Electronic Journal of Applied Statistical Analysis
EJASA, Electron. J. App. Stat. Anal.
http://siba-ese.unisalento.it/index.php/ejasa/index
e-ISSN: 2070-5948
DOI: 10.1285/i20705948v9n3p530

Statistical analysis of tooling cost in high speed end milling for hardened steel

By Faizi, Bourini

Published: 2 November 2016

This work is copyrighted by Università del Salento, and is licensed under a Creative Commons Attribuzione - Non commerciale - Non opere derivate 3.0 Italia License.
For more information see:
http://creativecommons.org/licenses/by-nc-nd/3.0/it/

Electronic Journal of Applied Statistical Analysis
Vol. 09, Issue 03, November 2016, 530-539
DOI: 10.1285/i20705948v9n3p530

Statistical analysis of tooling cost in high speed end milling for hardened steel

Muataz Hazza Faizi[a] and Islam Faisal Bourini *[b]

[a] *Department of Manufacturing and Materials Engineering, Faculty of Engineering, International Islamic University Malaysia, 53100 Kuala Lumpur, Malaysia*
[b] *College of Business Administration, Al Falah University, Dubai, UAE*

Published: 2 November 2016

One of the main challenges for any manufacturer is how to decrease the manufacturing cost without affecting the final quality of the product. One of the major cost factors in machining processes as a main part of manufacturing industry is the tooling cost associated with the High speed machining process. However, high speed hard milling (HSHM) is new advanced machining processes in industry that merges three advanced machining processes: high speed milling, hard milling and dry milling. The aim of this research is to analyses statistically the effect of three main independent factors: cutting speed, feed rate and cutting speed on the tooling cost associated with machining process. To achieve the objective of the research, the experimental work with statistical tools was integrated. The face centered cubic design (FCC) has been used to conduct the experiments to minimize the flank wear rate up to total length of 0.3mm based on the ISO standard to maintain the finishing requirements.

keywords: High speed end milling, statistical analysis, desirability function, optimization, JMP

1 Introduction

The current decade consider the revolution of quality whether at services or goods sectors, whereby organization emphasize on the quality sustainability or in other words quality assurance within the production process to meet the customers demands as well

*Corresponding author: islamburini@afu.ac.ae

©Università del Salento
ISSN: 2070-5948
http://siba-ese.unisalento.it/index.php/ejasa/index

as other considerations such as; market share, reputation and revenue. Quality Assurance can reduce the defects in production process as well as reduce several cost such as appraisal cost and avoidance cost. Thus, the current research will focus on a mechanism to reduce the cost without affecting the final quality of the product; the mechanism is High speed hard end milling. High speed hard end milling is one of important machining processes that merge high speed milling and hard milling. However, increasing the cutting speed will lead to reducing the need of coolant during machining. Therefore, the importance of this process is that it merges three advanced machining processes together. Many researchers have worked in optimizing the cutting parameter for high speed end milling (Ghani et al., 2004; Aslan et al., 2007; Ozcelik and Bayramoglu, 2006; Lu et al., 2009). However, there was lack of study in tooling cost optimization and the statistical analysis related to tooling cost and the main independent factors. Tooling cost is related directly to the tool life and then to flank wear rate. ISO 3685 (1993) recommended using tool life criteria of average flank wear equal to 0.3 mm in finishing. However, There are several researcher have been worked on flank wear rate and tool life (Wang and Liu, 2016; Wang et al., 2015; Jozić et al., 2015; Zhang et al., 2012).

Mohd Ezuwanizam (2010) claimed the optimal cutting parameters for cutting speed, feed rate and depth of cut in optimize the tool life of carbide insert coated with TiN in milling aluminum 6061. Xuan-Truong and Minh-Duc (2013) had explained the effect of cutting parameters on flank wear through the transformation of natural logarithm. They found that cutting speed has given major significant effect on flank wear and is mostly influenced by feed rate. While for depth of cut, they conclude that it only gives a minor effect for both surface roughness and flank wear especially at low cutting speed and feed rate.

However, in this research center composed design as one the effective statistical tools in surface response methodology has been used to analyses and investigate the three independent factors: cutting speed (V_c), feed rate (f) and depth of cut on the tool life and tooling cost to remove one cubic centimeter. In the various literatures and research done by researchers, they stated a lot of result and their opinion on flank wear which the main output related to the tool life and then to the tooling cost on high speed end milling operation on hardened steel material. Koshy et al. (2002) conducted experiment using indexable insert coated with TiCN at feed rate value of 0.05 and 0.1 mm. The result shows that tool life was better at higher feed rate and cutting speed only give minimal significant on tool life over range of speed between 50m/min to 150m/min. In the same article also Koshy et al. (2002) conclude that flank wear pattern indicated that chipping, adhesion and attrition were on general the governing mechanism responsible for tool wear. Kalpakjian and Schmid (2014) concluded the maximum allowable average flank wear to maintain the quality of surface roughness for different machining processes as in table 1.

