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OPTIMIZATION OF MATERIAL REMOVAL RATE, SURFACE ROUGHNESS AND TOOL LIFE ON CONVENTIONAL DRY TURNING OF FCD700

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ABSTRACT

Most of automotive components are manufactured using a conventional machining process, such as turning, drilling, milling, shaping and planning, etc. Ductile cast iron (FCD) is widely used for producing automotive components by turning process. This study aims to investigate the effect of the cutting speed, feed rate and depth of cut on material removal rate (MRR), surface roughness, and tool life in conventional turning of ductile cast iron FCD700 grade using TiN coated cutting tool in dry condition. The machining condition parameters were the cutting speed of 220, 300 and 360 m/min, feed rate of 0.2, 0.3 and 0.5 mm/rev, while the depth of cut (DOC) was kept constant at 2 mm. The effect of cutting condition (cutting speed and feed rate) on MRR, surface roughness, and tool life were studied and analyzed. Experiments were conducted based on the Taguchi design of experiments (DOE) with orthogonal L9 array, and then followed by optimization of the results using Analysis of Variance (ANOVA) to find the maximum MRR, minimum surface roughness, and maximum tool life. The optimum MRR was obtained when setting the cutting speed and feed rate at high values, but the optimum tool life was reached when the cutting speed and feed rate were set as low as possible. Low surface finish was obtained at high cutting speed and low feed rate. Therefore time and cost saving are significant especially is real industry application, and yet reliable prediction is obtained by conducting machining simulation using FEM software Deform 3D. The results obtained for MRR using the proposed simulation model were in a good agreement with the experiments.

Keywords: Optimization, material removal rate, surface roughness, tool life, finite element analysis.

1. INTRODUCTION

The effects of machining parameters on MRR and surface roughness in turning process were widely investigated by previous researchers. According to Qian and Hosan (2007), the cutting force and feed force increased with increasing feed, tool edge radius, negative rake angle, and workpiece hardness. Cutting force and feed force also increased linearly with the depth of cut. Cerenitti et al. (1996) found that the maximum temperature on a chip also increased with increasing cutting speed. This is due to the increase of required energy in the cutting processes. More heat will be generated when increase the cutting speed, consequently the temperature on the tool and workpiece's surface increase to a maximum value at higher cutting speed. The energy required to deform the workpiece material and the chips is mainly converted into heat. As shown in Figure 1, there are three zones in which the heat is generated (Seker et al., 2003) :

- Primary deformation zone; where plastic deformation takes place and Q_S is geneareted.
- Secondry deformation zone; where the deformation takes place in the tool-chip interface and as the result of friction force Q_C occurs.
- Tertiary deformation zone; where the heat is generated due to friction beween tool clearance face and newly generated workpiece surface, Q_F.

Thus, the total heat, Q_T can be obtained by the following Eq. (1).

