

surface roughness in milling operations as well. Da Silva *et al.* (2011) and Ginting and Nouari (2009) response that surface methodology is a collection of mathematical and statistical techniques that are useful for modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. RSM also quantifies relationships among one or more measured responses and the vital input parameters. Factorial designs are used widely in experiments involving several factors on a response. The meaning of factorial design is that each complete test or replications of all the possible combinations of the levels of the factors are investigated. Second order model are statistically insignificant. Some works have been done to establish a model between the cutting conditions and surface roughness in milling operations as well. Mansour and Abdalla (2002) created a surface roughness model for the end milling EN32 (a semi-free cutting carbon case hardening steel with improved merchantability). Besides concluding that an increase in either the feed rate or the axial depth of cut increases the surface roughness, whilst an increasing cutting speed decreases the surface roughness; based on the model created, they constructed contours of surface outputs in planes containing cutting speed and feed rate at a certain depth of cut in order to enable the selection of the proper combinations to increase the metal removal rate without sacrificing the quality of the surface finish. quality. Bouacha *et al.* (2010) presented an experimental study of hard turning with CBN tool of AISI 52100 bearing steel, hardened at 64 HRC. The relationship between cutting parameters (cutting speed, feed rate and depth of cut) and machining output variables (surface roughness, cutting forces) through the response surface methodology (RSM) are analysed and modeled. The combined effects of the cutting parameters on machining output variables are investigated while employing the analysis of variance (ANOVA). Aouici *et al.* (2012) Investigated the effects of cutting speed, feed rate, workpiece hardness and depth of cut on surface roughness and cutting force components in the hard turning AISI H11 steel. Mathematical models for surface roughness and cutting force components were developed using the response surface methodology (RSM). cutting force components are influenced principally by the depth of cut and workpiece hardness.

Selaimia *et al.* (2017) have presented an experimental to model the output responses namely; surface roughness (Ra), cutting force (F_c), cutting power (P_c), specific cutting force (K_s) and metal removal rate (MRR), during the face milling of the austenitic stainless steel X2CrNi18-9 with coated carbide inserts (GC4040). The results reveal that both of (Ra) and (K_s) are mostly influenced by (f_z). Both of (F_c) and (P_c) are found considerably affected by (ap), while (MRR) is influenced by both of (f_z) and (ap).

In the present work the performance of cutting inserts with coatings based on (TiN, TiCN, TiAlN) has been investigated to determine tool life and surface roughness during dry end milling of AISI 52100 bearing ball steel.

Statistical analysis of variance (ANOVA) has been used to conduct a design experiment. The aim of this work is to identify the influence of cutting parameters on output measures and multiple regressions in order to develop empirical models characterising the tool wear and the surface roughness.

2. Experimental procedure

2.1 Workpiece materials

The work piece is a box of 220 mm length and 80x80 mm² cross section made of AISI 52100 ball bearings steel. The corresponding chemical composition is given in Table 1.