Table 1: Allowable Average Flank Wear Land For Cutting Tool

Operation	Allowable Wear Land (mm), VB	
	High-speed Steels	Carbides
Turning	1.5	0.4
Face milling	1.5	0.4
End milling	0.3	0.3
Drilling	0.4	0.4
Reaming	0.15	0.15

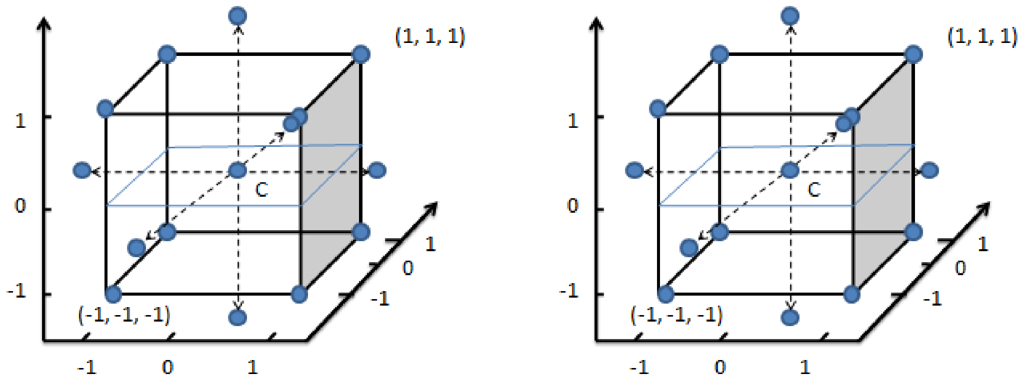
2 Central Composite Design (CCD)

A Central Composite Design (CCD) is an experiment design in which each numeric factor varied over five levels in axial points as shown in Figure 1. CCD is a fractional factorial design with center points that is augmented with a group of star points (Montgomery, 2008). It is built up from; two level factorial design plus center point and axial points represented by stars plus more center points (Whitcomb and Anderson, 2004).These axial points go outside of the factorial box. This has advantages and disadvantages. Its good to go further out for assessing curvature, but it may be inconvenient for the experimenter to hit the five levels required of each factor: low axial (star at smallest value), low factorial, center point, high factorial, and high axial (star at greatest value). One of the special cases in CCD is the Face Centered design that can be done in three levels. In many situations, the region of interest is cuboidal rather than spherical.

One of the special cases of this design is the face centered cube (FCC) which can run only with three levels. In these cases, a useful variation of the central composite design is the face-centered central composite design or the Face Centered Cube (FCC) (Montgomery, 2008). This design locates the star or axial points on the centers of the faces of the cube. This design is also sometimes used because it requires only three levels of each factor as shown in Figure 2.

3 Experiment Procedure

The experiment was conducted using the high-speed end milling modeled NEXUS 410A-II with vertical milling center. 30 mm diameter carbide inserts have been used as a cutting tool and work material used is hardened steel D2 with dimension of 200 mm $\times$ 100 mm $\times$ 50 mm hardened to 52-56 HRC. For this experiment, a fresh carbide inserts will be used for each run of the experiment. The result and analysis of using Face cubic center (FCC) for three levels using JMP statistical analysis software in analyzing and identify the optimizing the machining parameters in high speed end milling. Table 2



(a) Central Composite Design (b) FCC (Three Factors)

Figure 1: Sample Distribution

shows the experiment design boundaries.

Table 2: Ranges of cutting parameters of the experiment

Cutting Parameters	Min.	Max.
Cutting Seed (m/min)	120	240
Feed Rate (mm/tooth)	0.05	0.15
Depth of Cut (mm)	0.10	0.20

4 Output Estimation

In this research the tool life has been estimated using the average flank wear length to determine tool life based on ISO 3685 (1993) that recommended using tool life criteria of average flank wear equal to 0.3 mm in finishing. While the tooling cost will be calculated based on the following equations,

