ANALYSIS OF DRY TURNING PROCESS OF AISI316 FOR COATED AND UNCOATED INSERT TOOLS BASED ON ECONOMICAL METHOD

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Abstract— Sustainability and clean of production are of importance in the machining processes where high energy amount is consumed. Reducing the power consumption during machining process can significantly improve the economical and environmental performance of manufacturing systems. The objective of this research is to evaluate the coated and uncoated carbide insert performance in hard turning process for AISI 316 in terms of power consumption, and tool wear. Economical method was study by developed a new cost modeling by integrated different cost estimation methods based on energy and tool life considerations. The performance of Coated Carbide and Uncoated Carbide tools were evaluated under dry turning process. The influence of cutting parameters of cutting speed, feed rate, and depth of cut analysis based on energy consumption and economical method. The optimum cutting condition that provide minimum consumed of energy was found at parameters, cutting speed (100 m/min), feed rate (0.15 mm/rev) and depth of cut (0.8mm). The study concluded that the out performance of uncoated carbide inserts can be implemented in hard turning applications and extreme cutting conditions can reduce of energy and saving machining cost.

Keywords— turning process; coated and uncoated; economy method; power consumption; tool wear.

1. INTRODUCTION

The improvements of industrial productivity can be achieved by making manufacturing processes more efficient and sustainable. Cost analysis one of the most important elements of evaluation production operation. The Manufacturing process cost consists of several factors including the material cost and cutting tools, the power consumption cost one of the most important factors among of them.

The basic endeavor in any production process is to produce an acceptable component of the minimum possible cost. In order to achieve this objective several ways are undertaken such as-Optimizing the cutting parameters, cooling system, energy consumption and tool life in order to minimize the production cost and maximizing the production rate. Some work has been done in the economical aspect of machining process in an effort to reduce the operation cost. Lee and Tarng [1] was reported investigated of optimal cutting parameters for maximizing production rate or production cost with consideration of operation time for multistage turning operations that was constructed based on a polynomial network. More, Jiang, Brown and Malshe [2] conducted experimental to investigate of cost analysis based on total machining cost per part comparison of the economic viability between the cBN–TiN coated and PCBN in turning carried out on hardened AISI 4340 steel. They used Gilbert's approach to discussed cost analysis. The results was the total machining cost per part using cBN–TiN coated inserts is considerably lower than that of PCBN tipped tools, the savings in machining costs using cBN–TiN was between 12 and 30%. Gara, Bouzid, Ben Amar and Hbaieb [3] considered cutting time and cost, they developed models of cutting time and production cost based on experimental tests numerical models programmed in a Visual–Basic interface to find optimum values of cutting parameters and an estimation of cutting operation cost in high speed turning through an NC rough turning.

Sahoo[4] presented economical comparative study between uncoated and multilayer insert in turning high carbon high chromium based on total machining cost on Gilbert's approach. The results found tool life of TiN coated insert was approximately 30 times higher than the uncoated carbide insert under similar cutting conditions and produced lower surface roughness. The machining cost per part for uncoated carbide insert was 10.5 times higher than the multilayer TiN coated carbide inserts that indicates 90.5% cost was saving. Malakooti [5] presented discussion about tool life and its multi-cutting problem which were cost per part, production time per part, and quality of surface. Table 1 shown summery of equation for previous studies. Yusoff and Arsyad [6] studied effects of different cutting parameters on surface roughness and power consumption when machining FCD450 cast iron using coated and uncoated milling tool. They found the coated tools performed better than uncoated milling tools for responses of surface roughness and power consumption to increase machining productivity and profit.

Due to the continuous developments in cutting tools materials are being investigated to determine the potential of using them for use in extreme conditions as in hard turning. Coated carbide cutting tools one of the tools are using to machining hard material such as stainless steel. At the same time investigation of uncoated carbide inserts still conducted to determine the potential of using in cutting of hared material due to the their low cost compare to the coated inserts. In the past few years, different efforts focusing on optimization of cutting parameters in turning machining with energy-related studies of machine tools have been conducted. Nevertheless, very little work has been done in evaluation the performance of cutting tools based on minimum energy consumption and production cost considerations. In this article, study is the evaluate of the performance coated and uncoated carabid insert in hard turning process of AISI 316 based on Multi- Cutting Tool Criteria problem of tool cost, energy cost and time life of tools.