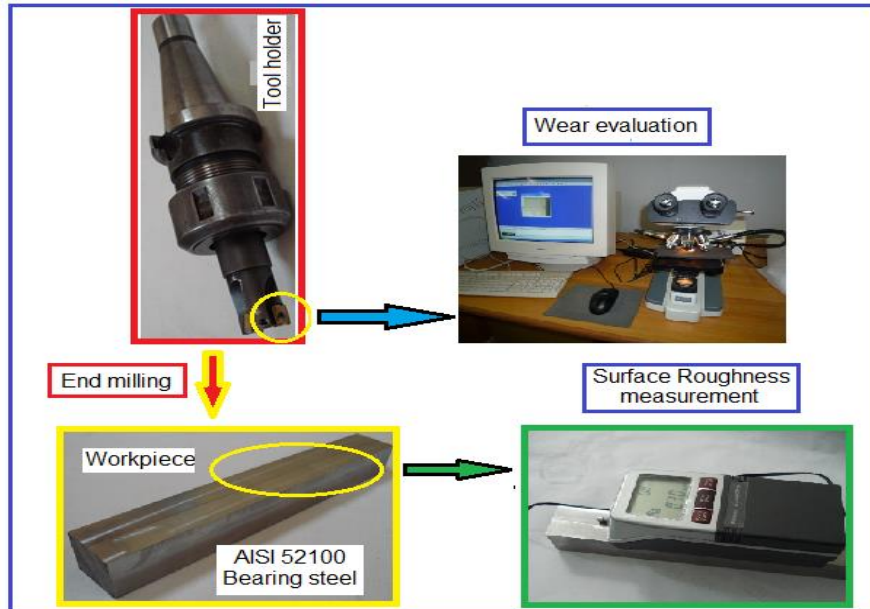


Fig. 1 Tool wear and surface roughness measurement equipments

2.2 Cutting inserts and tool holder geometry

Milling operations have been performed using three multilayer coated carbides (TiN, TiCN, TiAlN) inserts Sandvik Coromant R390 have been investigated. Milling has been carried using a 25 mm mill cutter.

2.3 Wear and roughness tests

Tool wear and surface roughness tests have been carried on a vertical EmcoMILL E350 CNC milling Machine. Measurement of tool flank wear evolution has been followed through cutting time incremental observation using Motic optical microscope until its critical value of 0.3 mm is reached. Respectively, the corresponding roughness value R_a is recorded using a portable Mitutoyo Surf Test SJ201.7. Fig 1 shows the layout of the equipment for tool wear and surface roughness investigation during end milling of AISI 52100.

2.4 Planning experiments

Design experiments have been achieved using Taguchi's technique which consists in analysing the collected data from tool wear and surface roughness measurements. The input parameters are the cutting speed, the feed rate and the depth of cut. The experiments have been conducted using Taguchi27 in terms of orthogonal array in order to involve efficiently several parameters. Table 2 shows the Taguchi27 layout together the measured tool wear and surface roughness. Experimental results have been treated using the analysis of average and the analysis of variance.

The performance of end milling process of AISI 52100 ball bearings steel is achieved according to the procedure illustrated in Fig 2.

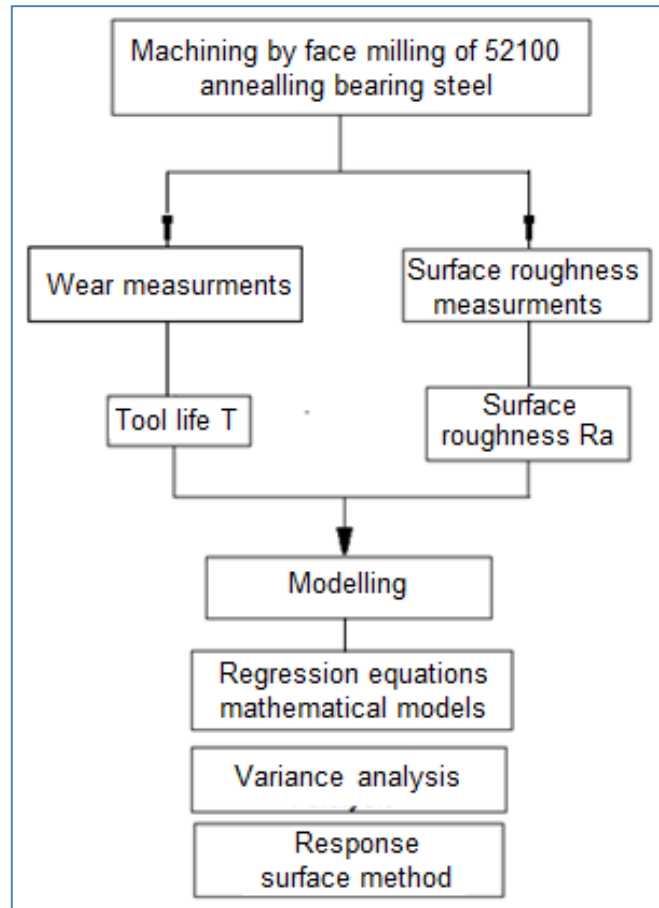


Fig. 2 Schematic illustration of performance analyses of end milling process of steel

Tool life is required to evaluate the performance of cutting inserts during machining. Surface roughness is required to evaluate the surface finish. The mathematical models express the relation between T , Ra and the cutting parameters (V_c , f_z , ap) during face milling of AISI 52100 steel. Analysis of the variance is used to determine the degree of influence of each parameter. Response surface method defines the trend and the effect of each cutting parameter upon T and Ra response parameters.

