

# Influence of Feed Motion on Surface Friction of AISI 1045 Steel Machined by a Fine-Grinding Process


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## ABSTRACT

Fine-grinding is a final machining method used to reach the low friction and high-quality surface. The workspeed ( $v_w$ ) and crossfeed ( $v_c$ ) motions are perpendicular to each other and differ in value during the grinding process. Thus, the surface quality in workspeed and crossfeed direction is not the same and leads to the anisotropy of friction in the working surface. This paper presents the results of the study on the direct effect of grinding parameters on anisotropic surface friction of AISI 1045 Steel. The research was performed on the UCETR- UMT multifunctional test system, and the experimental samples were ground under the workspeed of 15,4; 19,2, and 23 m/min, respectively, and crossfeed of 0.3 m/min. The research results show that the experimental coefficient is 7 to 17% larger than the calculated friction coefficient. The experimental friction force consists of 2 components:  $\vec{F}_x$  is friction force according to the measuring motion direction,  $\vec{F}_y$  is the perpendicular anisotropic friction force  $\vec{F}_x$ . Total friction ( $\vec{F}_x + \vec{F}_y$ ) changes 8-18% in the workspeed direction and 15-23% in the crossfeed direction in the experimental region. The value of the anisotropic friction force  $F_y$  varied from 0.78% to 41% compared to  $F_x$ . Therefore, the anisotropy friction can be expressed by the angle  $\alpha_{ani} = \arctg F_y / F_x$ , which depends on the direction of motion during the grinding and the grinding parameters.

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## 1. INTRODUCTION

Surface friction force and friction coefficient, in particular, directly have a serious effect on the performance of moving parts in machine tools and the quality of machining surface. The study to determine the relationship between the cutting parameters of the machining method to the quality surface has gained a lot of attention. The study

aims to determine the relationship between the cutting parameters of the machining method to the quality surface. The problem is gained much research attempt in the literature, such as the machining cutting parameters have a significant impact on surface roughness [1-4] revealed through the estimated parameters of surface characteristics face. Taranveer Singh's research showed that the type of abrasive material had the

most significant effect on surface roughness, followed by the working speed when cylindrical grinding on AISI 1045 steel[1]. The surface roughness in flat grinding is better than in cylindrical grinding. The value of surface roughness ( $R_a$ ) is  $0.757\text{ }\mu\text{m}$  in cylindrical grinding and  $0.66\text{ }\mu\text{m}$  in a flat surface grinding[2]. The study result of Mukesh Kumar et al. showed the grain size and working speed are the most important factors affecting material removal rate and surface roughness [3]. The results of Niraj Kumar and Punit Kumar have shown  $R_a$  value is increases with an increase in feed rate and depth of cut when convenient [4]. On the other hand, the coefficient of static friction is found to decrease with increasing  $R_a$  values. Currently, various finishing methods have been applied to improve the quality and reduce surface friction are grinding, spraying balls, rolling balls, etc. In particular, fine grinding is the final processing method to achieve machining quality in terms of roughness, tolerance, and accuracy assembly criteria. The fine grinding method can be achieved surface grade 8-9; roughness with maximum height of profile irregularities ( $R_{max}$ )  $R_{max} = 4.7 - 2.4\text{ }\mu\text{m}$ ; the parameters of the roughness distribution curve with height in the range:  $b = 1.6 - 2.3$ ,  $v = 1.8 - 1.6$ ; the average radius of curvature of the undulating peak in the range:  $r = 370 - 550\text{ }\mu\text{m}$ ; and the average of horizontal waves in the range: Height of waveform( $H_b$ )  $H_b = 1.2 - 1.3\text{ }\mu\text{m}$ , wavelength of waveforms( $S_b$ )  $S_b = 750 - 1400\text{ }\mu\text{m}$ ,  $R_b = 15 - 50\text{ }\mu\text{m}$ ,  $S_b/H_b = 100 - 700$ ; the average of longitudinal wave parameters:  $H_b = 1.2 - 12\text{ }\mu\text{m}$ ,  $S_b = 2.4 - 3.5\text{ }\mu\text{m}$ ,  $R_b = 30 - 350\text{ }\mu\text{m}$ ,  $S_b/H_b = 280 - 2900$  [5,6].

Regarding the study on the surface roughness, the grinding inputs - wheel speed, table speed, depth of cut, and the dressing mode have been investigated. K. Pal and V. Shivhare [7] studied the influence of cutting parameters of the surface grinder on the finishing surface and surface hardness of structural steel. They mentioned that the speed and cross-feed have the most significant effect on the surface roughness of grounded EN18 medium carbon steel. Besides, the surface roughness was increase as the value of the speed and crossfeed increase. A.S. Padda et al. [8] studied the effect of the variance of cutting parameters on the surface roughness of stainless steel. They revealed that the quality of grinding surface was the most influential by wheel speed, and the surface roughness can be minimized if the value of grain size and depth of cut can be properly selected.

The combination of shaping movements, including spindle rotation and tool movements [9,10] on a machine tool, produces the part shape with a defined precision. The feed motions are often perpendicular to each other and have different values. Therefore, surface quality, roughness, and top radius of curving undulating in two directions (vertical and horizontal) have different values [9,10]. Q. Chen et al. [11] used characteristic roughness to study the characteristics of anisotropic and isotropic processing surfaces machined by several machining methods. The authors stated that the different machining methods with the same  $R_a$ , the value, and difference  $\tau^*$  (denotes characteristic roughness) of the anisotropic surfaces are reduced in the cases of isotropic surfaces. Thus, the traditional surface roughness parameter ( $R_a$ ) wasn't comprehensively enough to reflect the microscopic morphology characteristics of the surface contour. For anisotropic surfaces, the direct influence of measurement on the  $\tau^*$  was greater for isotropic surfaces.