2. Economical Analysis

A higher process rate requires higher cutting speed, and the whole tool life decreases in a certain range of cutting speed. Since the effect of tool cost is still more dominant compared to the energy cost, the increases in terms of process rate, so the optimum process parameters are determined by considering the trade-off relationship between the energy consumption and the manufacturing cost [7]. There are studies have been done to expressed the energy consumption which can significantly in overall process cost. The material removal rate (MRR) of a machining process is largely affected in overall energy consumption. Currently, many studies have built various models of power consumption using material removal rate (MRR) value, most of them expresses the energy efficiency of machining process by use Specific Energy Consumption (SEC). Gutowski, Branham, Dahmus, Jones, Thiriez and Sekulic [8] proposed that there was a function relationship between energy consumption which are divided into power for the auxiliary function and material removal rate in machining process. Kara and Li [9] suggested empirical model in which power was inversely proportional to mass rate removal. The model has been proved in the lathe and milling machine, and compared differences of the model under the condition of dry and wet cutting. Li, Yan and Xing [10] also improved Specific Energy Consumption model considering the spindle rotation speed in air-cutting status to removal material ratio. Diaz, Redelsheimer and Dornfeld [11] conducted experiment and proposed a similar model from others Specific Energy Consumption (SEC) equations, that difference coefficients' meaning. They obtained the relationship curve between SEC and MRR by changing the cutting depth and width continuously in the experiment. Yoon, Lee, Kim and Ahn [12] introduced tool wear in building energy consumption model of milling machine, and found that the material-removal power increased with the flank wear of the tool. The model was empirically modeled using response surface methodology under three kinds of tool wear condition, mild, moderate and severe. Lv, Tang and Jia [13] proposed that new module by calculating energy consumption for machining process was to merge action elements. Al-Hazza, Adesta, Ali, Agusman and Suprianto [14] conducted experiment study to optimize mathematical model of energy cost for high speed hard AISI4340 steel turning using response surface method (RSM), artificial neural network (ANN) analysis.

For this study, the cost analysis was observation for turning a cylindrical workpiece with a finished diameters (D_a) of 53mm, length of cut (L) of (30 mm) and with this cutting parameters v = 100 m/min, f = 0.1 mm/rev, and a_p = 0.4 mm. Mathematical equations were derived for the calculation of the economics of machining process.

Total machining cost per part C is the sum of machining cost per part Cm, the total energy cost Ce and the total cost of tool and changing tool per part Ct shown in the equation (1)

$$C = Cm + Ce + Ct \quad (1)$$

The total machining time per part t can be calculated from three times shown in equation (2) where t_1, t_2 and t_3 are setup time, actual cutting time and tool change time respectively [min].[15]

$$t = t_1 + t_2 + t_3 \quad (2)$$

The cutting time based parameters t_2 is express by equation (3)

$$t_2 = \frac{\pi . Da . l}{V . f} \quad (3)$$

where D_a is the average diameter for workpiece [mm], l is the length of cut [mm]. The energy in turning processing was calculated as shown in equation (4)

$$E = E_1 + E_2 \quad (4)$$

Where E_1 is energy consumed during setup, E_2 is energy consumed during cutting process of turning machining. The total machining energy cost per part C_e express in equation (5)

$$C_e = x_1 . E \quad (5)$$

where x_1 is the energy cost rate [RM/Ws].
The Machining cost per part Cm estimated using equation (6)

$$Cm = x_2 . t \quad (6)$$

Where x_2 is estimate total cost of labor charge, machine charge and the overhead.
The total cost of tool changing Ct per part was calculate through the following equation.