3. Result and discussion

3.1 Main effect plots for tool life (T)

Fig. 3 gives the main factor plots of V_c , f_z and ap for tool life, T . The trend of the plots are almost linear showing that the most significant parameter is V_c that causes the tool life to decrease when life V_c increases. Meanwhile, when increasing f_z and ap , the tool life remain almost constant. This result is in good agreement with literature.

Table 2 Taguchi table for end milling of AISI 52100 annealed bearing steel using multicoated carbide tool

Trial No.	Input parameters			Output parameters	
	V_c m/min	f_z mm/t	a_p mm	Tool life (min)	Surface roughness, R_a (μm)
1	74	0,02	0,50	365	0.68
2	74	0,02	0,75	390	0.61
3	74	0,02	1,00	340	0.90
4	74	0,05	0,50	305	0.61
5	74	0,05	0,75	320	0.39
6	74	0,05	1,00	310	0.73
7	74	0,10	0,50	296	1.03
8	74	0,10	0,75	298	1.04
9	74	0,10	1,00	297	1.05
10	96	0,02	0,50	255	0.46
11	96	0,02	0,75	240	0.41
12	96	0,02	1,00	218	0.43
13	96	0,05	0,50	228	0.45
14	96	0,05	0,75	220	0.42
15	96	0,05	1,00	209	0.45
16	96	0,10	0,50	230	0.84
17	96	0,10	0,75	215	1.12
18	96	0,10	1,00	215	1.07
19	141	0,02	0,50	125	0.35
20	141	0,02	0,75	118	0.35
21	141	0,02	1,00	105	0.44
22	141	0,05	0,50	115	0.52
23	141	0,05	0,75	118	0.45
24	141	0,05	1,00	100	0.42
25	141	0,10	0,50	97	0.72
26	141	0,10	0,75	100	0.80
27	141	0,10	1,00	90	0.73