The relationship between typical geometric parameters of the surface and friction has been studied in both experimental and theoretical investigations. Regarding the theoretical approaches, the mathematical expressions of friction force, or friction coefficient based on material properties, typical geometric parameters [5,6] were formulated. Besides, in the experimental approaches, the effect of typical geometric parameters of the surface on friction is also conducted [4,12]. The typical geometric parameters of the surface change according to the feed motion directions [12] and are directly affected by friction, which is the anisotropy of surface friction. The anisotropy of surface friction causes the occurrence of randomly horizontal vibrations as well as the wear of contacted surfaces. However, the influence of the surface geometry parameters on wear and friction only exists in the running process[6]. Y. Zhou et al. [13] investigated the influence of surface roughness on the friction property of the textured surface on the UMT-3 tribometer with SAE30. The author revealed that the friction coefficient decreases if the surface roughness is decreased at the frequency of 2 Hz. At the frequency of 4 and 6 Hz, the first friction coefficient first decreases, then it increases when decreasing surface roughness. There are areas of the surface roughness in which the best friction is reduced. A. Lenart et al. [14] investigated the effect of the surface texture of steel

disc on friction and fretting wear. They showed that the surface texture has a significant effect on the friction coefficients. And, if ball movements were perpendicular to main disc texture directions, the friction coefficients gain the smallest value.

When studying the effect of roughness height and lay orientation on friction, with different riblet tapes mounted longitudinally and transversely, Yeau -Ren Jeng [15] mentioned that lower roughness height yields lower friction and that transverse roughness have lower friction than longitudinal roughness. Pradeep, Kishore, and Satish [16] studied the effect of roughness parameter and grinding angle on the coefficient of friction if sliding of Al-Mg Alloy over EN8 steel and transfer layer formation. They noticed that the coefficient of friction increases as the grinding angle (the angle between the direction of scratch and grinding marks increases) and the coefficient of friction at grinding angle 90 deg were higher at 0 deg grinding angle.

Most of the above-mentioned studies focus on the effect of machining parameters on surface quality through roughness value and research on the effect of roughness on surface friction. There are few studies on machining parameters affecting surface friction [4]. This paper focuses on research on the direct influence of cutting parameters when grinding on the surface anisotropic friction during the run-in. The study results can be used to control anisotropic surface friction through the choice of the working direction and cutting parameters.

## 2. CALCULATING FRICTION COEFFICIENT

The molecular-mechanical theory of friction [5,6] proposed a model for calculating the coefficient of friction for a pair of friction consist of a hard spherical that slides on a softer surface, with mechanical properties and surface geometry parameters. The coefficient of friction of the friction pair, then be calculated by the following formula.

$$f = \left( \frac{\sqrt{\pi}}{2^{1/2\nu} \cdot k_v} \right)^{\frac{2\nu}{2\nu+1}} \times \frac{\tau_0 \Theta^{\frac{2\nu}{2\nu+1}}}{p_c^{\frac{1}{2\nu+1}} \cdot \Delta^{\frac{\nu}{2\nu+1}}} + \beta + 0,19 \cdot K_{vf}^y \cdot \left( \frac{2\sqrt{\pi}}{k_v} \right)^{\frac{1}{2\nu+1}} \cdot \alpha_{hys} \cdot \left( p_c \cdot \Theta \right)^{\frac{1}{2\nu+1}} \cdot \Delta^{\frac{\nu}{2\nu+1}} \quad (1)$$

where:

$\Delta$  - Complex parameter of surface roughness,

$$\Delta = \frac{R_{\max}}{r \cdot b^{1/\nu}},$$

$b, \nu$  - Parameters of the bearing-area curve,

$\tau_0, \beta$  - Molecular bond shear strength parameters of materials,

$\Theta$  - Elastic constant of material,

$p_c$  - Actual pressure,

$\alpha_{hys}$  - Hysteresis loss factor during sliding,

$K_v, K_{vf}^{dh}$  - Coefficients as a function of the parameter  $\nu$ .

The coefficient of friction calculated for AISI 1045 Steel has the following basic specifications [5,6]:

$$\tau_0 = 20.39 \text{ kG} / \text{mm}^2, \beta = 0.044$$

$$\Theta = \frac{1 - \mu^2}{E}$$

where:

$$\mu = 0.27 - 0.3,$$

$$E = 2.1 \cdot 10^4 \text{ N/mm}^2$$

$$\alpha_{hys} = 2.5\alpha; \alpha = 0.02$$

AISI 1045 Steel has machined by surface grinding method, achieves the following surface geometry parameters [5,6]: (surface roughness class 9).

$$R_{\max} = 2.4 \text{ } \mu\text{m}, r = 550 \text{ } \mu\text{m};$$

$$\Delta = 2.64 \cdot 10^{-3}, \nu = 1.6, b = 2.3;$$

$$p_c = N/A_c = 1341.9 \text{ kgf/cm}^2$$

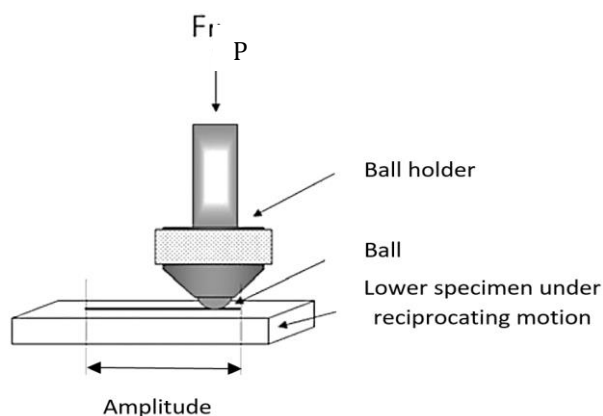
$$K_v = 0.65; K_{vf}^{dh} = 0.85 [5].$$

Plug the parameters into the formula (1), and We have  $f = 0.232$ .