$$Ct = x . t_3 . y \left(\frac{t_2}{T}\right) \quad (7)$$

Where y is mean value of a single cutting edge, T is tool life time (min).
Finally, substituting equation (5), (6) and (7) into equation (1), leads to equation (8) for the cost of turning machining

$$C = x_1 . E + x_2 . t_2 + \left(\frac{t_2}{T}\right)(x_2 . t_3 . y) \quad (8)$$

3. EXPERIMENTAL METHOD

The present work studies evaluate the performance and compare of coated and uncoated tools. There CNMG 120408 (Coated Carbide) PC8110 coating and CNMG 120408 (Uncoated Carbide) in machining of hard steel (AISI 316) under turning machine. The influence of cutting parameters (cutting speed, feed rate and depth of cut) with their three (3) levels as labelled in Table 1. Energy requirements (Kwh) was determine during the experiments. The required number of experiments for estimation of three (3) parameters was 9 experiments. The economic viability was investigated of cost analysis and comparison between the TiN coated carabid and uncoated. Gilbert's approach, maximize production rate and minimize cost graphical approach and metal removal equation was apply to analysis machining cost.

Table1: Cutting parameters with their levels

Factors	Process parameters	Level 1	Level 2	Level 3
A	Cutting speed (m/min)	100	150	200
B	Feed rate(mm/rev)	0.1	0.15	0.2
C	Depth of cut(mm)	0.4	0.8	1

Table2: The chemical composition of the AISI316

Material	C	Si	Mn	Ni	S	Cr	Mo
Wt. %	0.078	0.337	5.81	3.68	0.29	18.28	0.049

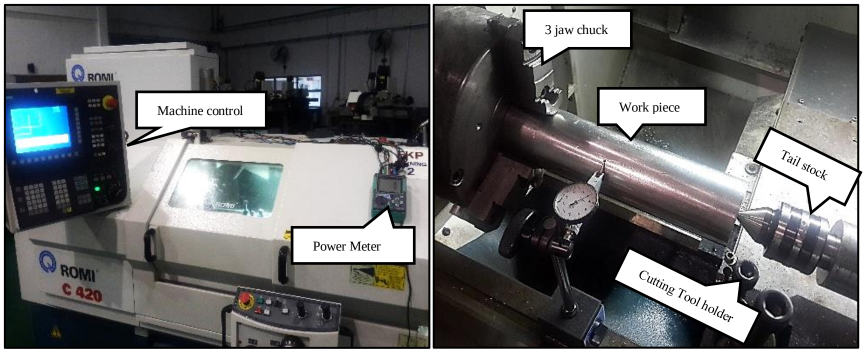

Figure 1: Experimental setting under CNC lathe machine ROM 240

The overall steps of this project are presented know. It was started with the preparation of raw material to prepare samples, equipment with measuring devises was prepared also, following by the preparation of experiment. Finally, come with cost analysis. The Fig. 1 shown the experimental setting under CNC lathe machine ROM 240. The work piece material that was used for the present investigation is Stainless steel 316. Standard of material was available in the form of cylindrical rod with axial length 120 mm and diameter 63 mm. Table 2 shown the chemical composition of the work piece material.

In this experimental study, CNMG 120408 (Coated Carbide) PC8110 coating and CNMG 120408 (Uncoated Carbide) were used. The selected inserts were base on the several previous studies [16] [17], and suppler recommendation due to low cost, better surface finish, work with different situation, varies parameters rang, highest material removal, easy replacement, reduce setup time and high hardness over a wide range of temperatures. The digital Power Meter KEW6305 was used to capture the power utilized during the cutting process. The measuring steps was start by ensuring the safety. Preparation and setting measurement, measured demand values was displayed on the LCD at the. Fig. 2 shows power measurement settings and the equipment.

