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Effect of Milling Parameters on Surface Roughness and Dry Friction: An Experimental and Modeling Study

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Abstract: Aquantitative relationship is demonstrated between the coefficient of static friction and the milling process parameters. Different levels of surface roughness are obtained by varying the spindle speed, depth of cut and feed which is followed by measurement of surface roughness using stylus profile meter. The corresponding coefficients of static friction are measured for all specimens using inclined plane method. The surface roughness (R_a) value is found to increase with increase in feed rate and depth of cut and vice-versa. The surface roughness is found to marginal decrease with increasing spindle speed. The coefficient of static friction is found to decrease with increasing R_a values.

Keywords: Surface Roughness, Feed, Cutting Speed, Friction

1. Introduction

It is well-known that good surface finish improves the strength and appearance of the finished products. Besides, surface finish also influences the friction behavior of interacting surfaces in various tribo-pairs. As surface finish is governed primarily by machining parameters (such as, cutting speed, feed rate and depth of cut), it is very important to correlate the machining parameters with the friction characteristics so as to predict and/or control friction under a given set of conditions.

[1] stated that surface finish affects the production cost, appearance and various other failures. Therefore, many researches worked to obtain good surface finish by optimizing the cutting conditions.[2] presented RSM model to assess the surface roughness of a machined surface.[3] found nose radius to influence the surface finish of machined surfaces to a large extent. [4] reported that an improper selection of cutting conditions may damage the surface finish completely. [5] used Taguchi method for the design optimization of surface quality. [6] reported that surface roughness had significant influence on friction under some specific conditions. [7] reported that the machining parameters influence the surface finish of machined workpiece significantly. In general, the study showed that feed rate was the most dominant factor. [8] reported Taguchi method to be useful to find the optimal value of surface roughness under optimum cutting conditions while turning SCM 440 alloy steel. [9] presented empirical models for tool life, surface roughness and cutting force in turning operation. [10] used artificial neural network algorithm to calculate the surface finish in end milling of inconel 718 alloys. [11] reported that on line flank wear directly influenced the surface quality and productivity. [12] developed ANN models and showed the effect of feed rate, cutting speed and depth of cut on surface roughness during turning process. [13] evaluated that real coded genetic algorithm (RCGA) was real and accurate for solving the cutting parameter optimization problem with multiple decision variables. [14] observed that feed rate had significant effect on surface finish for all three materials considered. [15] observed that the higher values of spindle speed and lower values of feed rate led to decrease in surface roughness value. [16] revealed that the vibration amplitude and feed rate had significant effect on surface roughness. [17] found the tool life and surface quality to be strongly influenced by vibrations. [18,19,20] reported that the feed rate had the most significant effect on surface roughness. (R_a) value increased with increased machining feed.

As mentioned above, the issues pertaining to machining process and friction have been addressed exclusively without establishing any correlation. However, as the prediction of friction still remains a great challenge, it is important to develop an integrated approach to understand the issues related to friction and its prediction. Unfortunately, the effect of surface roughness on dry friction behavior has not been studied adequately and the relevant studies are not conclusive. Therefore, the primary objective of the present study is to demonstrate the interrelationship between machining parameters, surface roughness and static friction. It is expected that this work will be useful for prediction and control of dry friction. This has been accomplished byperforming milling operation on mild steel specimens at different values of machining parameters so as to obtain different levels of surface roughness. The coefficient of friction for each specimen is measured and conclusions are drawn on the basis of the results so obtained.

2. Experimental Set up and Measuring Equipment

The experiments are performed on vertical milling machine as shown in Figure 1. A high-speed-steel milling cutter is used for machining mild steel specimens rectangular in shape. It is a conventional down milling operation wherein the milling cutter turns in the same direction as the movement of work piece. The milling parameters viz, spindle speed, feed rate and depth of cut are varied within the ranges specified in Table 1 so as to study the effect on surface roughness and static friction.

Figure 1. *Vertical milling machine.*

Table 1. *Milling machine input parameters, symbol and range.*

Sr. No.	Input parameter	Symbol	Range
1	Spindle speed	s	63-180 rpm
2	Feed rate	f	20-160 mm/min
3	Depth of cut	d	0.5-1.5 mm

The equipment used here for measurement of surface roughness is Surfcom Flex 50 A depicted in Figure 2. The surface roughness tester used to traces the irregularities of the specimen surface and displays the surface profile and surface roughness (R_a) value on a screen. Some of the main specifications of this equipment are listed in Table 2.