## 3. METHOD AND EXPERIMENTAL EQUIPMENT SYSTEM

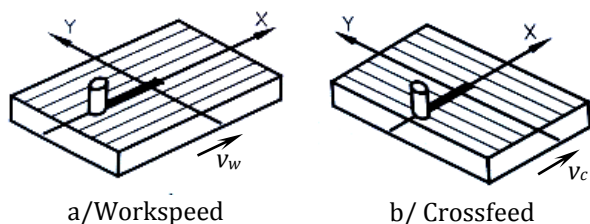
### 3.1 Principle of measuring friction force

Diagram of the principle of measuring friction force on UMT machine using a ball-on-flat configuration according to the ASTM G 133 standard test method [17] which is shown schematically in Figure 1.



**Fig 1.** Diagram of the principle of measuring friction force

A constant load was applied normally to the ball holder on the flat lower specimen under reciprocating motion. The anisotropic frictional force will appear when there is a friction interaction of the ball and the rough surface of AISI 1045 Steel. Measuring the anisotropic friction force in the two directions of feed motion: workspeed and crossfeed, as shown in Fig 2.

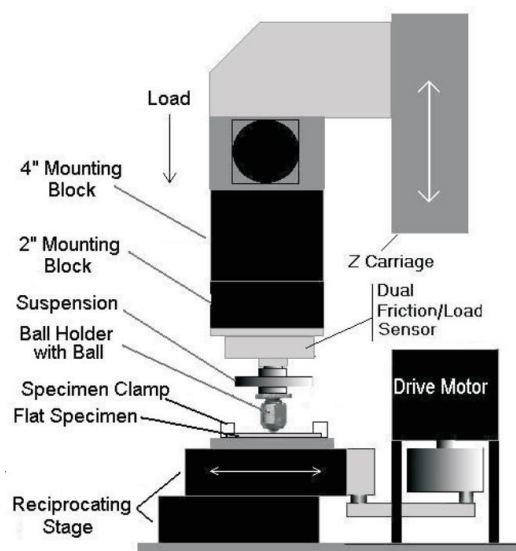


**Fig 2.** Diagram of measurement in the directions of feed motion

### 3.2 Experimental equipment system

The frictional tests were conducted a CETR-UMT multifunctional test system, which is shown in Figure 3.

This apparatus was equipped with a loading range from 10 N to 1 kN, linear reciprocating velocity from 0.1 mm/s to 50 m/s, and spindle speed from 0.001 to 10000 r/min. Tests were performed in ambient air at 22°C and 50% relative humidity. The reciprocating motion is driven by a servo motor. A constant load of 20 N was applied normally to the upper specimen during all of the tests, and the friction generated in the direction of movement was measured by an x-force sensor. The upper specimen was made of P20. The friction test condition is shown in Table 1.



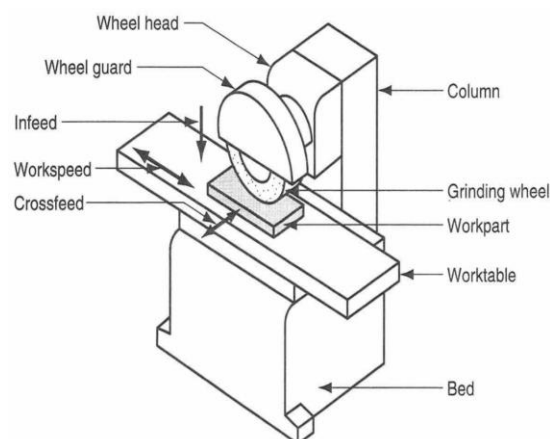
**Fig 3.** CETR-UMT multifunctional test system

**Table 1.** Friction test conditions.

No	Parameters	Value
1	Upper specimen	P20
2	Lower specimen	AISI 1045 STEEL
3	Load P (N)	20
4	Reciprocating frequency (Hz)	3
5	Time (s)	300
6	Amplitude(mm)	10
7	Lubricant	No
8	Temperature	22°C

### 3.3 The lower specimen

The lower specimen is made from AISI 1045 Steel with dimensions of 50x30x10 mm; it is fine grinding with the parameters, as shown in Table 2. The schematic diagram of the surface grinding of the lower specimen with longitudinal and cross feed is shown in Figure 4.