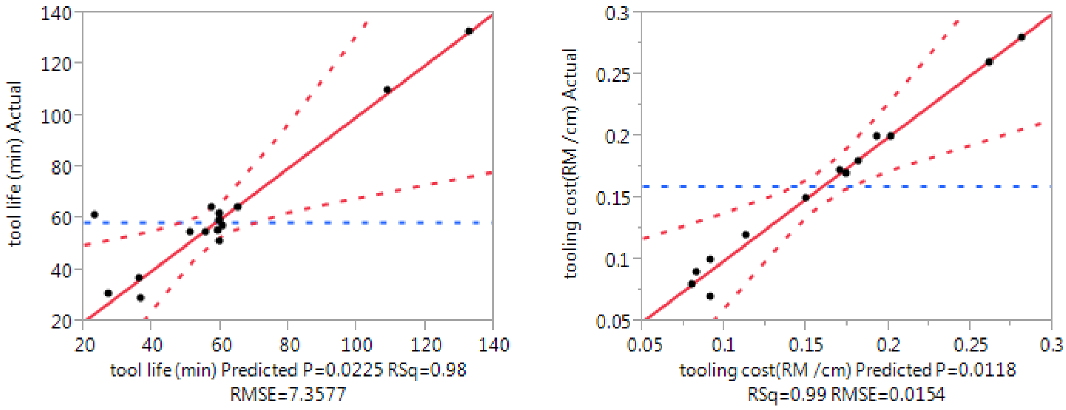
$$C_{TC} = (T_{it}/\text{Tool Life})C_T \tag{1}$$

Where T_{it} Time of insert in touch with work piece (min) and C_T is the tool cost per edge taking in consideration the tool holder and the insert cost.

5 Statistical Analysis

The analysis of variance ANOVA has been used to analyze the results and the main and interaction effects of the independent factors on the tool life and the tooling cost using JMP statistical software. Finally, the optimum cutting parameter have been identify using the desirability function method in order to get the maximum tool life and minimum tooling cost the need to remove one centimeter.

Figure 3 shows the comprism between the actual and predicted values of the tool life and tooling cost.



(a) Tool Life (b) Tooling Cost

Figure 2: Actual with Predicted Values

These results have been analysed using different statistical measures. Table 3 summarizes the results of R square values and other measures of fitness.

The table shows that R^2 is close to one for both models and very close and almost unity with the adjusted R^2 which means that the models are reliable for predicting the tool life and the tooling cost. However, the analysis of variance shows that both models are reliable. The results concluded in table for moth models and show that the F ratio for both models is below 5%. Table 4 concluded the results.

Table 4 shows that F ratio for tool life model is equal to 2.25% and for tooling cost is 1.18%. These values prove that both models are significant and reliable to predict and estimate the tool life and tooling cost. However, the effect of main factors and the interaction factors have been analyses and sorted based on the most effective to the least effect on the tool life and tooling cost. Table 5 and table 6 concluded these results.

From table 5 it was clear the most effective factors are the cutting speed with t ratio of (-6.33) and Prob $> |t|$ of about 0.008 and then the feed rate of (-3.44) of t ratio with Prob $> |t|$ is equal 0.0411. and finally the depth of cut with the value of (4.59) as t ratio with Prob $> |t|$ is equal to 0.194. Therefor the results show that both cutting speed and feed rate have a negative affect on the tool life while increasing the depth of cut has a

Table 3: Summary of Fit

(a) Tool Life

RSquare	0.979033
RSquare Adj	0.916131
Root Mean Square Error	7.357702
Mean of Response	58.52938
Observations (or Sum Wgts)	13

(b) Tooling Cost

RSquare	0.98649
RSquare Adj	0.94596
Root Mean Square Error	0.015441
Mean of Response	0.159396
Observations (or Sum Wgts)	13

positive effect. However the interaction between the main factors show the other side of the model and show that the interaction between the feed rate and the depth of cut comes in the second step after the cutting speed with the value of (-4.66) with Prob$>|t|$ equal to (0.187).

The results in Table 6 are supporting the results in table 5 and show very clear that increasing the cutting speed and feed rate will increase the tooling cost. in contrast the depth of cut as one of the main factors show insignificant effect on tooling cost and comes in the last after sorting the parameters with the t ratio of (-0.94) with Prob $>|t|$ is equal to 0.41.

In order to investigate the effect of cutting parameters combination of high speed end milling on tool life of insert carbide and the tooling cost, 3D contour plot were generated using JMP software. Figure 4a, 4b and 4c below shows the interaction between cutting parameters and tool life of the insert carbide. And Figure 5a, 5b and 5c for tooling cost.