Figure 2. *Surface roughness tester.*

Table 2. *Specification of Surfcom Flex 50 A.*

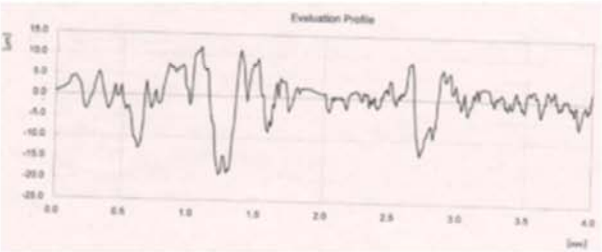
Parameters	Specification
Measuring range	50 mm
Maximum measuring force	0.75mN
Stylus material	Diamond
Stylus tip radius	2 µm
Power source	Built- in rechargeable battery

3. Effect of Feed Rate on Surface Roughness

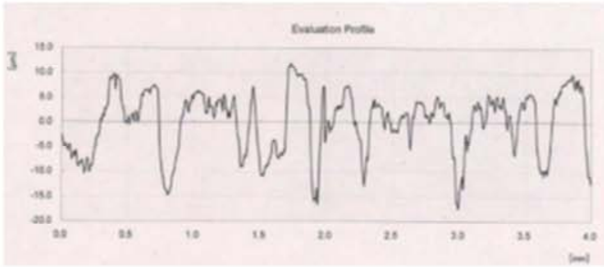
Milling operation is performed on mild steel specimens for eight combinations of spindle speed (s), depth of cut (d) and feed rate (f). The surface roughness of all the workpieces are given in Tables 3. The measured surface roughness profiles are shown in Figure 3 and 4. The effect of feed rate shown in figure 5 (a) through (d).The surface roughness (R_a) value is found to increase with increase in feed rate and depth of cut. The surface roughness is found to marginal decrease with increasing spindle speed. However, the effect of feed rate on surface roughness is most pronounced as reported by several researchers. If R_a is assumed proportional to f^a, the exponent a is found to vary between 0.1 and 0.27 under the present conditions, whereas, the exponents pertaining to s and d have relatively lower maximum values.

Table 3. *Measured (R_a) values for different combinations of milling parameters.*

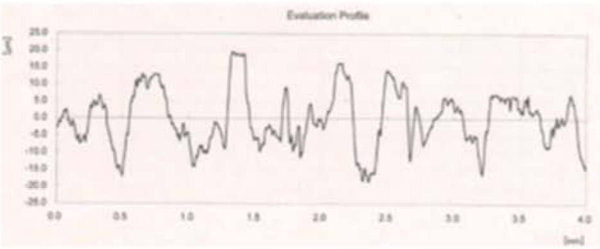
S. No.	Spindle speed (rev/min)	Depth of cut (mm)	feed rate (mm/min)	R_a(µm)
1	63	0.5	20	3.570
2			80	5.211
3	63	1.5	20	3.971
4			160	6.672
5	180	0.5	20	2.769
6			80	3.205
7	180	1.5	20	3.205
8			160	4.006