$$Q_T = Q_S + Q_C + Q_F \qquad (1)$$

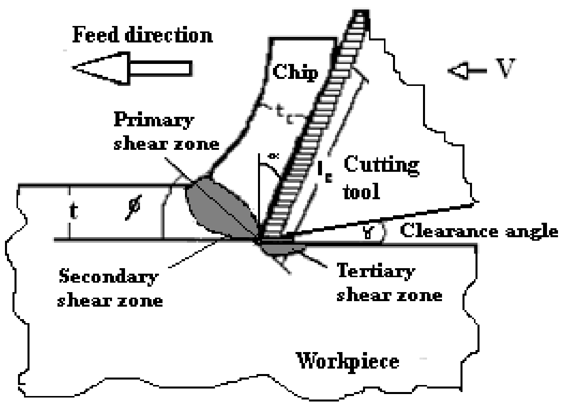


Figure 1 Generation of heat in orthogonal

According to Jaharah et al. (2009a), the *Ra* produced was significantly affected by the feed rate, followed by the cutting speed and depth of cut where the contribution of feed rate, the cutting speed and depth of cut were 45%, 32%, and 23% respectively. Ghani et al. (2002) investigated that surface finish of the workpiece was not influenced by the tool wear; however, increasing cutting speed, feed rate or depth of cut will affecting the surface finish. Tool performance was evaluated with respect to tool wear, surface finish produced and cutting forces generated during turning (Yigit et al., 2008). The wear of the cutting tool was the critical issue in metal cutting as well as in turning of metal, consequently caused the tool failure (Woodrow, 2005). Ozel and Zeren (2004) proved that in turning steel, coated carbide tool performed better than uncoated carbide tool. In this study, TiN coated carbide tool was used, because the ductile cast iron FCD700 grade workpiece material is known for hard and difficult to machine. This material was chosen due to its applications in the automotive components such as connecting rod and crankshaft. The machining problems of cast iron have been not necessary foundry-related, but most of problem were due to the microstructure formation during the machining process itself. Jaharah et al. (2009b) said that the width formation of microstructure changes, increases with the increase in wear land and feed rate. Therefore, study on the machinability of ductile cast iron FCD700 grade is required to improve the productivity as well as to obtain the optimal machining parameters. Taguchi methods DOE was used to optimize the MRR, surface roughness and tool life value. Taguchi methods is a powerful tool for designing a high-quality system that provides smaller, less costly experiments and yet withdraw a valid conclusion. Taguchi's parameter design also offers a simple, systematic approach and can be used to optimize design for performance, quality and cost. Signal-to-noise (S/N) Ratio and orthogonal array are two major tools used in robust design. Signal-to- noise (S/N) ratio, which measures quality with emphasis on variation, and orthogonal arrays, which accommodates many design factors simultaneously (Park 1996, Phadke 1998). Taguchi method also offers the quality of product is measured by quality characteristics such as: nominal is the best, smaller is better and larger is better (Phadke 1998). Taguchi techniques were widely used in engineering analysis in the system, parameter and tolerance design (Peace, 1993). Other researchers (Hascalik and Caidas, 2008; Pawade et al., 2008; Kurt et al., 2009) also utilized Taguchi methods in their various research activities. The first finite element modelling of machining was published in1973 by Klamecki. Improvement on the theory and application were published by Strenkowski and Carroll (1985), followed by comprehensive review of general FEM code in machining application by Marusich and Ortiz (1995). The analysis in this study was based on the result of machining simulation using advanced FEM program package (Deform-3D).

The aim of this study is to find the optimum MRR, surface roughness, and tool life. The optimum parameters obtained can help an automotive industry to be competitive in machining operation from the economical and manufacturing perspective.

2. LITERATURE REVIEW

Turning process is performed to modify shape, dimension, and surface roughness of a workpiece by removing the unwanted material it in the form of chips. The theory of metal cutting and chip formation are complicated, not only plasticity but also thermodynamic and mathematical analysis are involved (Lee and Shaffer, 1951). Schematic diagram of orthogonal metal cutting and its configuration is shown in Figure 2.

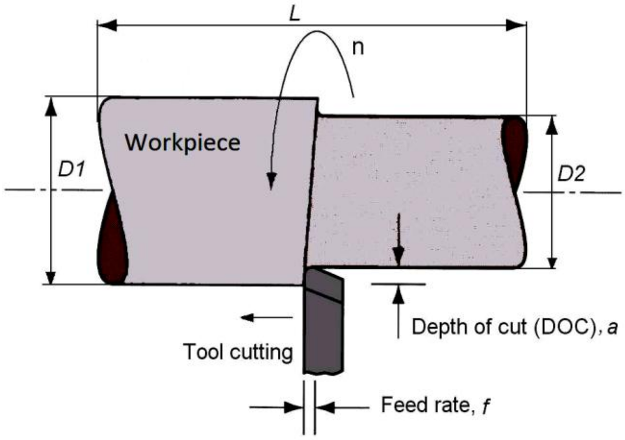


Figure 2 Schematic diagram of the orthogonal metal cutting configuration

2.1. Material Removal Rate (MRR)

Understanding of material removal concept (MRR) in metal cutting is very important in designing process and cutting tool selection to ensure the quality of the product (Shet and Deng, 2000). The material removal rate (MRR) in turning operations is the volume of material/metal that is removed per unit time in mm^3/min. For each revolution of the work piece, a ring shaped layer of material is removed. The following are the derivation of important machining parameters:

2.1.1 Spindle Speed (V)

From Figure 2, the equation of spindle speed (n) to achieve a specific cutting speed can be expressed as Eq. (2).

$$n = \frac{k.V}{\pi.D_1} \qquad (2)$$

If n is spindle speed in revolutions/minute (*rpm*), k is a constant to correct the cutting speed (V) and V is the desired cutting speed, and D_1 is the largest part diameter (initial size). The value of a constant of k depends on the unit choice of the cutting speed (V), as follow:

- V is given surface feet per minute (in *sf/min* or *sfpm*), and D_1 in inches: $k = 12$
- V given meters per second (in *m/s* or *mps*) and D_1 in mm: $k = 60000$
- V given meters per minute (in *m/min* or *mpm*) and D_1 in mm: $k = 1000$

If cutting speed in m/min for a given rpm rate is desired, k =1000, solve above equation for cutting speed (V) is

$$V = \frac{\pi . d . n}{1000} \quad (3)$$

2.1.2 Cutting Time (CT)

Cutting time for a length of workpiece (L) is as in Eq. (4).

$$CT = \frac{(L + A)}{f . n} \quad (4)$$

Where, CT is cutting time in min, L is length of cut in mm, A is allowance or starting offset in mm^2, f is machine feed rate mm/revolution.

2.1.3. Material Removal Rate (MRR) for Turning

$$MRR = \frac{Volume.removed}{CuttingTime(CT)}$$

$$MRR = \frac{\pi . L(D_1^2 - D_2^2)}{\frac{4.L}{f.n}} \quad (5)$$

If D_1 and D_2 is diameter workpiece before and after machining, L is length of machined workpiece and a *is* the depth of cut in mm, so by substituting Eq. (2) to (5) will be found:

$$MRR = 1000.V.f.\frac{(D_1 - D_2)}{2}.\frac{(D_1 + D_2}{2D_1}$$

$$\frac{(D_1 - D_2)}{2} \approx a$$

And,

$$\frac{(D_1 - D_2)}{2D_1} \approx 1$$

Therefore, MRR in mm^3/min is:

$$MRR = 1000.V.f.a \quad (6)$$

2.1.4. Surface Roughness

Out of all the surface condition criteria, Ra and Rt (expressed in μm) are often used to characterize the roughness of machined surfaces. Rt is total roughness (maximum depth or amplitude of the roughness), and Ra is arithmetic roughness (mean arithmetic deviation from the mean line of the roughness) as given in Eq. (7).

$$R_a = \frac{\sum A + \sum B}{L} \quad (7)$$

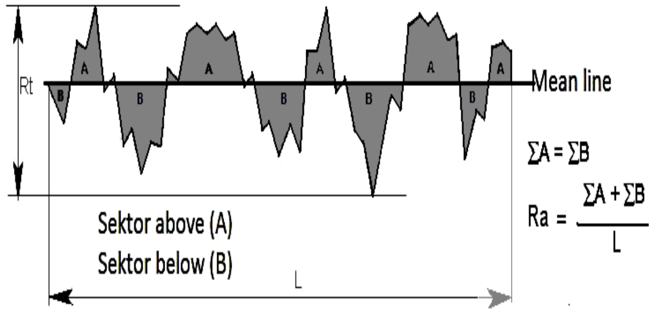


Figure 3 Schematic of parameter definition used to compute the mean arithmetic deviation (Ra) and total roughness (Rt)

Definition of the mean line is $\Sigma A = \Sigma B$ as shown in Figure 3. Surface condition is be determined by several factors :

- Cutting parameters (cutting speed, feed)
- Tool geometry (angle and sharpness of the cutting edge, corner radius, etc)
- The material the cutting tool is made from the rigidity of the assembly and of the machine,
- The forming of chips, cutting forces, etc.

2.1.5. Tool Life

The basic Taylor equation for tool wear (Stephenson, 1997) can be rewritten as Eq. (8).

$$VT^n = C_t \quad (8)$$

From this equation, it can be analyzed that there are reversely relationship between cutting speed and tool life. If the cutting speed increases, the tool life will be reduced.

The basic Taylor equation (Eq.8), it only reflects the dominant influence of cutting speed on tool life, but does not account for effects of the feed rate and the depth of cut. So, for this reason, it is used a modified version of Taylor's equation that is called the extended Taylor equation as shown at Eq. (9) [Stephenson, 1997].

$$VT^n f^a d^b = K_t \quad (9)$$

Where V is cutting speed, T is cutting time, f is feed, d depth of cut and n, a, b and K_1 are specific tool grades and are sometime tabulated in tool catalog.

Machining simulation allows the phenomenon at the interface between tool cutting and workpiece to be analyzed in details. Qi and Mills (1999) said that fundamental understanding of the interaction between the cutting tool and workpiece during machining was also essential in determining the tool life.