6 Optimization

Desirability Function approach has been used as one of the most widely used methods in industry for dealing with the optimization of multiple response processes. In this technique, a multiple response problem is converted to a single objective optimization problem using mathematical transformations. The measured responses are transformed to a dimensionless desirability (d_i) scale according to the optimization target. The optimization objective for the desirability function can be categorized into the following:

Table 4: Summary of Fit

(a) Tool Life

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	7583.3883	842.599	15.5645
Error	3	162.4073	54.136	**Prob > F**
C. Total	12	7745.7956		**0.0225***

(b) Tooling Cost

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	0.05222774	0.005803	24.3399
Error	3	0.00071526	0.000238	**Prob > F**
C. Total	12	0.05294299		**0.0118***

- Nominal the best
- Larger the better
- Smaller the better

$$d_i = 0 \quad y_i \geq y(\max) \tag{2}$$

$$d_i = (y_i - y_{\max}/y_{\min} - y_{\max})^w \quad \text{for min} \tag{3}$$

$$d_i = 1 \quad y_i \leq y(\min) \tag{4}$$

where i is the number of responses, is the expected value of the response, are design boundary and s is the weight. For $s = 1$, the desirability function increases linearly towards the target and for $s \leq 1$ the function is convex and for $s \geq 1$ the function is concave. It is assigned a value from 01 to 10. In general the weight are assumed as 1 to get linear desirability functions, so for this study the weight for all factors will equal to one. The optimum values based on desirability function as shown in Table 7 and Figure 6.

The results show a high value of desirability equal to 93% with cutting speed of 120 mm/min and 0.07 mm/tooth for feed rate and finally the depth of cut equal to 0.181 mm. These cutting levels will lead to tool life of 126.9 min and then the tooling cost of $0.045 to remove one cubic centimeter of the materials.

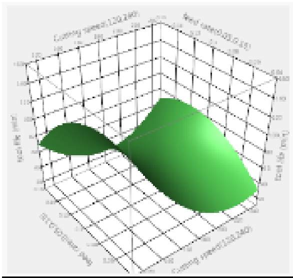


Figure 4a: Effect of cutting speed and feed rate on tool life

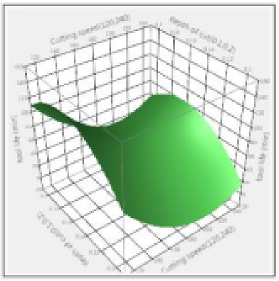


Figure 4b: Effect of cutting speed and DOC on tool life

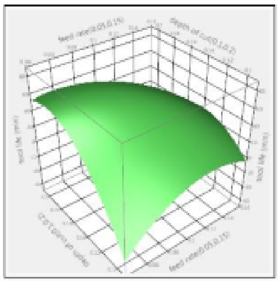


Figure 4c: Effect of feed rate and DOC on tool life

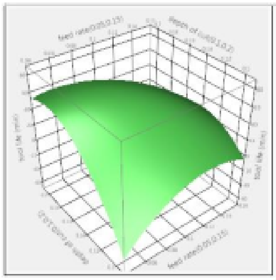


Figure 5a: Effect of cutting speed and feed rate on tooling cost

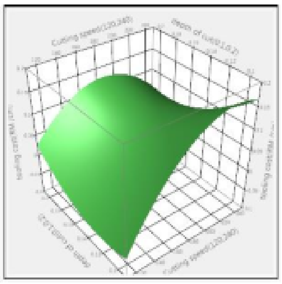


Figure 5b: Effect of cutting speed and DOC on tooling cost

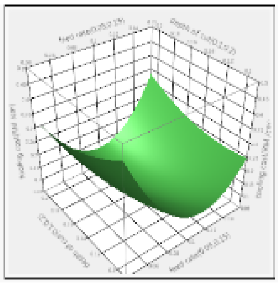


Figure 5c: Effect of feed rate and DOC on tooling cost

Table 5: Optimum Values

Cutting speed (m/min)	Feed rate (mm/tooth)	Depth of cut (mm)	Tool life (min)	Desirability
120	0.07	0.1815	126.9825	93%

7 Summary

The experimental process was successfully done and the data was collected through High Speed End Milling process. The data were analyzed using JMP statistical software. The statistical analysis shows a high correlation between the cutting parameters combination and the output responses. The new model for flank wear rate have been developed in terms of cutting speed, Vc (m/min), feed rate, f (mm/tooth) and depth of cut, DOC (mm). the desirability function was implemented to determine the minimize the flank wear rate and maximize the signal noise ratio. It was found that with desirability 0f 93%, the cutting speed 120 mm/min, feed rate of 0.07 mm/tooth and 0.18 mm of depth of cut that will lead to tool life of 126 min and tooling cost of $0.04 for removing one cubic centimeter.