(a) d =0.5 mm, f =20 mm/min



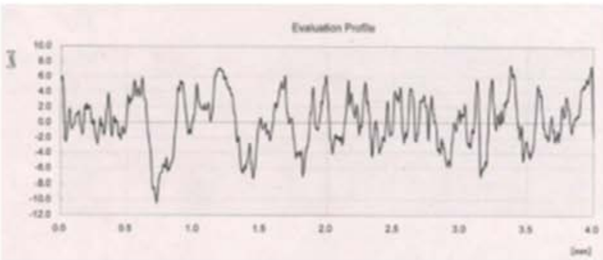
(b) d =0.5 mm, f =80 mm/min



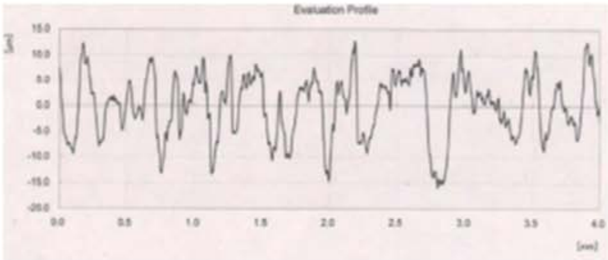
(c) d =1.5 mm, f =160 mm/min

(d) d =1.5 mm, f =20 mm/min

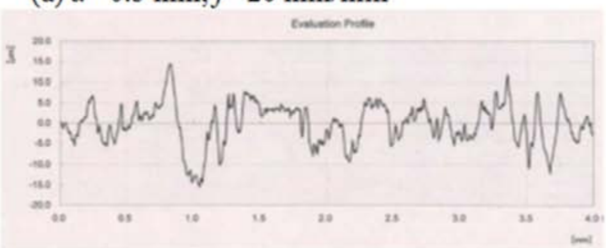
Figure 3. *Measured surface roughness profiles for specimens milled at s =63 rev/min.*



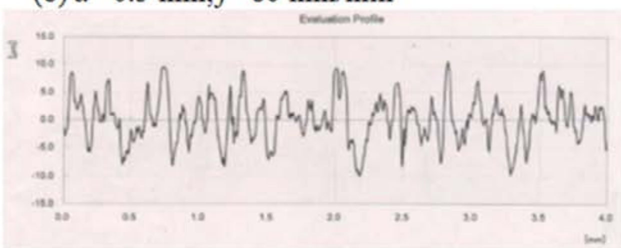
(a) d =0.5 mm, f =20 mm/min



(b) d =0.5 mm, f =80 mm/min



(c) d =1.5 mm, f =160 mm/min



(d) d =1.5 mm, f =20 mm/min

Figure 4. *Measured surface roughness profiles for specimens milled at s =180 rev/min.*