**Fig 4.** The principle of surface grinding on Grinding machine 3E 711B

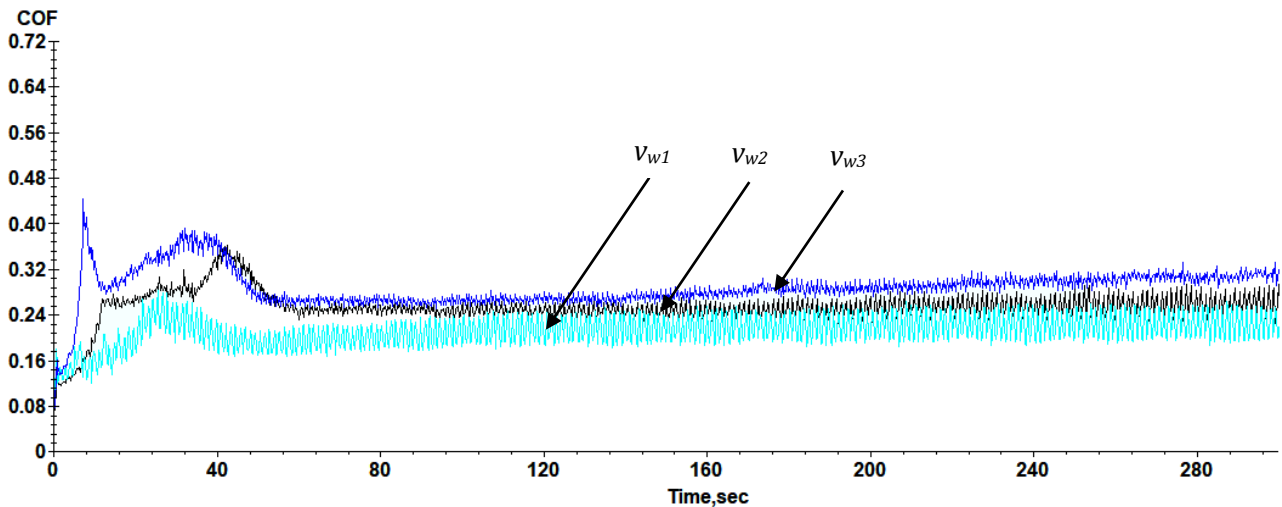
**Table 2:** Parameters of the fine grinding process

No	Parameters	Symbol	Value
1	Grinding machine	3E 711B	
2	Grinding wheel	Ct 60 – TB1G, V.250.40.75	
3	Wheel speed(m/s)	$V$	35
4	Depth of cut (mm)	$d$	0.03
5	Cross feed (m/min)	$v_c$	0.3
6	Workspeed (m/min)	$v_w$	$v_{w1}=15.4,$ $v_{w2} = 19.2,$ $v_{w3} = 23$

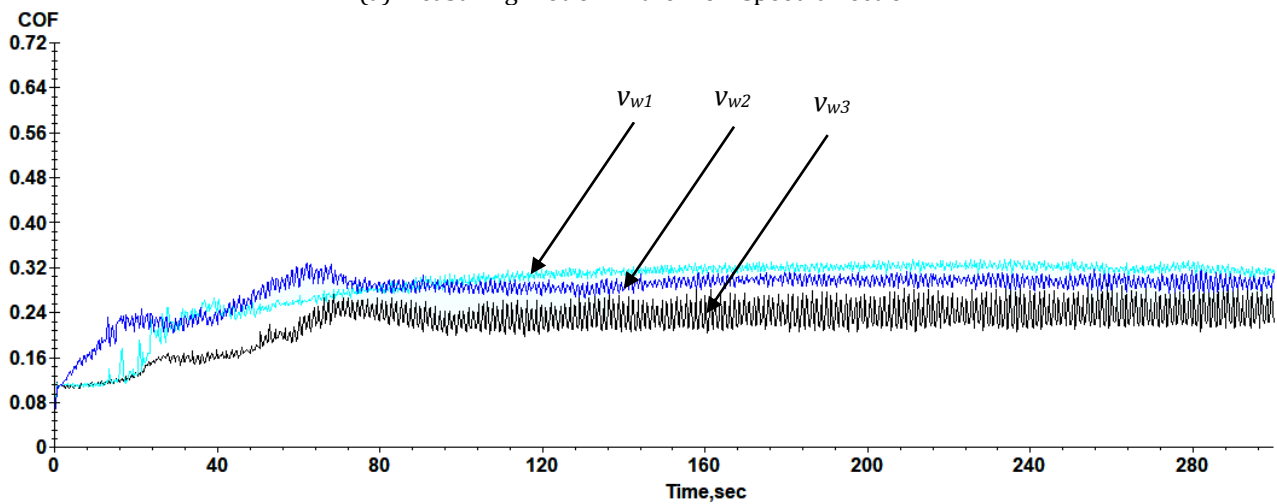
## 4. RESULTS AND DISCUSSION

### 4.1 Friction coefficient determined from experiment

Figure 5. shows that the results of measuring the surface friction coefficient of AISI 1045 Steel after fine grinding with three different feed motions: (a) Measuring motion in the workspeed direction and (b) Measuring motion in the crossfeed direction.



(a) Measuring motion in the workspeed direction



(b) Measuring motion in the crossfeed direction.

**Fig 5.** The coefficient of AISI 1045 Steel after fine grinding with different feed motion

Thus, the coefficient of friction on the surface of AISI 1045 Steel after fine grinding has different behaviors, depending on the workspeed and the direction of measurement motion. The average value of the friction coefficient of the above-mentioned cases is shown in Table 3.

**Table 3:** Average coefficient of friction of the lower specimen in the workspeed and crossfeed direction

No	friction coefficient	Workspeed (m/min)			Average value
		15.4	19.2	23	
1	$f_w$	0.215	0.251	0.283	0.249
2	$f_c$	0.309	0.237	0.293	0.279

It can be seen from Figure 5 and Table 3 that there is a clear difference between the values of the friction coefficient in the workspeed and crossfeed directions, which can be explained by the surface shaping motion, workspeed, and crossfeed that are always different in directions and values. When workspeed increases, the coefficient of friction increases. In other words, the increase in machining productivity leads to an increase in the coefficient of friction. Therefore, to minimize the surface friction coefficient, improve the performance of the part, it is necessary to pay attention to the movement direction when working in line with the workspeed direction as well as the value of feed motion when machining.