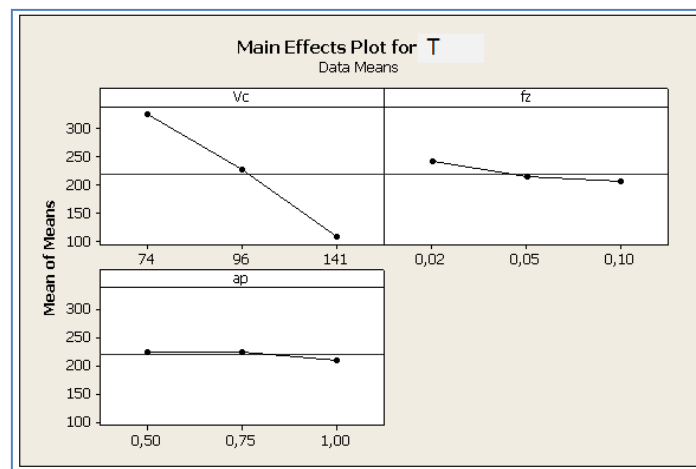


Fig. 3 Main factor plots for tool life T

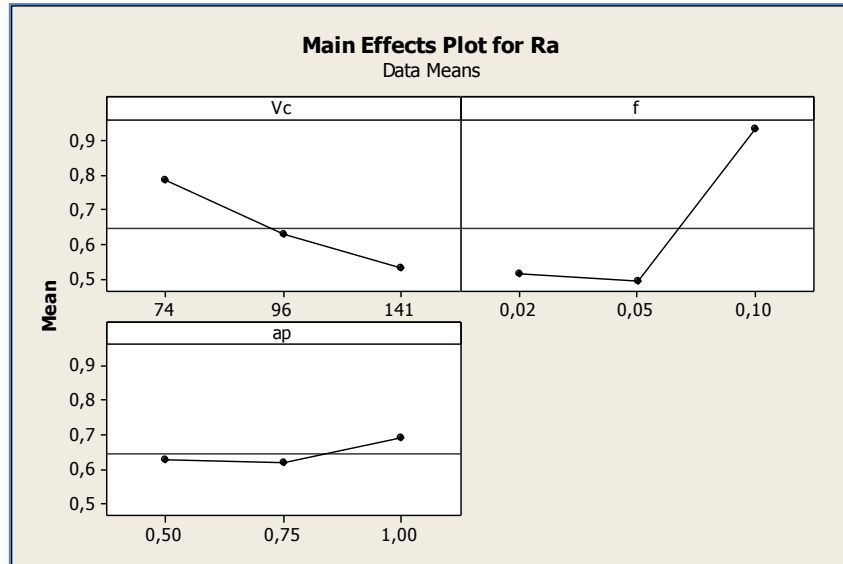


Fig. 4 Main factor plots for Ra

Table 3 Analysis of variance for surface roughness, Ra

Source	DF	SS	MS	F	P	Remarks
Vc	2	0,288763	0,144381	29,66	0,000	Significant
fz	2	1,108541	0,554270	113,87	0,000	Significant
ap	2	0,026496	0,013248	2,72	0,125	Insignificant
Vc*fz	4	0,109259	0,027315	5,61	0,019	Significant
fz*ap	4	0,049926	0,012481	2,56	0,120	Insignificant
Vc*ap	4	0,051037	0,012759	2,62	0,115	Insignificant
Error	8	0,038941	0,004868			
Total	26	1,672963				

$S = 0,0697681$

$R-Sq = 97,67\%$

$R-Sq(adj) = 92,44\%$

3.2 Main effect plots for surface roughness (Ra)

Fig. 4 illustrates the respective main effect plots for surface roughness. In this case the most significant effect is attributed to fz above 0.05mm/t as the mean increased drastically when fz double. The cutting speed comes in second position but is still within a linear effect showing that when Vc increases, T decreases. With regard to the depth of cut, the effect is not that announced. The present results are in good agreement with literature data suggesting that surface roughness decreases with increasing cutting speed.

Meanwhile, when the feed per tooth increases the roughness increases particularly in (0.05-0.1mm / t) range. There is a slight effect of Ra when depth of cut increases in the interval (0.75-1mm).

Table 4 Analysis of variance for tool life, T

Source	DF	SS	MS	F	P	Remarks
<i>Vc</i>	2	212442	106221	2197,68	0,000	Significant
<i>fz</i>	2	6002	3001	62,09	0,000	Significant
<i>ap</i>	2	1321	660	13,66	0,003	Significant
<i>Vc*fz</i>	4	3017	754	15,60	0,001	Significant
<i>fz*ap</i>	4	577	144	2,99	0,088	Insignificant
<i>Vc*ap</i>	4	553	138	2,86	0,096	Insignificant
Error	8	387	48			
Total	26	224299				

$$S = 6,95222$$

$$R-Sq = 99,83\%$$

$$R-Sq (adj) = 99,44\%$$

3.3 Analysis of variance

Analysis of variance has been conducted for a significance level of $\alpha=0.05$, and a confident level of 95%. Tables 3, 4, 5 and 6 show the P-values corresponding to the conducted significance levels, associated with the F-tests for each source of variation. The sources with a P-value less than 0.05 are considered to have a statistically significant contribution to the measure performance. Variance analysis confirms the results obtained by the Taguchi method. The contribution in percent of each variable on surface roughness *Ra* is first (65%) for *fz*, then (17%) for *Vc*, and (1.5%) for *ap*. The interactions between these parameters have no significant effect on the roughness. Obviously, the analysis of variance reveals that the most largely dominant contribution for tool life is the cutting speed with a contribution of (94%) in front of *fz* (2.7%) and *ap* (0.58%). In addition, it has revealed that the (*Vc-fz*) interaction has a significant effect on the tool life.