3. EKSPERIMENTAL DETAILS

3.1 Machine, Workpiece and Cutting Tool

The machining trials were carried out in dry condition without coolant on Machine CNC Colchester model Tornado T4. The workpiece material used was ductile cast iron FCD700 grade (JIS). The cylindrical workpiece was prepared in the form of round bar 100 mm in diameter and 300 mm in length. The hardness, tensile strength, and melting temperature are 250 HV, 416N/mm2, 1130^{o}C respectively. The graphite of ductile cast iron FCD700 grade is in form of pearlitic.

Table 1 Chemical composition of ductile cast iron FCD700 grade

Element Persentage [%]					
C	Fe	Mg	Mn	Ni	Si
3.3 to 3.8	91.6 to 94.5	0.02 to 0.07	0.2 to 0.5	0 to 1	2 to 3

Source: Granta, 2009

Table 1 shows the chemical composition of ductile cast iron FCD700 grade. Sumitomo's carbide insert with TiN coated (DNMG431 ENZ) was used in this experiment. The surface roughness of the workpiece was measured using a surface roughness tester model Mahr Perthometer M1. The surface roughness of the workpiece was measured using a surface roughness tester model Mahr Perthometer M1. Flank wear values were measured under a tool maker's microscope equipped with scale in mm and an insert was rejected when the flank wear exceeded 0.3 mm. The experiments were carried out using the machining parameters as given in Table 2.

Table 2 The machining parameter

Parameters/ factors	Unit	Level 1	Level 2	Level 3
A: Cutting speed	m/min	220	300	360
B: Feed rate	mm/rev	0.2	0.3	0.5
C: DOC	mm	2	2	2

3.2. Machining Trial

Experiments were conducted using the design of experiments (DOE) technique with orthogonal L9 array of Taguchi methods, and then followed by optimization of the results using Analysis of Variance (ANOVA) to find the maximum MRR, minimum surface roughness, and maximum tool life. The nine of machining trials were as tabulated in Table 3.

The ranges of machining conditions were based on the real industry practice for machining ductile cast iron FCD700 grade by one of Malaysian local automotive company. Each of experiment trials was started with a new cutting edge and machining was stopped at a certain interval of time to measure the flank wear land and the surface roughness of the workpiece material.

3.3. FEM Machining Simulation

The finite element analysis was performed using Deform-3D software (Columbus, 2007) to study in detailed the chip formation process, and its relation to the material removed rate (MRR) during the turning process. Table 4 shows the cutting condition and material properties of cutting tool and workpiece for the simulation models.

Table 3 Experimental detail of the machining trial

Experiment no.	Cutting speed, *V* *(m/min)*	Feed rate, *f* *(mm/rev)*	DOC, *a* *(mm)*
1	220	0.2	2
2	220	0.3	2
3	220	0.5	2
4	300	0.2	2
5	300	0.3	2
6	300	0.5	2
7	360	0.2	2
8	360	0.3	2
9	360	0.5	2

4. RESULTS AND ANALYSIS

The results of the machining experiment for material removal rate (MRR), surface roughness and tool life were as tabulated in Table 5. The commercial software package MINITAB15 was explored to analyze the mean effect of Signal-to-Noise (S/N) ratio to achieve the multi-objective features and carried out the optimization analysis for MRR, surface roughness and tool life. The MRR was calculated using Eq. (6) and the surface roughness and tool life were plotted based on the experiment measurements.

Table 4 Cutting condition, material properties of cutting tool and workpiece for the simulation models

Carbide insert cutting tool (DNMG431 ENZ , coated with TiN)	
Rake angle (α), deg	-5
clearance angle (β), deg	-5
Nose radius (µm)	0.8
Tool's material properties	
Modulus of elasticity (GPa)	670
Thermal expansion	5e-06
Poison ratio	0.25
Boundary condition	
Initial temperature (^{o}C)	20
Shear friction factor	0.6
Heat transfer coefficient at the workpiece tool interface (N/s mm°C)	45
Ambient temperature (°C)	20
Workpiece geometry	
Thickness of worpiece (mm)	1.25
Width of workpiece (mm)	3.4
Length of workpiece (mm)	7
Hardness (HV)	250
Tensile strength (MPa)	416
Compression Strenth (MPa)	425
Workpiece's material properties (Ductile cast iron FCD700 grade)	
Modulus of elasticity (GPa)	172
Thermal conductivity (W/m. °C)	35.2
Thermal expansion coefficient ($\cdot 10^{-6}$ °C^{-1})	12.5
Heat capacity (N/mm^2 °C)	3.7
Emissivity	0.95
Melting point (°C)	1130
Poison ratio	0.27
Material constitutive model (Oxley,1989)	
Equation for flow stress σ models	$\sigma = \sigma_1 \varepsilon^n$
Material constants	σ_1, n=$f(T_{mod})$
Variables	ε, έ, T