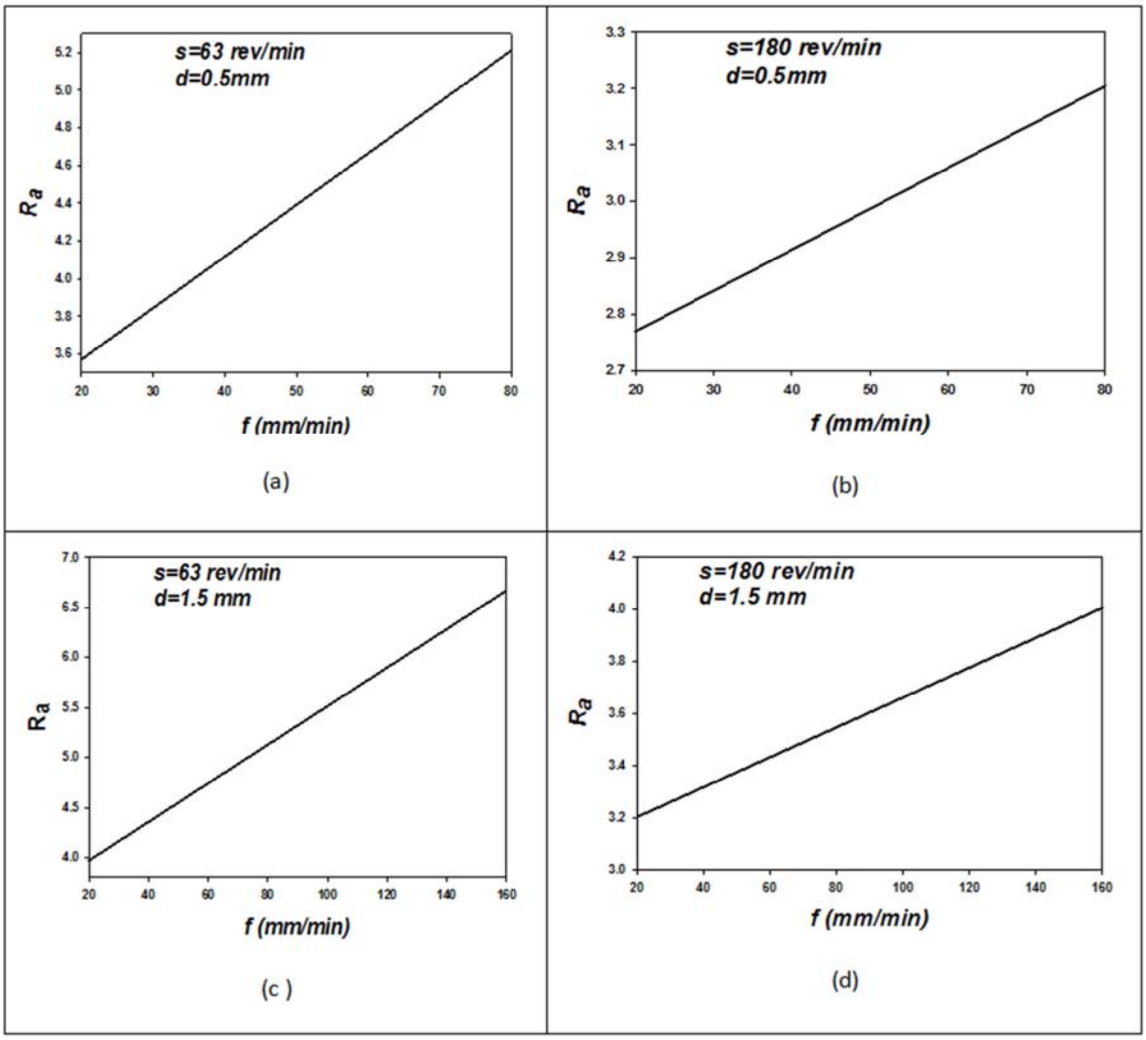


Figure 5. *Comparison of measured surface roughness behavior for specimens machined on vertical milling at different feed rates.*

4. Mathematical Modeling

The following equation has been derived using 2^3 factorial approach.

Equation for vertical milling machine:

$$\mu = 0.3930 - 0.0002D - 0.0128F + 0.0059S + 0.0035DF + 0.0044DS - 0.0104FS + 0.0036DFS \quad (1)$$

where

$$D = \frac{d - \left(\frac{d_1 + d_2}{2}\right)}{\left(\frac{d_2 - d_1}{2}\right)}, F = \frac{f - \left(\frac{f_1 + f_2}{2}\right)}{\left(\frac{f_2 - f_1}{2}\right)},$$

$$S = \frac{s - \left(\frac{s_1 + s_2}{2}\right)}{\left(\frac{s_2 - s_1}{2}\right)}$$

s_1, f_1, d_1 are the minimum values of cutting speed, feed and depth of cut used in this paper.

s_2, f_2, d_2 are the maximum values of cutting speed, feed and depth of cut used in this paper.

It can be seen that the magnitude of the coefficient of F is greater than those of D and S. This reconfirms the dominance of fed rate over the other two machining parameters.

5. Effect of Feed Rate on Coefficient of Static Friction

The effect of surface roughness and hence, milling machine cutting parameters on dry firction behavior, the coefficient of dry friction (μ) is measured for each specimen using inclined plane. Figures 6(a) through (d) compare the values ofdry friction (μ) at two different feed rates for four combinations of depth of cut and spindle speed. It is clear from these figures that increase in feed rate the coefficient of friction decreases rapidily. Also, the value of dry friction (μ) is found to decrease slightly with increase in depth of cut.whereas, the value of dry friction is found to increase with increasing spindle speed.

These observations clearly indicate the dependence of static friction on surface roughness.Therefore, it may be concluded that static friction increases as the surface becomes smoother under the present conditions. This is in agreement with the adhesion theory of friction which states that adhesion occurs between the contacting surfaces leading to the formation of cold welded junctions at the asperity tips. Friction is the force required to shear these junctions and initiate sliding. That is why, it is a popular belief that if the surfaces are perfectly smooth, adhesion will be the strongest and hence, firction will be maximum.