3.4 Tool wear and surface roughness models

From the analysis of variance (ANOVA), regression equations can be determined to develop the engineering models of tool wear and surface roughness. As a result, the corresponding for surface roughness is given in Eq. (1).

$$Ra = 0,3039 - 0,000579Vc + 6,042fz + 0,4763ap - 0,00554Vc.fz - 0,003491Vc.ap + 0,177fz.ap \quad (1)$$

Applying the significance level of 0.05, then as the effect of *ap*, the interactions (*Vc,ap*) and (*fz,ap*) is not significant (Table 3), Eq. (3) can be reduced into a simplified linear model of surface roughness with a coefficient of correlation of 0.92

$$Ra = 0,3039 - 0,000579Vc + 6,042fz - 0,00554Vc.fz \quad (2)$$

$$R^2 = 0,92$$

The corresponding model for tool wear is given in Eq. (3)

$$T = 639,41 - 3,42Vc - 1449fz - 42,19ap + 6,59Vc.fz - 0,1315Vc.ap + 467,3fz.ap \quad (3)$$

When removing the non significant effect of of ($V_c.ap$) and ($f_z.ap$) as suggested in Table 4, then the simplified linear model for tool wear can be expressed by Eq (4) with a coefficient of correlation of 0.97

$$T = 639,41 - 3,42V_c - 1449f_z - 42,19ap + 6,59V_c.f_z \quad (4)$$

$$R^2 = 0,97$$

3.5 Optimization through RSM

The response surface method has been used in order to optimize the effect of the interaction of most significant parameters. In Fig 5, the response surface shows the evolution of the output parameter (T) as a function of the combined averages of parameters V_c and f_z can be extrapolated from the orientation of the surface locating the range of optimal values ($V_c = 80\text{m / min}$ and $f_z = 0.05\text{ mm / d}$). In Fig 6 the response surface that shows the evolution of the output parameter (R_a) as a function of the combined averages of parameters V_c and f_z . According to the orientation of the surface the range of optimal values are located at ($V_c = 120\text{ m / min}$ and $f_z = 0.02\text{ mm / d}$). As a consequence, statistical analysis allows the reduction of number of test and adopts a reduced plan of Taguchi. Thence, the optimised response can be extrapolated from the RSM plots for a maximum value of tool wear resistance, T in the a combination of factor levels presented in Table 7 by setting the low and high limits for the three cutting parameters