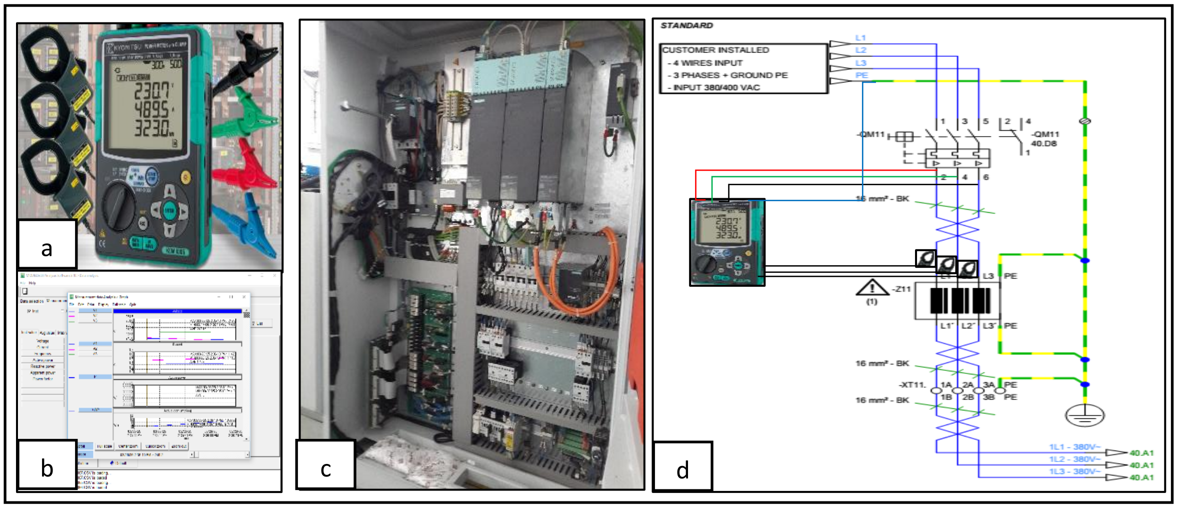

Figure 2: Power measurement where (a) 3Phase Power Meter 6300 (b) Kew Power Plus software (c) Main Electric diagram of CNC (d) Connection to power meter

4. Results and Discussion

4.1. Power consumption

The evaluation of power consumption to machining parameters during turning machining were presented. In this experiment, it was found that as power consumption increases, when cutting speed increases. While a reverse relationship for feed rate, depth of cut and power consumption. It was found that the power consumption is decrease when the feed and depth decrease. However, coated tools show little larger power consumption than uncoated tools for both effects of cutting speed and feed rate, with no more difference for depth of cut. The depth of cut more significant on power consumption through reduce the time of cut.

Fig. 3 shows significant influence of cutting speed on the power consumption of the dry turning process. It is shown the increase of cutting speed leads to increase of energy consumption. Therefore, the low value of spindle speed suitable to machining part with minimum energy consumed. Fig. 3 shows also the uncoated insert slightly better than coated to reduce power consumption. Some previous studies reported similar result, Camposeco [18] concluded that the low cutting speed value and the high feed rate value provided the minimum energy consumption by the machine tool during cutting process. Hanafi *et al.*[19], Bhushan [20] and Camposeco-Negrete [21] concluded to achieve minimum energy consumption, the level of cutting speed must be at its lowest.

Feed rate one of the most factors effect on energy consumption during cutting machining. Fig. 4 shows the high value of feed rate provided less power for both cutting tools coated-uncoated. While Fig. 5 shows that the power consumption decrease within high depth of cut value due to reduce the cycle time of cutting process. However, uncoated tools performed better to decrease power consumption compared to coated tools for cutting speed and feed rate cutting process parameters and meet to some extent for depth of cut. Thus, the optimum cutting condition for dry turning machine was found at parameters that provided minimum energy consumption, lowest cutting speed (100 m/min), feed rate (0.15 mm/rev) and depth of cut (0.8mm).

