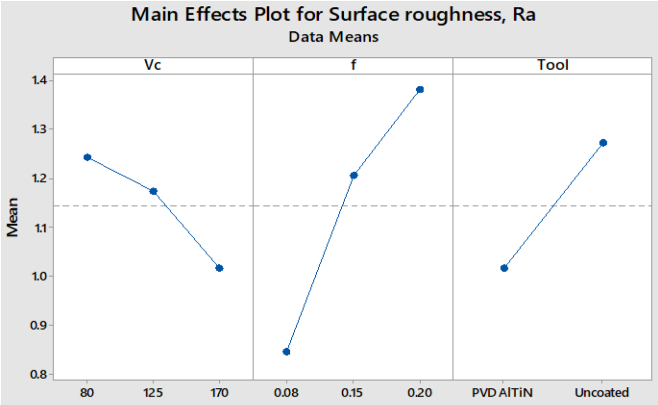


Figure 2 Main effects plot for surface roughness, Ra (µm)

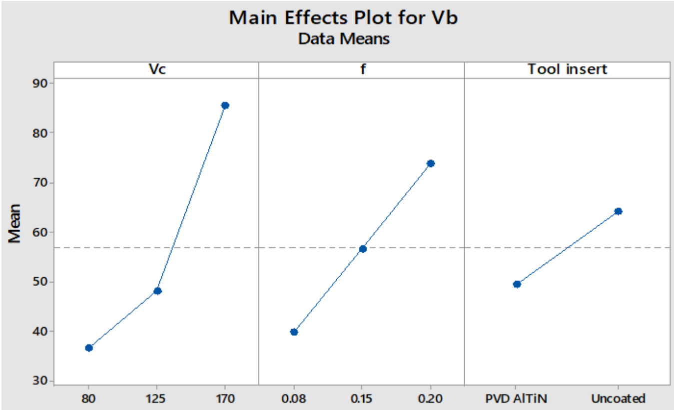
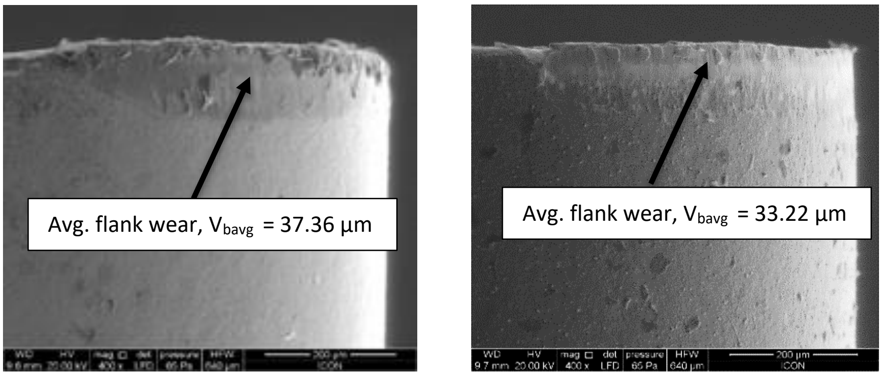


Figure 3 Main effects plot for average tool flank wear, Vb_{avg} (µm)



(a) **(b)**

Figure 4 Tool wear pattern of (a) Uncoated insert (b) PVD AlTiN insert at *Vc*: 125 m/min; *f*: 0.08 mm/rev