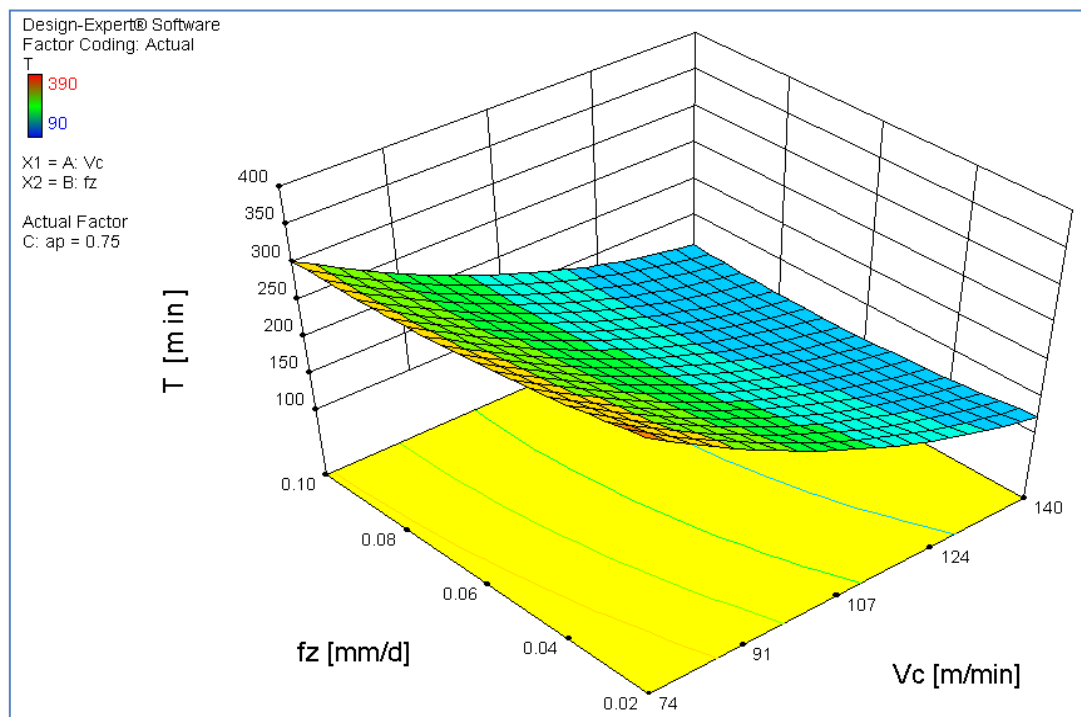
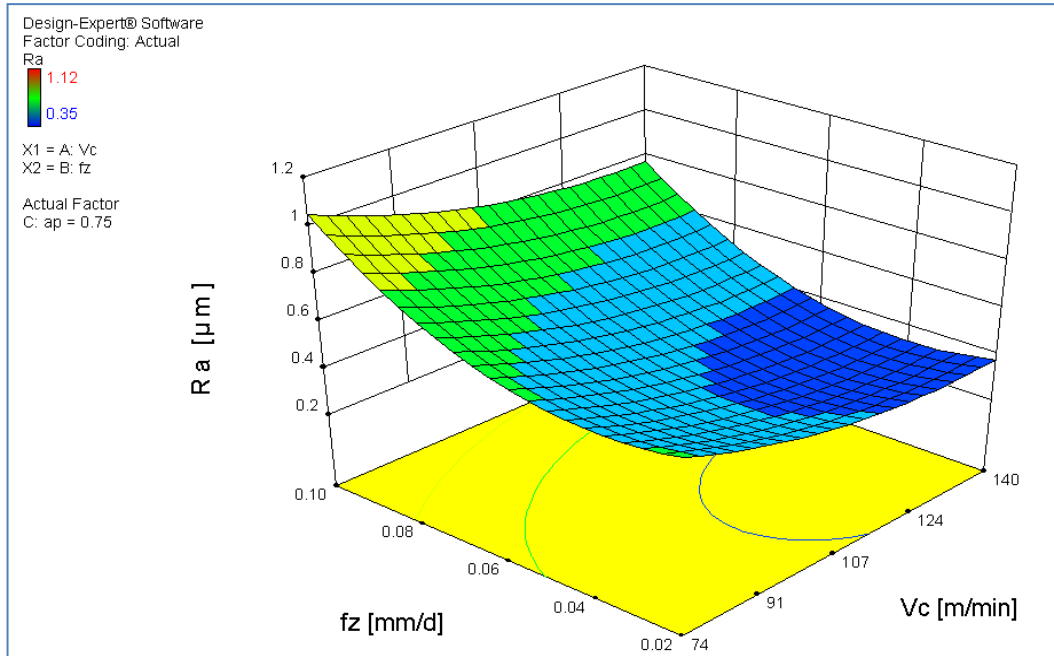


Fig. 5 Surface plot of T versus V_c, f_z

Fig. 6. Surface plot of Ra versus Vc, fz

3.6 Optimization through desirability function

Table 5 Limit values of parameters

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Importance
A:Vc	is in range	74	141	1	3
B:fz	is in range	0,02	0,1	1	3
C:ap	is in range	0,5	1	1	3
Ra	minimize	0,35	1,12	1	3
T	maximize	90	390	1	3

Table 6 Solution of optimum parameters

Solutions							
Number	Vc	fz	ap	Ra	T	Desirability	
1	74,000	0,026	0,576	0,552	352,475	0,786	Selected