The method of calculating the coefficient of friction in theory [5,6], without taking into account the influence of the measured motion direction compared to feed motion direction, can be determined  $f = 0.232$ . The experimental mean of the coefficient of friction with 3 workspeed changes  $\bar{f}_w = 0.249$  and  $\bar{f}_c = 0.279$ . Thus, the theoretical value of the coefficient of friction is less 7% than the experiment value of the coefficient according to the workspeed direction. The theoretical value of the coefficient of friction is less

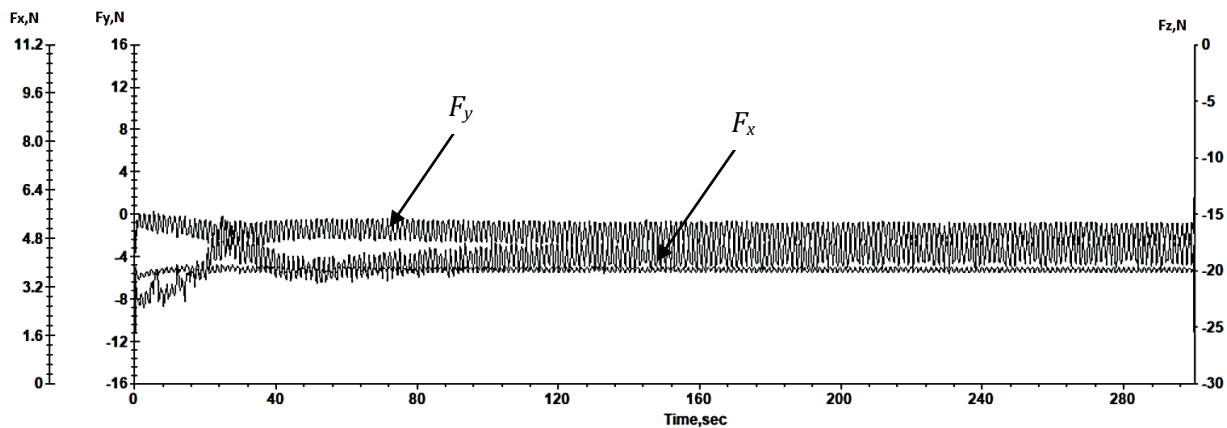
17% than the experiment value of the coefficient according to the crossfeed. In other words, the obtained friction coefficient changed from 1.07 to 1.2 times compared to the calculation.

It is considering the change in the amount of vertical feed motion when fine grinding: In the workspeed direction  $f_w = 0.92$  to  $1.2f$ ; In the crossfeed approach  $f_c = 1.01$  to  $1.32f$ . This shows that the surface friction coefficient is significantly influenced by the direction of feed motion, the machining mode, and the selection of direction and cutting parameters that can minimize actual friction on the surface.

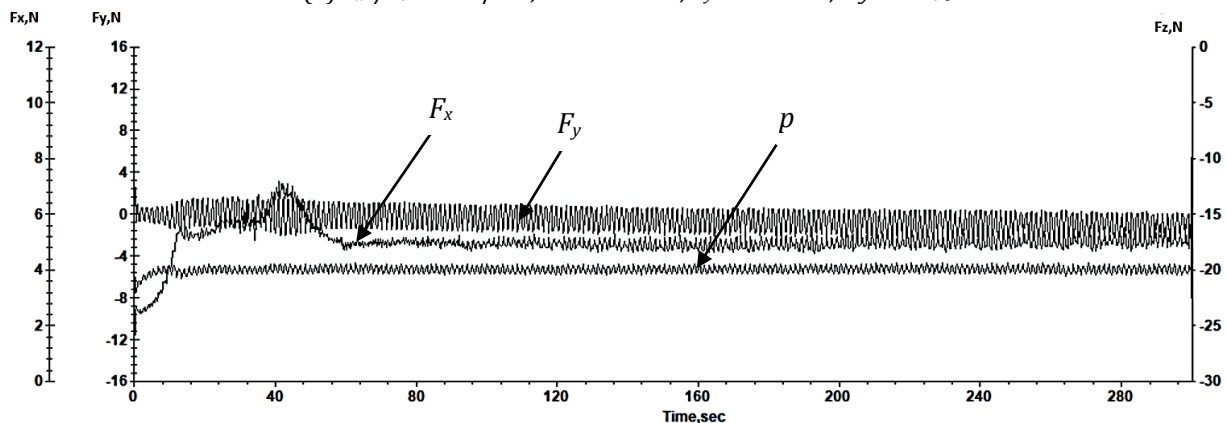
## 4.2 Effect of feed motion on surface friction

### 4.2.1 Experimental friction force in the workspeed direction

In the case of  $v_{w1}=15.4$  m/min,  $v_c=0.3$ m/min,  $v_{w1}/v_c=15.4/0.3$ . The friction force measurement result is performed in Figure 6a. Friction force consists of two components:  $F_x$ , along with the measured motion, and  $F_y$  is perpendicular to the measuring motion.  $F_x = 4.268$  N,  $F_y = 1.744$  N.