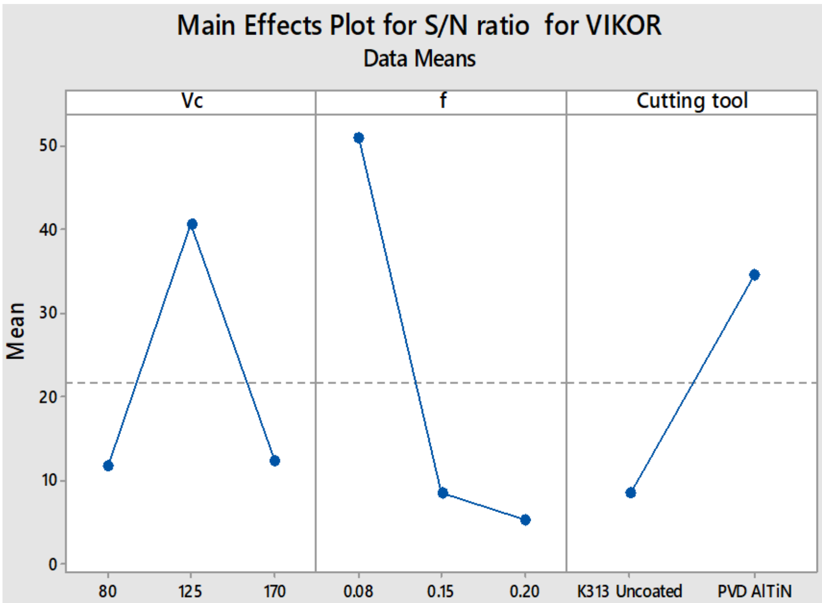


Figure 5 Average signal to noise ratio by control factor for VIKOR index

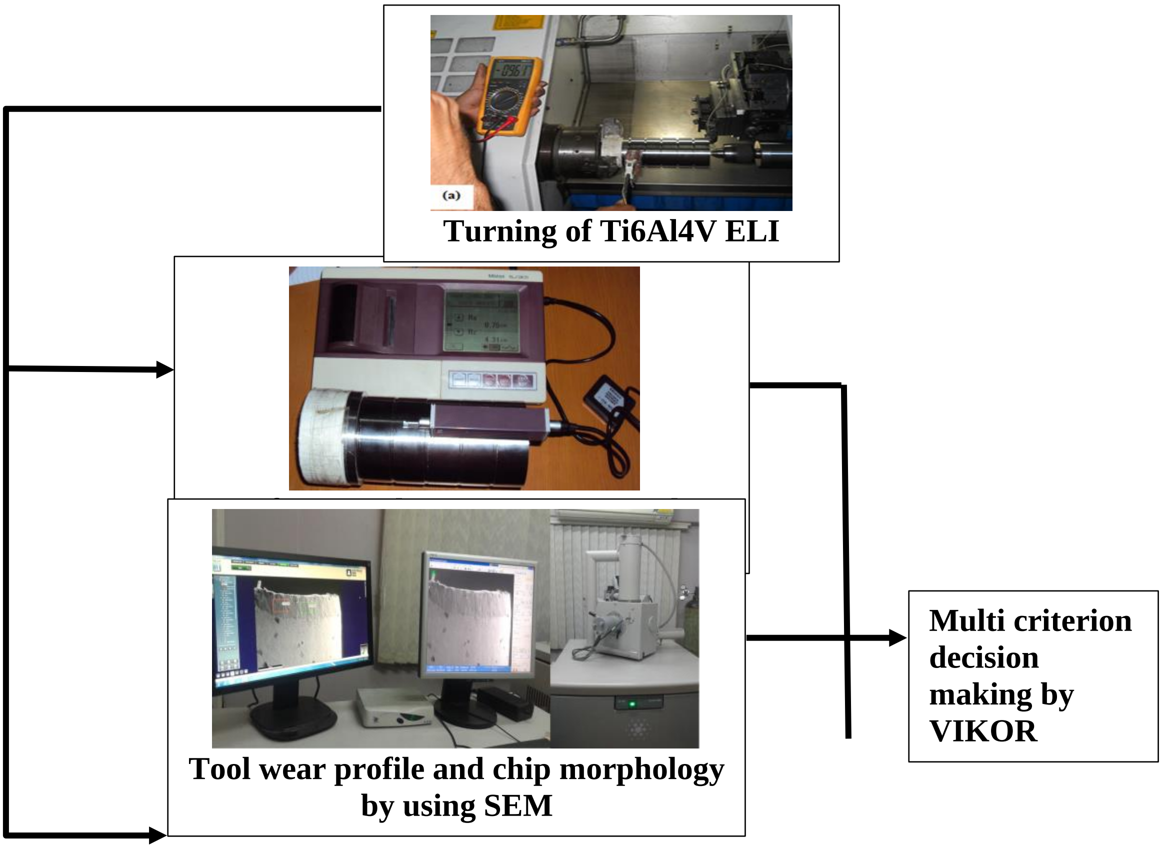


Figure 6 Stages of measurement and evaluation