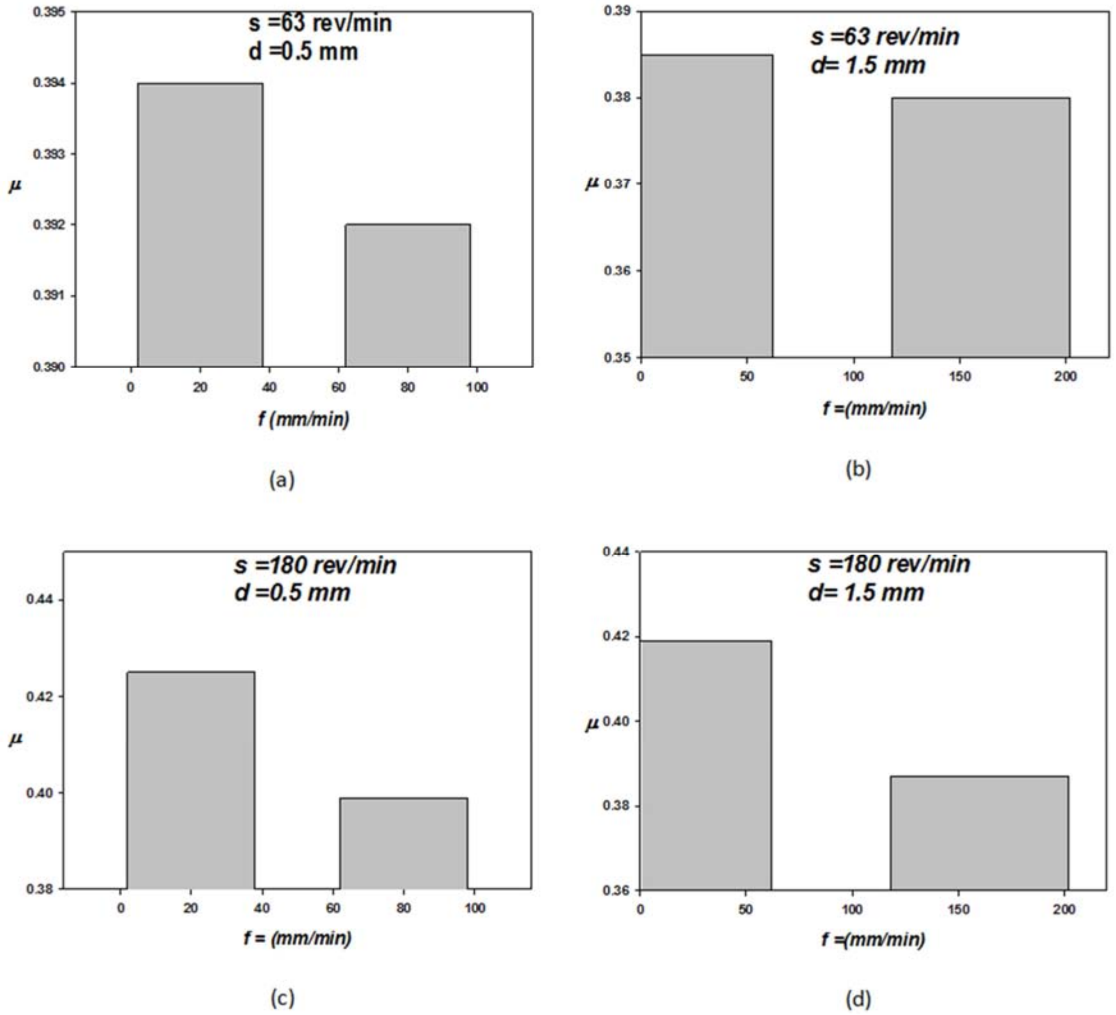


Figure 6. *Comparison of measured friction behavior for specimens machined on milling at different feed rates.*

6. Conclusions

Mild steel specimens are machined on a vertical milling machine with different values of machining parameters and surface roughness is measured using stylus profile meter. The measured R_a value is found to increase with increase in feed rate and depth of cut, whereas, a decrease is observed with increasing spindle speed. Furthermore, the coefficient of static friction is measured on steel substrate using inclined plane method. These measurements clearly show a strong negative correlation between the coefficient of friction and R_a values for all the cases considered herein. Using 2^3 factorial methods, the coefficient of friction is expressed as a function of feed, speed and depth of cut so as to demonstrate that static friction can be predicted or controlled within specific limits subject to the constraints imposed by the material properties. On the basis of other experimental work and my experimental work, the decision has taken that feed rate have pronounced effect on surface roughness and coefficient of static friction.

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