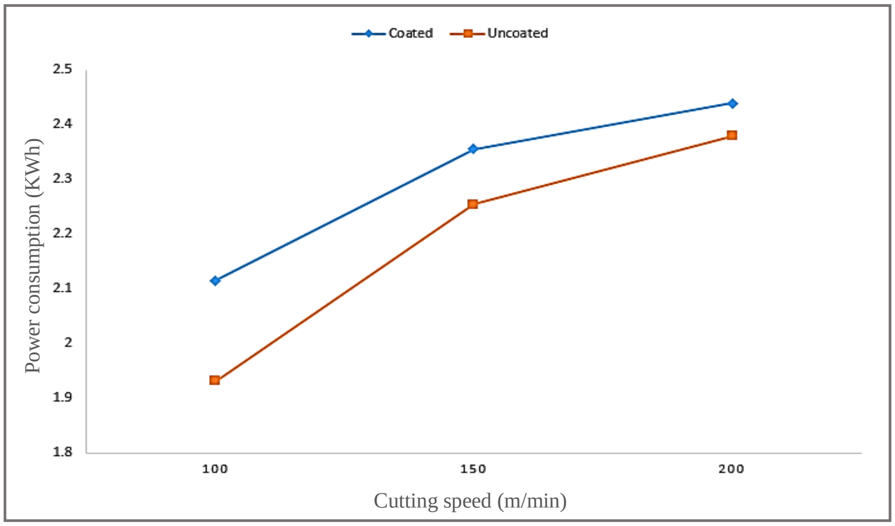

Figure 3: Effect of cutting speed on power consumption for coated and uncoated carbide tools

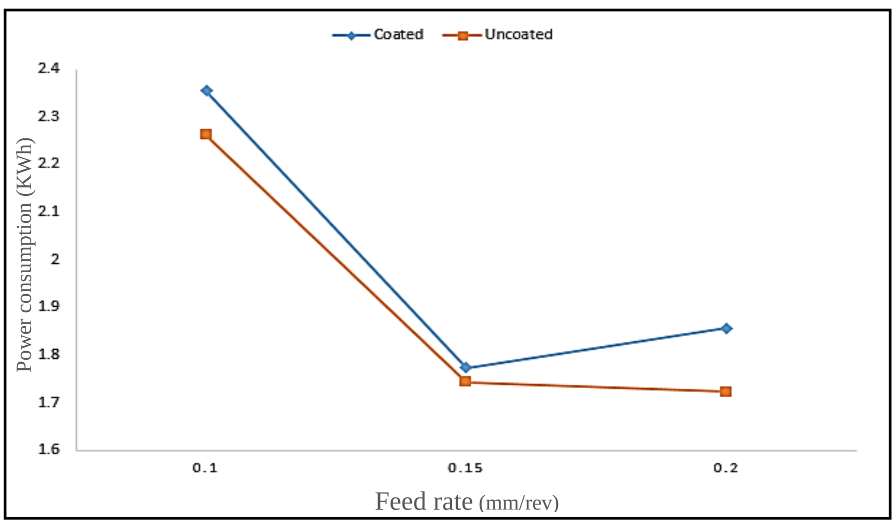

Figure 4: Effect of feed rate on power consumption for coated and uncoated carbide tools.

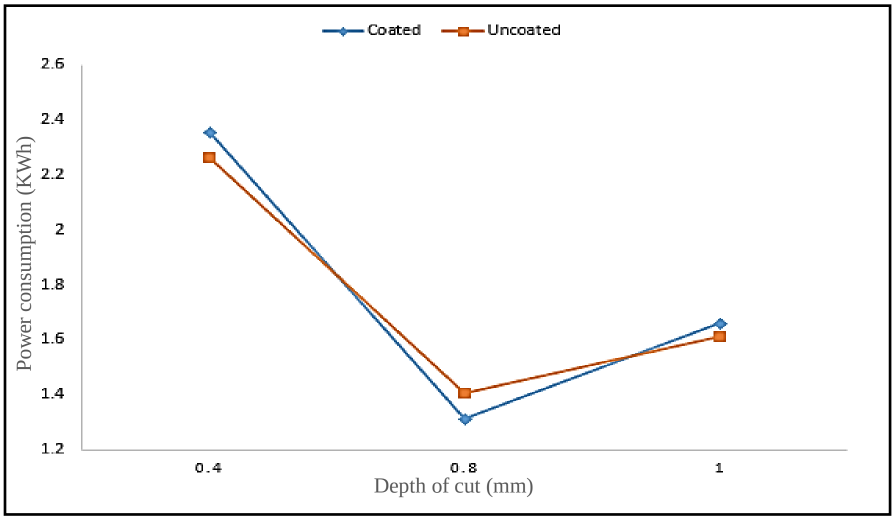

Figure 5: Effect of depth of cut on power consumption for coated and uncoated carbide tools.