Table 5 The results of machining experiments for material removal rate (MRR), surface roughness, and tool life

Cutting speed, *V* *(m/min)*	Feed rate, *f* *(mm/rev)*	DOC, *a* *(mm)*	MRR *mm^3/min (mm^3/sec)*	Surface roughness, *Ra* *(µm)*	Tool Life, *T* *(min)*
220	0.2	2	88000 (1467)	1.019	5.65
220	0.3	2	132000 (2200)	1.698	2.60
220	0.5	2	220000 (3667)	8.658	1.38
300	0.2	2	120000 (2000)	1.230	1.87
300	0.3	2	180000 (3000)	2.302	2.15
300	0.5	2	300000 (5000)	2.120	0.44
360	0.2	2	144000 (2400)	0.751	2.43
360	0.3	2	216000 (3600)	1.635	1.91
360	0.5	2	360000 (6000)	2.275	0.42

4.1. Results of material removal rate (MRR)

Figure 4 shows the main effects of cutting speed and feed rate parameters on MRR. The feed rate is more significant parameter than cutting speed in controlling the MRR. As the feed rate increase, MRR also increase, this is mainly due to more volume of chips generated during machining. The optimum of MRR is obtained at feed rate of 0.5 mm/rev and cutting speed of 360 m/min (the cutting speed and feed rate are set as high as possible).

ANOVA in Table 6 also shows that the feed rate has more influence on MRR than the cutting speed. Contribution of feed rate and cutting speed on MRR were 77.3% and 22.7% respectively. The residual is other influence like the interaction of cutting force and feed rate that has contribution of 0.0%.

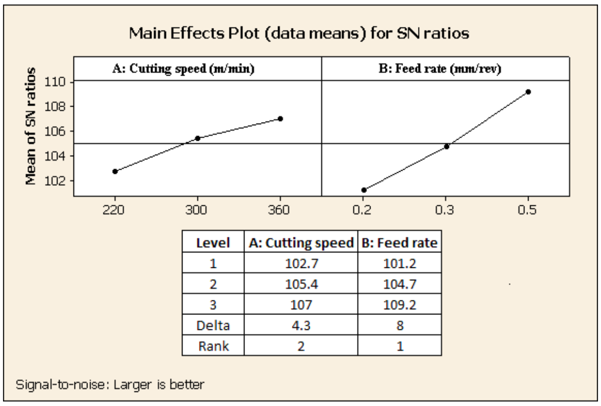


Figure 4 Main effects of cutting speed and feed rate parameters in the S/N ratio for MRR

Table 6 ANOVA analysis of S/N ratio for MRR

Parameter	DOF	Sum Sqr	Mean Sqr	F-Val	% Contr
Cutting speed	2	28.1	14.0	-	22.7
Feed rate	2	95.4	47.7	-	77.3
Residual	4	0.0	0.0		0.0
Net total		123.5			100.0

4.2. Results of Surface Roughness

Figure 5 shows the plot of main effects of cutting speed and feed rate parameters on the surface roughness. It is clearly shown that the feed rate and cutting speed significantly affecting the surface roughness (Ra). Feed rate is found more significant factor affecting the *Ra*.

The surface roughness is apparently to have a decreasing trend with decrease in feed rate. On the other hand, as the cutting speed increases, the surface roughness decreases. Therefore, to obtain a low value of surface finish on the machined part, the feed rate should be set at low possible and cutting speed should be set as high as possible.

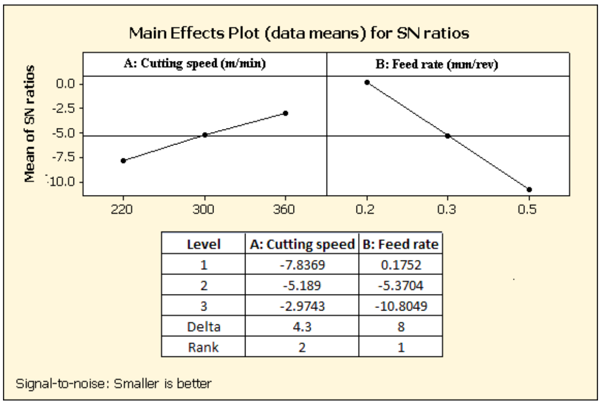


Figure 5 Main effects of cutting speed and feed rate parameters in the S/N ratio for surface roughness

Table 7 ANOVA analysis for S/N ratio for surface roughness

Parameter	DOF	Sum Sqr	Mean Sqr	F-Val	% Contr.
Cutting speed	2	35.6	17.8	-	14.0
Feed rate	2	180.8	90.4	-	71.4
Residual	4	73.4	18.4		14.6
Net total		290.4			100.0

Table 7 also proves that the feed rate has more influence on surface roughness than cutting speed. Contribution of the feed rate and cutting speed on MRR are 71.4% and 14.0% respectively. Other influence gives contribution of 14.6%.