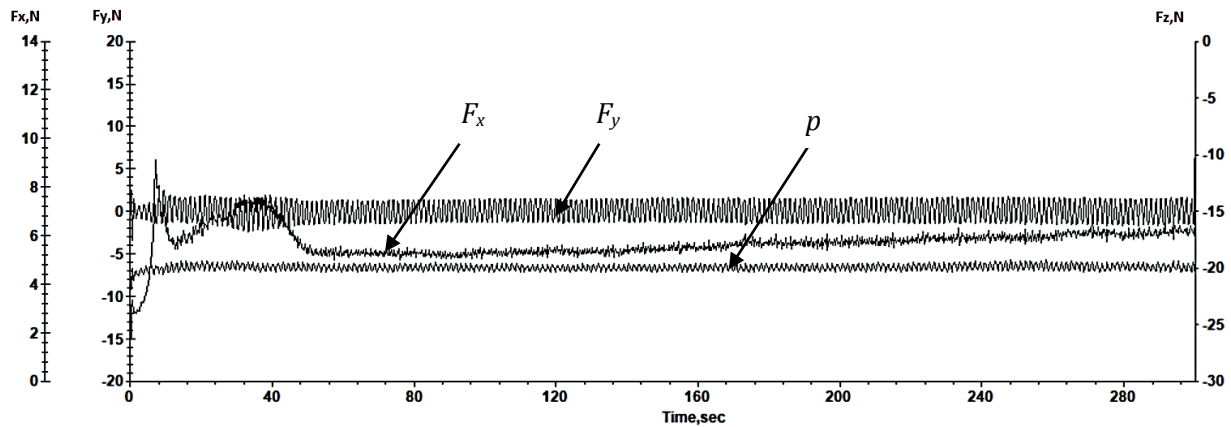


(a)  $v_{w1}/v_c = 15.4/0.3$ ;  $F_x = 4.268$  N,  $F_y = 1.744$  N;  $F_y \approx 41\% F_x$



(b)  $v_{w2}/v_c = 19.2/0.3$ ;  $F_x = 4.962$  N,  $F_y = 0.653$  N,  $F_y \approx 13\% F_x$





(c)  $v_{w3}/v_c = 15.4/0.3 = 23/0.3$ ;  $F_x = 5.64$  N;  $F_y = 0.08$  N;  $F_z \approx 1.4\%$   $F_x$

**Fig 6.** The change of friction force according to the workspeed direction,  $F_x$  – Friction force in the direction of the measuring motion;  $F_y$  – Anisotropic friction force, and perpendicular friction force  $F_z$

Variations of the  $F_x$  friction force overtime adhere to a general rule of 3 phases: Preliminary displacement, breakaway, and sliding [5,6]. A friction component  $F_y$  emerges, perpendiculars to the measuring motion X (coinciding with the crossfeed), oscillation, and  $F_y \sim 41\%$   $F_x$ .

Same for the two remaining cases:  $v_{w1}/v_c = 19.2/0.3$  (Figure 6. b) and  $v_{w1}/v_c = 23/0.3$  (Figure 6. c). In all three cases, there is friction in both X and Y directions while the lower specimen is moving only in X. Thus, there is the existence of anisotropic friction of  $F_y$  on the surface; the value is synthesized in Table 4.

**Table 4:** Friction force values  $F_x$  and  $F_y$  when measured motion in the workspeed direction

No	Friction force (N)	Workspeed (m/min)			Average value
		15.4	19.2	23	
1	$F_x$	4.268	4.962	5.64	4.96
2	$F_y$	1.744	0.653	0.077	0.825
3	$F_T = \sqrt{F_x^2 + F_y^2}$	4.61	5.0	5.64	5.09

Figure 6 and Table 4 show that when the workspeed increases from 15.4 m/min to 23 m/min, the friction force  $F_x$  increases from 16.3% - 32.1% but the anisotropic friction force  $F_y$  decreases from 62.6% - 95.6%. This shows that the ratio of the amount of the workspeed and crossfeed increases, the friction force increases; however, the anisotropic friction decreases, which means increase steadily in the direction perpendicular to the east motion and reduce horizontal vibration.