4.2. Tool Life

One of the most important element of machining costs is a cutting tool costs. Tool life is importance time indicator to know whenever a tool is needed to replace or reset. For this reason, tool life should be improved to stay a long time as possible. There are some methods using to improve performance of cutting tools, one of them is optimal cutting parameters.

The criteria maximum value of flank wear (VB_{max}) recommended by ISO3685:1993 [22] to define the effective tools, the limit of flank wear (VB) for carbide cutting tools are (0.3 -0.5) and (0.1-0.25) for roughing and finishing operation respectively. This investigation has been done under following condition: three levels of cutting speed (100, 150, 200 m/min) and constant value of depth of cut at (0.4 mm) and feed rate at (0.1mm/rev), and the tool life criteria were set at average flank wear width of 0.3mm or failure of tool.

Fig. 6 present the increase of cutting speed is accompanied by an increase in flank wear (VB), which in lead to decrease the tool life. The recorded tool life in this investigation at low cutting speed (100m/min) were 25 and 18.5 minutes for coated and uncoated inserts respectively. The life of coated tool longer than uncoated, that lead to effect on the machining cost. Generally, the tool life are satisfactory for both inserts. The previous works reported similar results, which also that the effect of cutting speed is highest effect to the tools [23].

4.3. Cost Analysis

This investigation of machining cost only considered energy cost and initial cutting tool cost. Based on current machining practice and assuming that the total charge (x) of the labor charge, machine charge and the overhead, is estimated to be RM25 per hour. The cost of power is 6.91 sent/kWh. The cost of single tip uncoated carbide inserts (CNMG 120408) is RM19 per piece. The cost of TiN coated tool inserts (CNMG 120408) is approximately RM28 per piece. Therefore, the mean value of a single cutting edge (y) is RM14 and RM9.5 for coated tool inserts and uncoated tool inserts, respectively. The summary of the all cost that collected based on the equations above was located in Table 3.

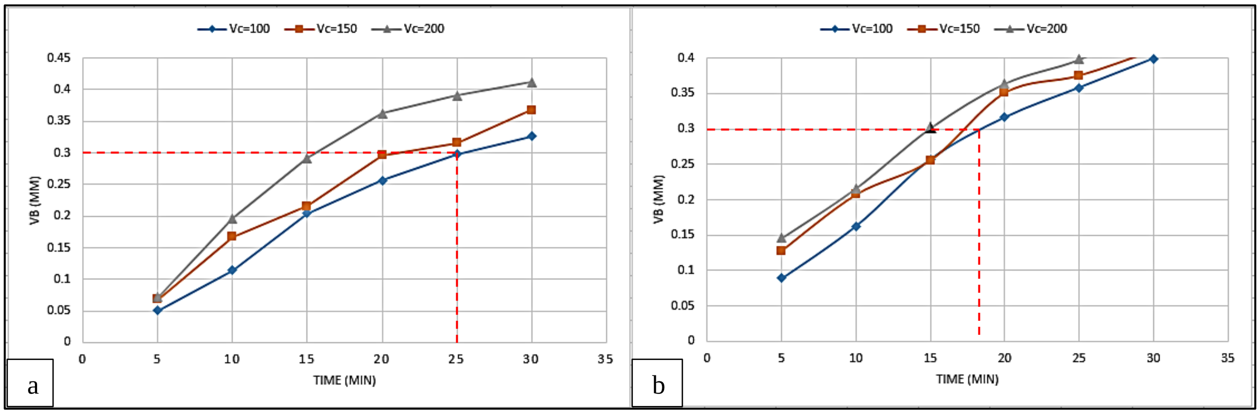

Figure 6: The correlation cutting speed (Vc) and flank wear (VB) to estimate of Tool Life for (a) Coated (b) Uncoated insert

Table 3: Comparison of machining costs for the coated and uncoated carabid inserts