These phenomenon is similarly obtained by Jaharah et al. (2009a) where the feed rate is significantly affecting the *Ra* produced, followed by the cutting speed and depth of cut. Besides, Ghani et al. (2002) investigated that surface finish of the work part was not influenced by the tool wear; however, it was influenced by increase of cutting speed, feed rate or depth of cut.

4.3. Results of Tool Life

Figure 6 shows the plot of factor effects on the tool life. It is clearly shown that both the cutting speed and feed rate significantly controlling the tool life. The effect of feed rate on tool life is more than the cutting speed.

The tool life is apparently to have the decreasing trend with increase in the cutting speed and feed rate, although it almost remain constant after the cutting speed more than 300 m/min. The decreasing trend occurs due to more wear occurs on the cutting edge at the higher cutting speed region. As the feed rate increases, the tool life decreases. The reason might be due to increase in feed rate that causes the bigger interface contact area between cutting tool and workpiece. Bigger contact area, resulted in more friction that caused more heat generated, consequently shorten the tool life. Therefore, to obtain a longest tool life, cutting speed and feed rate should be set as low as possible.

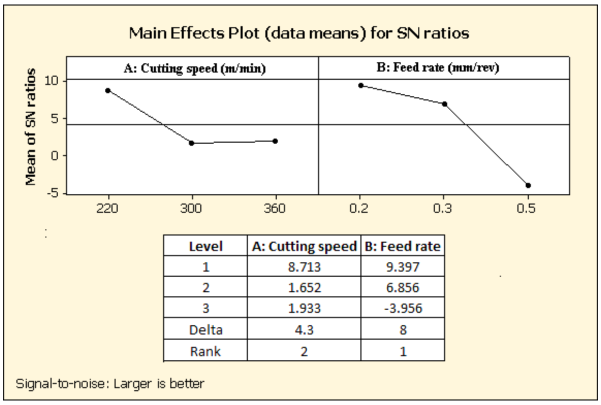


Figure 6 Main effects of parameters in the S/N ratio for tool life

ANOVA in Table 8 shows that the feed rate has more influence on tool life than cutting speed, this is agreeable with above plot of factor effect. The contribution of feed rate and cutting speed on tool life are 57.4% and 32.3% respectively. Other influence gives contribution of 10.2%.

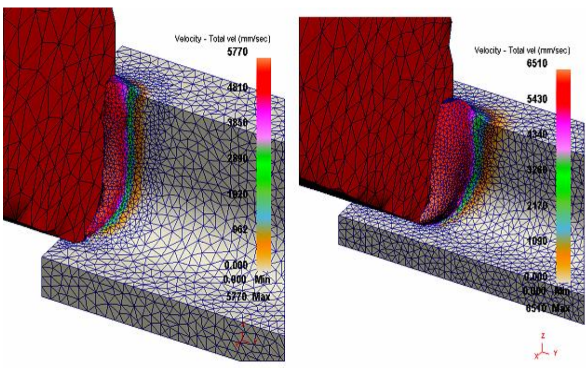
Table 8 ANOVA analysis for S/N ratio for tool life

Parameter	DOF	Sum Sqr	Mean Sqr	F-Val	% Contr.
Cutting speed	2	95.9	48.0	-	23.3
Feed rate	2	301.7	150.8	-	57.4
Residual	4	26.6	6.7	-	10.2
Net total		424.2			100.0

This result is also agreeable with the extended Taylor equation, Eq. (9) where the tool life is affected by feed rate, cutting speed, and depth of cut. Besides, Yigit et al. (2008) said that tool performance can be evaluated base on tool wear, surface finish produced and cutting forces generated during turning.