#### 4.2.2 Experimental friction force in the crossfeed direction

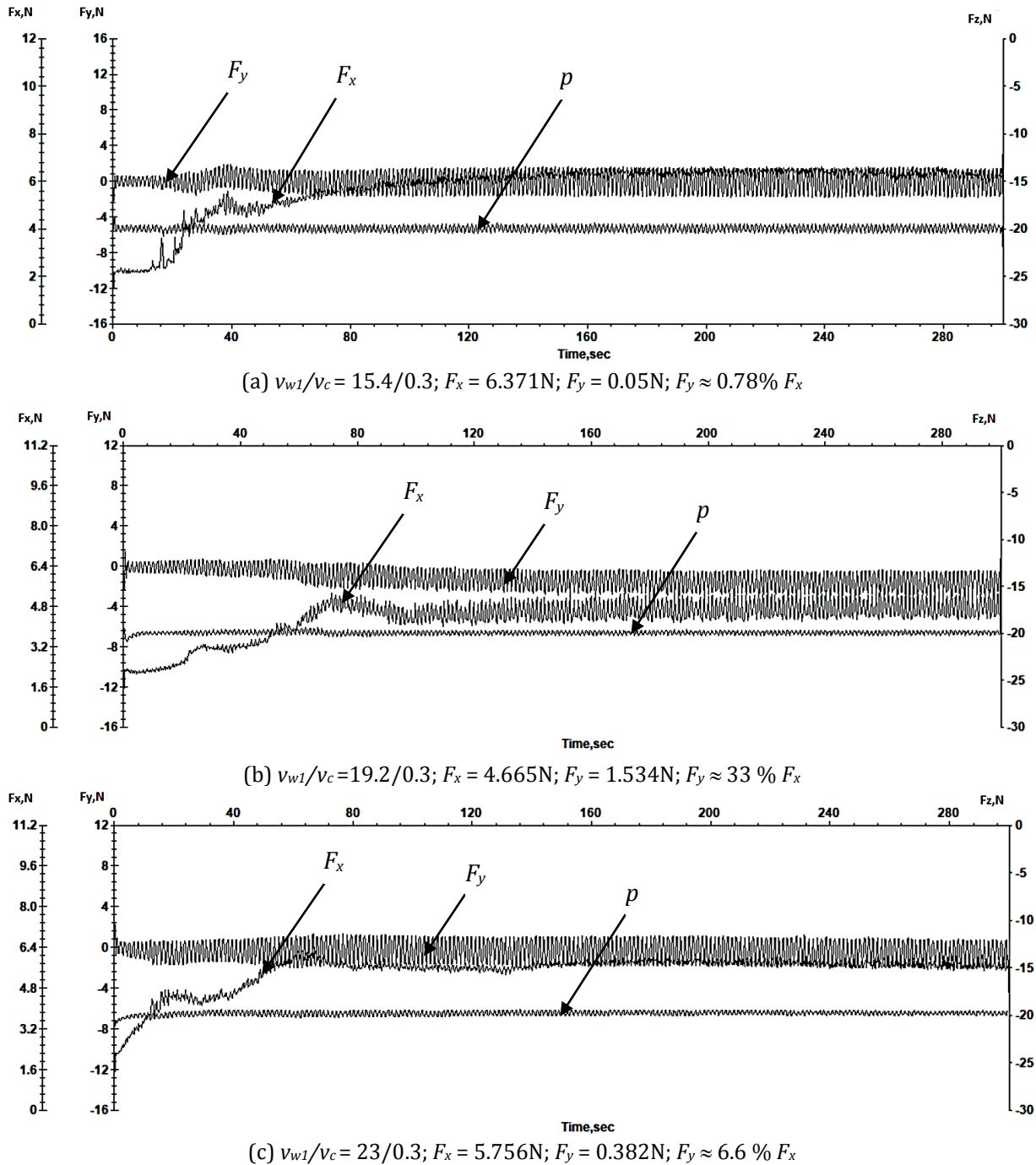
Experimental measurement of surface friction force in the direction of crossfeed motion with 3 cases. Case  $v_{w1}/v_c = 15.4/0.3$ . The results shown in Figure 7.a show that the friction force consists of two components:  $F_x$ , along with the measured motion (crossfeed direction) and  $F_y$  (workspeed direction).  $F_x = 6.371$  N,  $F_y = 0.05$  N; variation in friction force  $F_x$  over time follows the general principle; There is an anisotropic friction force  $F_y$  ( $F_y$  is perpendicular to the X measurement motion but coincides with the workspeed). The value of  $F_y$  fluctuates and is quite small compared to  $F_x$ ,  $F_y = 0.78\%$   $F_x$ .

Similar to the cases where  $v_{w1}/v_c = 19.2/0.3$  and  $v_{w1}/v_c = 23/0.3$  experimental results are shown in Figures 7.b and 7.c.

The measurement results in Figure 7 a, b, c shows the appearance of anisotropic surface friction force  $F_y$ . In the case of a crossfeed, the anisotropic friction force value  $F_y$  is quite small, ranging from 0.78% to 32.9%  $F_x$  as shown in Table 5.

**Table 5:** Friction forces  $F_x$  and  $F_y$  when measured in the crossfeed direction

No	friction force (N)	Workspeed (m/min)			Average value
		15.4	19.2	23	
1	$F_x$	6.371	4.665	5.756	5.597
2	$F_y$	0.05	1.534	0.382	0.655
3	$F_T = \sqrt{F_x^2 + F_y^2}$	6.371	4.91	5.769	5.683



**Fig 7.** The change of friction force according to the crossfeed

When the X-measurement motion coincides with the crossfeed, the friction force still varies with the amount of the workspeed. Friction force in the direction of motion measures  $F_x$  at  $v_{w2}$  by 73% at  $v_{w1}$  and 81% at  $v_{w3}$ . The total friction force  $F_y$  at  $v_{w2}$  is 77%  $v_{w1}$  and 85% at  $v_{w3}$ . Anisotropic friction value  $F_y$  at  $v_2$  is the largest and equal to 30%  $F_x$ . Thus, there exists a set of processing parameters so that the total surface friction is smaller than other regions, but the anisotropic friction has a significant value. This

sometimes causes horizontal oscillations that are perpendicular to the movement, wear surfaces that limit horizontal movement.

Thus, the direction of metal peeling on the surface when grinding depends on the workspeed and crossfeed, and it affects the isotropy of the machined surface geometry. This is the cause of the anisotropic friction of the surface. This anisotropy exists only in the run-in process and is affected by the machined

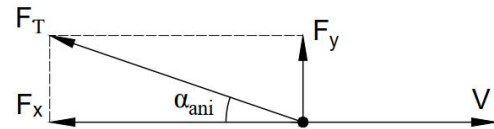


surface geometry. After the run-in process, the secondary surface geometry is formed and stabilized, the working parameters and material properties determine it. Thus, the research results are consistent with the process of changing surface geometry during the run-in process[5,6].