Cost item	Coated carbide	Uncoated carbide
Power consumption of a part (Pc) (Kwh)	2.303	2.1885
Energy consumed during setup (E1) (Kwh)	0.81	0.81
Energy cost (Ce) (6.91 sent/kWh) (rm)	21.51	20.6
Machining time per part (Tc) (min)	30	30
Estimated Value of machine(x) (rm)	25 per hour	25 per hour
Machining cost per part(Cm) (rm)	12.5	12.5
Tool life time for single edge (T) (min)	25	18.5
Tool change cost per part (Ct) (rm)	1.176	1.078
Total machining cost per part (C) (rm)	35.186	34.178

Results of the cost analysis based on the above data are given in Table 5. It can be seen that the total machining cost per part was found to be RM34.17 and RM35.18 for uncoated and coated carbide insert respectively. This indicates slightly less the machining cost per part for uncoated carbide. Therefore, the performance of uncoated carbide tools can be carry out at stainless steel turning applications in extreme cutting conditions.

5. CONCLUDING

The analysis of the results Turning of AISI 316 austenitic stainless steel was performed by using coated and uncoated carbide tools in environment cutting process without fluid. The cutting parameters were varied at cutting speed (m/min) 100, 150, 200, feed rate (mm/rev) 0.1, 0.15, 0.2 and depth of cut (mm) 0.4, 0.8, 1. The machining responses evaluated were power consumption and tool life. The analysis of the results for power consumption shows that the power consumption increase for cutting speed and decrease for feed rate and depth of cut due to reduce of time. However, uncoated tools performed slightly better to decrease power consumption compared to coated tools for cutting speed and feed rate cutting process parameters and meet together to some extent for depth of cut. The result also presented that the coated carbide insert a longer life compared with uncoated insert. The effect of cutting speed is highest effect to the tools. Thus, the increase of cutting speed is continues of reduce in tool life. The optimum cutting condition that provide minimum consumed of energy was found at parameters, cutting speed (100 m/min), feed rate (0.15 mm/rev) and depth of cut (0.8mm). The cost analysis it can be seen that the total machining cost per part using uncoated inserts is slightly lower than coated carbide tools. Therefore the out performance of uncoated carbide inserts can be implemented at hard turning applications. Future experimental investigations will be conduct by use different cutting parameters within variation type of cooling/lubrication strategies and study their impact on the economic and quality.

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REFERENCES

[1] B. Y. Lee and Y. S. Tarng, "Cutting-parameter selection for maximizing production rate or minimizing production cost in multistage turning operations," *J. Mater. Process. Technol.*, vol. 105, pp. 61–66, 2000.

[2] A. S. More, W. Jiang, W. D. Brown, and A. P. Malshe, "Tool wear and machining performance of cBN–TiN coated carbide inserts and PCBN compact inserts in turning AISI 4340 hardened steel," *J. Mater. Process. Technol.*, vol. 180, no. 1, pp. 253–262, 2006.

[3] S. Gara, W. Bouzid, M. Ben Amar, and M. Hbaieb, "Cost and time calculation in rough NC turning," *Int. J. Adv. Manuf. Technol.*, vol. 40, no. 9–10, pp. 971–981, 2009.

[4] A. K. Sahoo and B. Sahoo, "A comparative study on performance of multilayer coated and uncoated carbide inserts when turning AISI D2 steel under dry environment," *Measurement*, vol. 46, no. 8, pp. 2695–2704, 2013.

[5] B. Malakooti, *Operations and production systems with multiple objectives*. John Wiley {&} Sons, 2013.

[6] A. R. Yusoff and F. Arsyad, "Evaluation of Surface Roughness and Power Consumption in Machining FCD 450 Cast Iron using Coated and Uncoated Irregular Milling Tools," in *IOP Conference Series: Materials Science and Engineering*, 2016, vol. 114, no. 1, p. 12017.

[7] H.-S. Yoon, E.-S. Kim, M.-S. Kim, J.-Y. Lee, G.-B. Lee, and S.-H. Ahn, "Towards greener machine tools–A review on energy saving strategies and technologies," *Renew. Sustain. Energy Rev.*, vol. 48, pp. 870–891, 2015.