Table 7 Combination of factor levels for a maximum tool wear

Factor	Low	High	Optimum
Vitesse de coupe Vc	74,0	141,0	74,0
Avance	0,02	0,1	0,02
Profondeur de passes	0,5	1,0	0,552996

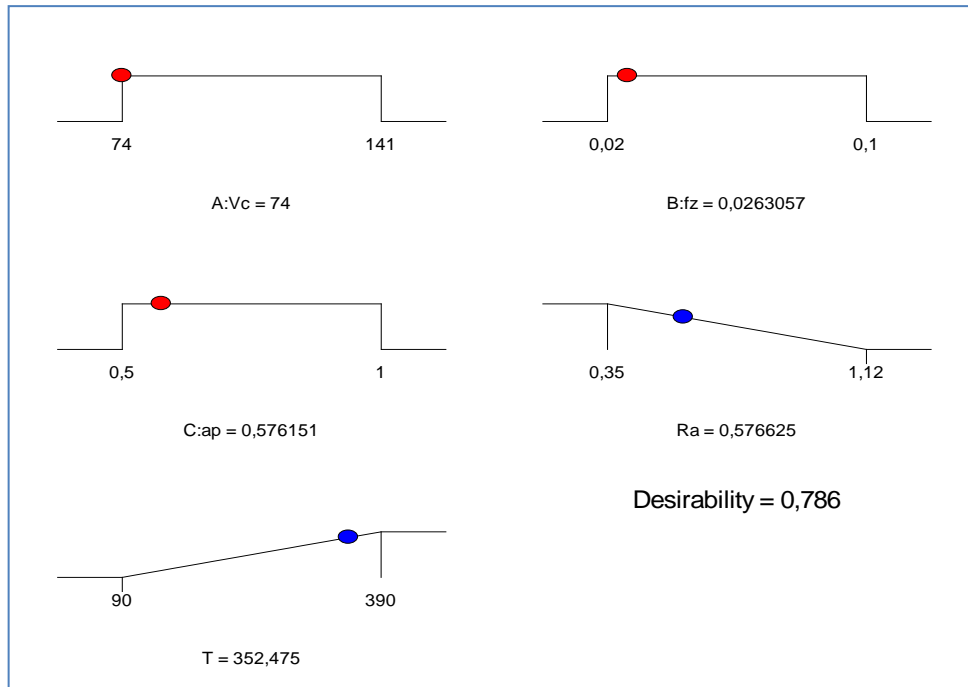


Fig. 7 Ramp Diagram of desirability function

The ramp diagram of Fig. 7 shows the optimal values of the input parameters which are a cutting speed $V_c = 74 \text{ m/min}$ with a feed per tooth $f_z = 0.02 \text{ mm/t}$ and a depth of cut $a_p = 0.57 \text{ mm}$. these values gave a tool life $T = 352 \text{ min}$ and a surface roughness $R_a = 0.57 \mu\text{m}$. these values will be used for industrial application in the case of milling AISI 52100 steel.

4. Conclusion

The following conclusions can be drawn based on the experimental results of this study:

- Response surface methodology combined with the Taguchi27 design of experiment is found to be a successful technique to perform trend analysis of surface roughness and tool life with respect to various combinations of design variables (cutting speed, feed rate, and depth of cut).
- Among the cutting parameters, feed rate has the greatest influence, followed by cutting speed. Higher feed rates lead to higher surface roughness values, whereas cutting speed has a contrary effect and cutting depth has no significant effect.
- The first order mathematical models are found to adequately represent the surface roughness and tool life..
- The model indicates that the feed rate was the most dominant parameter on surface roughness followed by cutting speed and depth of cut has less influence on surface roughness.
- The model indicates that the cutting speed was the most dominant parameter on tool life followed by feed per tooth and depth of cut has less influence.
- The machining performance of PVD coated multi-layer TiCN/Al₂O₃/TiN carbide tool was assessed during milling of AISI 52100 bearing alloy steel at different levels of cutting parameters

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