#### 4.3 The characteristic of anisotropic friction

The movement of the lower specimen with velocity under the effect of the load  $P$  was considered, as shown in the experiment shown in Figure 8. There is a friction of the  $F_T$  deviation from the motion with a velocity of an angle  $\alpha_{ani}$  ( $\tan \alpha_{ani} = \frac{F_y}{F_x}$ ). The angle  $\alpha_{ani}$  then

considered as the characteristic of the anisotropic angle of surface friction, calculated by the ratio of the anisotropic friction force perpendicular to the direction of motion  $F_y$  and the force of friction in the direction of motion  $F_x$ .



**Fig 8.** Anisotropic characteristic of surface friction  $\alpha_{ani}$

The characteristic of the anisotropic of surface friction  $\alpha_{ani}$  of AISI 1045 Steel after fine grinding is shown in Table 6

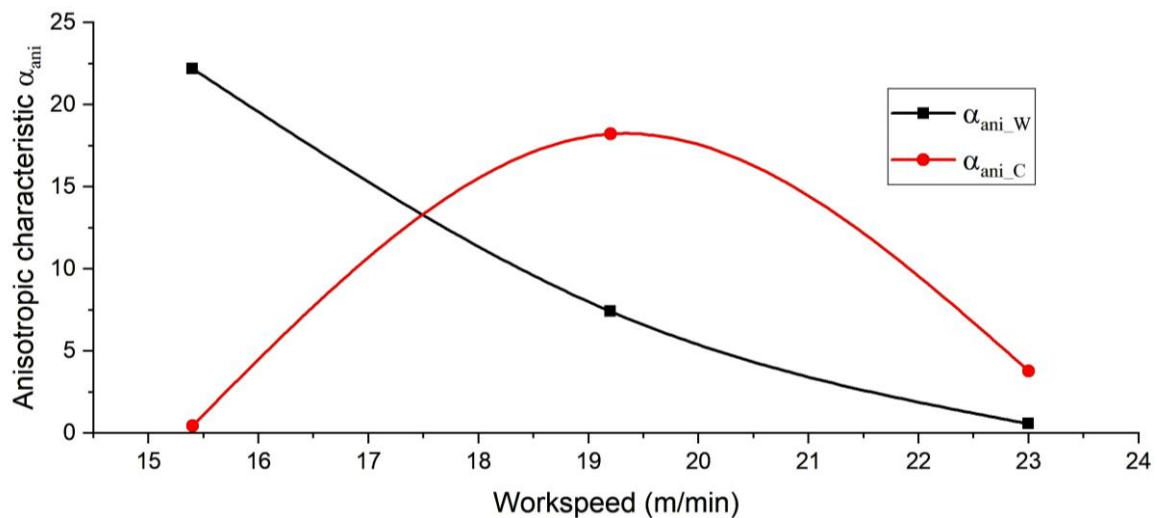
**Table 6:** Anisotropic characteristic  $\alpha_{ani}$  of surface friction in two directions of feed motion when fine grinding AISI 1045 steel

$\alpha_{ani}$	$v_w/v_c$ (m/min)		
	15.4/0.3	19.2/0.3	23/0.3
$\alpha_{ani\_W}$	22.2°	7.41°	0.57°
$\alpha_{ani\_C}$	0.45°	18.22°	3.78°

where

$\alpha_{ani\_W}$ : Angle anisotropic angle when the motion is measured in the workspeed direction

$\alpha_{ani\_C}$ : Angle anisotropic angle when the motion is measured in the crossfeed direction.



**Fig 9.** Anisotropic properties of surface friction  $\alpha_{ani}$  in two feed motion directions

It can be seen from Figure 9 that characteristic of the anisotropic of surface friction when the amount of feed motion change. The motion is measured in the workspeed direction; the anisotropic characteristic  $\alpha_{ani}$  decreases from 22° to 1° when the amount of feed motion is increased. The motion is measured in the crossfeed direction; The anisotropic characteristic  $\alpha_{ani}$  has high nonlinearity, and the maximum value is 18° at  $v_w = 19.2$  m/min.

Therefore, in order to reduce the anisotropic properties of surface friction  $\alpha_{ani}$  in both directions of the feed motion, it is necessary to increase the value of the workspeed or to increase the  $v_w/v_c$  ratio. This result has been demonstrated that machining parameters could control the surface friction, which is similar to the study result [4].

#### 4. CONCLUSIONS

The effect of feed motion on surface friction of AISI 1045 Steel after grinding has been studied on the CETR-UMT multifunctional test system. The results of the calculation and experiment show the existence of the anisotropic friction on the steel surface after a fine grinding process, and the friction depends on the feed motion and the direction of measurement motion. The results are summarized in the following points:

1. The friction coefficient values of the calculation and the experiments are the difference about 7% in the direction of workspeed motion and about 17% in the crossfeed motion direction. The friction coefficient and the anisotropy was measured in the run-in process.
2. The experiment result shows that in the run – in the total friction force is in a range of 8-18% if the measuring motion is along with the workspeed direction, and it is from 15% to 23% if the measuring motion is along with the crossfeed direction. At the same time, the anisotropic friction force  $F_y$  varies from 0.78% to 41% of the friction force  $F_x$ .
3. The anisotropic properties  $\alpha_{ani}$  of friction in the run-in depend on the direction of movement and cutting parameter. Thus, the anisotropic properties  $\alpha_{ani}$  can be controlled through the feed motion direction and the suitable cutting parameters.
4. The anisotropic friction in the run-in will cause the instability of the part in the direction perpendicular to the motion, causing the vibration and wear of the work-parts. Thus, in industrial practice, choosing the working direction to coincide with the workspeed direction when grinding will lead to a stable running process and reduce vibration

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