4.4. MRR Results for FEM Machining Simulation (Comparison with Experiment Results)

In this work, MRR can be analyzed using the machining simulation program package of Deform-3D. This program package applies the theory in a user-friendly graphical user interface (GUI) that is very robust compared to many custom FEM code. The FEM software Deform-3D was developed by SFTC (Columbus, 2007).
The effect of the cutting speed on MRR is shown Figure 7. At the higher cutting speed, higher velocity is applied to deform the chip in turning process. Figure 7 depicts the comparison for turning simulation at cutting speed of 300 m/min and 360 m/min (at the same feed rate of 0.02 mm/rev and DOC of 2 mm). The turning simulation at cutting speed of 360 m/min has higher total velocity (6510 mm/sec) than at cutting speed of 300 m/min (5770 mm/sec).



a). Cutting speed of 300 m/min, feed rate of 0.2 and DOC of 2 mm

b) Cutting speed 360 m/min, feed rate of 0.2 mm/rev and DOC of 2 mm

Figure 7 The comparison of total velocity between cutting speed of 300 m/min and 360 m/min (the same feed rate of 0.2 mm/rev and DOC of 2 mm)

The effect of feed rate on MRR based on FEM is shown in Figure 8. It depicts the comparisons of meshed geometries between turning simulation at feed rate of 0.3 mm/rev and at feed rate of 0.2 mm/rev (both have the same the cutting speed of 220 m/min and DOC of 2 mm). At feed rate of 0.3 mm/rev, more number of nodes and meshes than 0.2 mm/rev. This means that at the higher feed rate, there are more interface contact area (*A = f x a)* between tool cutting and workpiece, so there are larger volumes of deformed material occurred in the machining process. In other words, increasing the feed rate resulted in more MRR.

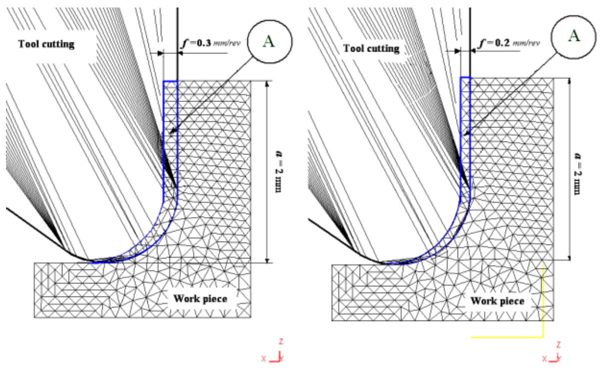


Figure 8 Comparison of meshed geometries between feed rate of 0.3 mm/rev and 0.2 mm/rev (the same cutting speed of 220 and DOC of 2 mm)

The total velocity data that was obtained from machining simulations in various cutting speeds and feed rates and the calculation result of MRR using Eq. (6) are tabulated in Table 9.

Table 9 The results of MRR for various cutting speed and feed rate

Cutting speed, *V* *(m/min)*	Interface velocity, *v* *(mm²/sec)*	*A = f. a* *mm²*	*MRR* *mm3/sec*
V= from 220 to 360 m/min, *f* = 0.2 mm/rev			
220	3910	0.2 x 2	1564
300	5770	0.2 x 2	2308
360	6510	0.2 x 2	2604
f = from 0.2 to 0.5 mm/rev, *V*= 360 m/min			
360	6510	0.2 x 2	2604
360	6635	0.3 x 2	3981
360	6970	0.5 x 2	6970

The machining simulations were conducted for cutting speed of 220, 300 and 360 m/min, while feed rates were kept constant at 0.2 mm/rev. The results of MRR for various cutting speed are compared with the experiment results as can be seen in Table 10. Figure 9 shows that MRR increase as cutting speed increase. The simulation results perform that the highest MRR (2604 mm^3/sec) is obtained at cutting speed 360 m/min and the lowest MRR is 1564 mm^3/sec at cutting speed of 220 m/min.

The simulation results are good agreeable with experiment results that give the errors from 6.6 to 15.4% (less than 17%).