[8] T. G. Gutowski, M. S. Branham, J. B. Dahmus, A. J. Jones, A. Thiriez, and D. P. Sekulic, "Thermodynamic analysis of resources used in manufacturing processes," *Environ. Sci. {&} Technol.*, vol. 43, no. 5, pp. 1584–1590, 2009.

[9] S. Kara and W. Li, "Unit process energy consumption models for material removal processes," *CIRP Ann. Technol.*, vol. 60, no. 1, pp. 37–40, 2011.

[10] L. Li, J. Yan, and Z. Xing, "Energy requirements evaluation of milling machines based on thermal equilibrium and empirical modelling," *J. Clean. Prod.*, vol. 52, pp. 113–121, 2013.

[11] N. Diaz, E. Redelsheimer, and D. Dornfeld, "Energy consumption characterization and reduction strategies for milling machine tool use," in *Glocalized solutions for sustainability in manufacturing*, Springer, 2011, pp. 263–267.

[12] H.-S. Yoon, J.-Y. Lee, M.-S. Kim, and S.-H. Ahn, "Empirical power-consumption model for material removal in three-axis milling," *J. Clean. Prod.*, vol. 78, pp. 54–62, 2014.

[13] J. Lv, R. Tang, and S. Jia, "Therblig-based energy supply modeling of computer numerical control machine tools," *J. Clean. Prod.*, vol. 65, pp. 168–177, 2014.

[14] M. H. F. Al-Hazza, E. Y. T. Adesta, A. M. Ali, D. Agusman, and M. Y. Suprianto, "Energy cost modeling for high speed hard turning," *J. Appl. Sci.*, vol. 11, no. 14, pp. 2578–2584, 2011.

[15] M. F. Rajemi, P. T. Mativenga, and A. Aramcharoen, "Sustainable machining: selection of optimum turning conditions based on minimum energy considerations," *J. Clean. Prod.*, vol. 18, no. 10, pp. 1059–1065, 2010.

[16] M. Y. Noordin, Y. C. Tang, and D. Kurniawan, "The use of TiAlN coated carbide tool when finish machining hardened stainless steel," *Int. J. Precis. Technol.*, vol. 1, no. 1, pp. 21–29, 2007.

[17] A. Gupta, H. Singh, and A. Aggarwal, "Taguchi-fuzzy multi output optimization (MOO) in high speed CNC turning of AISI P-20 tool steel," *Expert Syst. Appl.*, vol. 38, no. 6, pp. 6822–6828, 2011.

[18] C. Camposeco-negrete, "Optimization of cutting parameters for minimizing energy consumption in turning of AISI 6061 T6 using Taguchi methodology and ANOVA," *J. Clean. Prod.*, vol. 53, pp. 195–203, 2013.

[19] I. Hanafi, A. Khamlichi, F. M. Cabrera, E. Almansa, and A. Jabbouri, "Optimization of cutting conditions for sustainable machining of PEEK-CF30 using TiN tools," *J. Clean. Prod.*, vol. 33, pp. 1–9, 2012.

[20] R. K. Bhushan, "Optimization of cutting parameters for minimizing power consumption and maximizing tool life during machining of Al alloy SiC particle composites," *J. Clean. Prod.*, vol. 39, pp. 242–254, 2013.

[21] C. Camposeco-Negrete, "Optimization of cutting parameters using Response Surface Method for minimizing energy consumption and maximizing cutting quality in turning of AISI 6061 T6 aluminum," *J. Clean. Prod.*, vol. 91, pp. 109–117, 2015.

[22] ISO3685, "Tool-life testing with single-point turning tools," *ISO 3685 Second Ed. 1993-11-15*, vol. 1993, pp. 1–48, 1993.

[23] M. Y. Noordin, D. Kurniawan, Y. C. Tang, and K. Muniswaran, "Feasibility of mild hard turning of stainless steel using coated carbide tool," *Int. J. Adv. Manuf. Technol.*, vol. 60, no. 9–12, pp. 853–863, Jun. 2012.