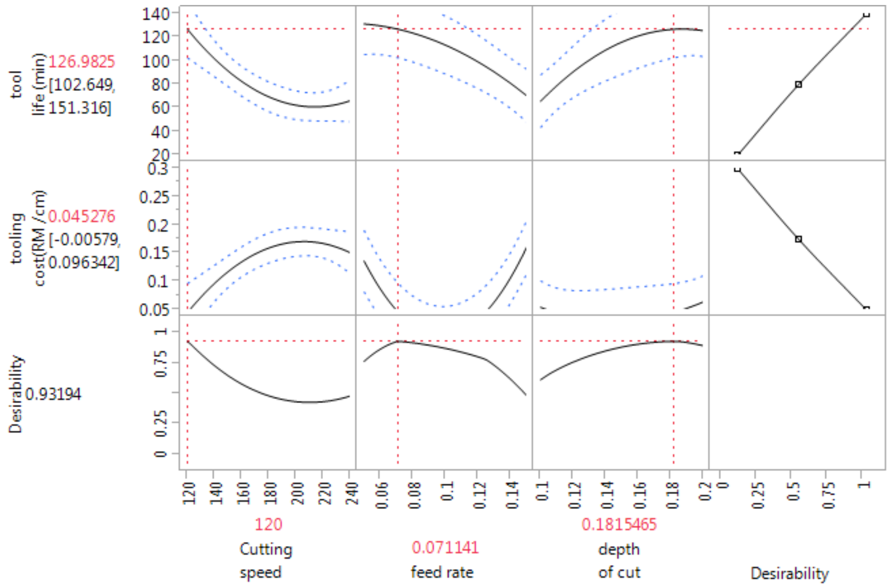


Figure 3: Desirability function results for multiple optimization objectives

References

Aslan, E., Camuşcu, N., and Birgören, B. (2007). Design optimization of cutting parameters when turning hardened aisi 4140 steel (63 hrc) with al 2 o 3+ ticn mixed ceramic tool. *Materials & design*, 28(5):1618–1622.

Ghani, J. A., Choudhury, I., and Hassan, H. (2004). Application of taguchi method in the optimization of end milling parameters. *Journal of Materials Processing Technology*, 145(1):84–92.

Jozić, S., Bajić, D., and Stoić, A. (2015). Flank wear and surface roughness in end milling of hardened steel. *Metalurgija*, 54(2):343–346.

Kalpakjian, S. and Schmid, S. (2014). Manufacturing processes for engineering materials–5th edition. *agenda*, 12:1.

Koshy, P., Dewes, R., and Aspinwall, D. (2002). High speed end milling of hardened aisi d2 tool steel (58 hrc). *Journal of Materials Processing Technology*, 127(2):266–273.

Lu, H., Chang, C., Hwang, N., and Chung, C. (2009). Grey relational analysis coupled with principal component analysis for optimization design of the cutting parameters in high-speed end milling. *Journal of materials processing technology*, 209(8):3808–3817.

Mohd Ezuwanizam, M. (2010). *Optimization of tool life in miling*. PhD thesis, Universiti Malaysia Pahang.

Montgomery, D. C. (2008). *Design and analysis of experiments*. John Wiley & Sons.

Ozcelik, B. and Bayramoglu, M. (2006). The statistical modeling of surface roughness in high-speed flat end milling. *International Journal of Machine Tools and Manufacture*, 46(12):1395–1402.

Wang, B. and Liu, Z. (2016). Cutting performance of solid ceramic end milling tools in machining hardened aisi h13 steel. *International Journal of Refractory Metals and Hard Materials*, 55:24–32.

Wang, C., Xie, Y., Qin, Z., Lin, H., Yuan, Y., and Wang, Q. (2015). Wear and breakage of tialn-and tisin-coated carbide tools during high-speed milling of hardened steel. *Wear*, 336:29–42.

Whitcomb, P. J. and Anderson, M. J. (2004). *RSM simplified: optimizing processes using response surface methods for design of experiments.* CRC press.

Xuan-Truong, D. and Minh-Duc, T. (2013). Effect of cutting condition on tool wear and surface roughness during machining of inconel 718. *Int J Adv Engg Tech/IV/III/July-Sept*, 108:112.

Zhang, S., Li, J., and Wang, Y. (2012). Tool life and cutting forces in end milling inconel 718 under dry and minimum quantity cooling lubrication cutting conditions. *Journal of Cleaner Production*, 32:81–87.