Table 10 Experiment and simulation result comparison for MRR (cutting speeds of 220; 300 and 360 m/min, feed rate kept constant at 0.2 mm/rev)

Feed rate, kept constant at 0.2 mm/rev			
Cutting speed (m/min)	220	300	360
	MRR (*mm3/sec*)		
Experiment	1467	2000	2400
Simulation	1564	2308	2604
Error (%)	6.6	15.4	8.5

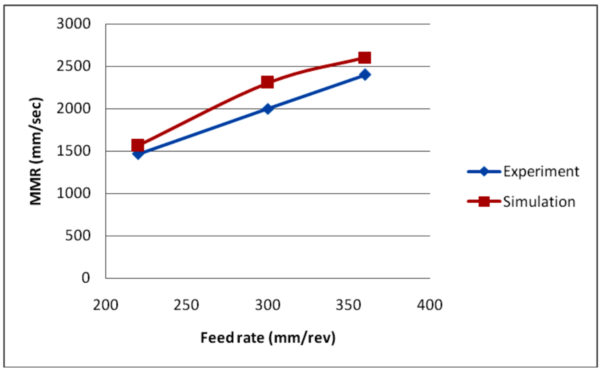


Figure 9 Feed rate vs MRR (cutting speeds of 220; 300 and 360 m/min, feed rate kept constant at 0.2 mm/rev)

Table 11 Experiment and simulation result comparison for MRR (feed rate of 0.2; 0.3 and0.5 mm/rev, cutting speeds kept constant at 360 m/min)

Cutting speed, kept constant at 360 m/min			
Feed rate (*mm/rev*)	0.2	0.3	0.5
	MRR (*mm^3/sec*)		
Experiment	2400	3600	6000
Simulation	2604	3981	6970
Error (%)	8.5	10.6	16.2

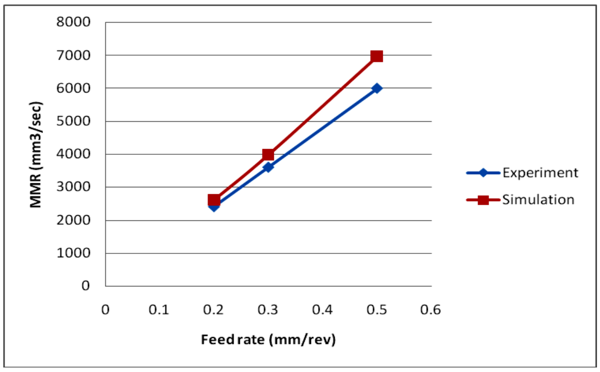


Figure 10 Feed rate vs MRR (feed rate of 0.2; 0.3 and 0.5 mm/rev, cutting speed kept constant at 360 m/min)

Analyzing the simulation results, the simulated feed rates exhibit the same behavior as the experimental results; this can be seen in Table 11. Figure 10 shows that the increase of feed rate from 0.2 to 0.5 mm/rev (the cutting speeds kept constant at 360 m/min) causes the increase of MRR from 2604 to 6970 mm^3/sec. The maximum MRR is obtained at feed rate of 0.5 mm/rev. The simulation results agree reasonable well with experiment results that give error from 8.5 to 16.2 (only less than 17%).

4.5. Optimum Condition

Optimum condition of the turning process is concerned with minimizing the surface roughness, while maximizing the MRR and tool life, but these cannot be achieved simultaneously with a particular combination of control parameter settings. It can be seen that the optimum Ra and MRR are obtained at highest level of cutting speed, whereas the optimum value of a given control factor tool life is lower level of cutting speed. Anyway, the optimum condition for MRR is resulted at cutting speed of 360 m/min, feed rate of 0.5 mm/rev (or cutting speed should be set as high as possible and feed rate also should be set as high as possible). The optimum surface roughness is resulted at cutting speed of 360 m/min, feed rate of 0.2 mm/rev (or cutting speed should be set as high as possible and the feed rate should be set as low as possible), and for the optimum tool life is resulted at cutting speed of 220 m/min, feed rate of 0.2 mm/rev (cutting speed and feed rate should be set as low as possible).

5. CONCLUSION

Experimental results demonstrate that the optimal condition of the responses cannot be achieved simultaneously with a particular combination of control parameters settings because the optimum condition of the turning process is concerned with minimizing surface roughness, while maximizing the MRR and tool life. For instance, the optimum Ra and MRR are obtained at highest level of cutting speed, whereas the optimum value of a given control factor tool life is lower level of cutting speed. However, to obtain maximum MRR, cutting speed should be set as high as possible and feed rate also should be set as high as possible. To acquire a minimal surface finish of workpiece, cutting speed should be set as high as possible and the feed rate should be set as low as possible. To obtain maximum tool life, cutting speed and feed rate should be set as low as possible. Based on FEM simulation, the higher feed rate will give more number of meshes, result more interface contact area and more MRR. Higher cutting speed should cause more velocity in creating the deformed chip, and this resulted in more MRR. The simulations results of MRR were agreeable with MRR experiment results and the errors are less than 17%.

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