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Research Paper

An experimentally studying on effects of ultrasonic vibration on the friction for a pair of high speed steel and aluminum alloy

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ABSTRACT: *This paper presents experimental studying effects of ultrasonic vibration on the friction for a pair of high speed steel and aluminum alloy. The experimental system was implemented; the sliding speed, normal force and friction force were collected throughout the implementation. Experimental results revealed that the coefficient of sliding friction almost depends on the sliding speed. The higher the sliding speed gets, the lower the coefficient of friction is, both in with and without vibration. The greater the sliding speed, the greater the reduction in coefficient of friction. Friction coefficient with ultrasonic vibration assisted is significantly reduced comparing to that without ultrasonic vibration. These results can be used in ultrasonic assisted machining processes.*

KEYWORDS: *Friction, Ultrasonic assisted, Friction coefficient, Sliding friction.*

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I. INTRODUCTION

Generally, the friction coefficient plays an important role in engineering. It is well known, the friction impedes relative motion between contacting surfaces, thus causing energy loss due to heat generation, and phenomenon wear [1]… In many ultrasonic applications, such as in machining or in transmission by ultrasonic motors, reducing friction is beneficial. However, increased friction is a beneficial effect in another application, such as ultrasonic welding, also known as friction welding. Studies on the friction effect have been interested by many researchers with different approaches. The previous studies showed that, friction force can be greatly reduced by adding an ultrasonic vibration to the relative motion between two contact surfaces in different directions, longitudinal vibration (i.e. parallel with motion direction) and transverse vibration (i.e. perpendicular with motion direction).

The influence on sliding friction of ultrasonic vibration both parallel and perpendicular to the sliding direction has been studied by mathematics model and experiments [1]. But the defect of [1] is at high contact pressures, in the contact region where significant metallic transfer occurs from the softer material to the harder, those models are less accurate in predicting the friction. H. Storck et al [2] using a theoretical approach based on Coulomb's friction law described macroscopic friction reduction observed in ultrasonic applications. The model then was confirmed by experiments either perpendicular or parallel to a macroscopic motion. In [3], a model of friction contact with two degrees of freedom is adopted, considering non-linear normal contact flexibility of rough surfaces acting on each other. The results proved that, if normal contact micro-vibrations present, the major cause of the reduction of the friction force is due to certain dynamic processes taking place within the contact region. This reduction is not due to lower values of the friction coefficient, nor lower mean values of the normal reaction and real contact area. J Qu and P.J. Blau [4] developed a model using thermal drilling (or friction drilling). Advantage of this model is represented for material plastic flow in terms of the yield in shear rather than the yield in compression. Leus, M. and P. Gutowski [5] using Coulomb and Dahl model taking into account tangential contact deformability analyzed longitudinal tangential contact vibration effect of friction. It was showed that the Coulomb friction model is not sufficient to describe the friction force in the case of vibration motion with low amplitude. The numerical calculations conducted using the Dahl model showed that the friction force in sliding motion in the presence of excited longitudinal tangential contact vibration can be decreased without changing the sign of the friction force vector. Eric Vezzoli et al [6] found that, under ultrasonic vibration condition, intermittent contact is the dominant mechanism for the friction. They also found that the phenomenon is systematically dependent on the vibrational amplitude and, frequency, intrinsic friction coefficient, and exploration velocity. And it is independent on the applied normal force and the mechanical properties of the surface.

From different approaches, many models were adopted and developed. This paper presents experimental study effects of ultrasonic vibration on the friction for a pair of high speed cutting steel and aluminum alloy. The results can be applied to cutting process of aluminum alloys using machine tool made of high speed steel (HSS) cutting materials.

II. EXPERIMENTAL SET UP

The experimental scheme is shown in figure 1. The aluminum plate (4) mounted on the three-component force sensor (5) was fixed on the table (6). The slider (3) is attached to ultrasonic conversion (2) which is clamped on head of milling machine. The pressure on the contact surface is regulated by the vertical up-down movement of the table and amplified by an amplifier (8). Displacement sensor LDVT (7), one end fixed to the body, another end moved along the table, was used to determine the relative position between the slide head and the aluminum plate. A DAQ (10) was used to collect the signals from LVDT and force sensor. The three-component force sensor (5) was used to measure normal force (F_n) and friction force (F_f), as shown in figure 1. The ultrasonic wave chosen is parallel the direction of relative sliding motion.

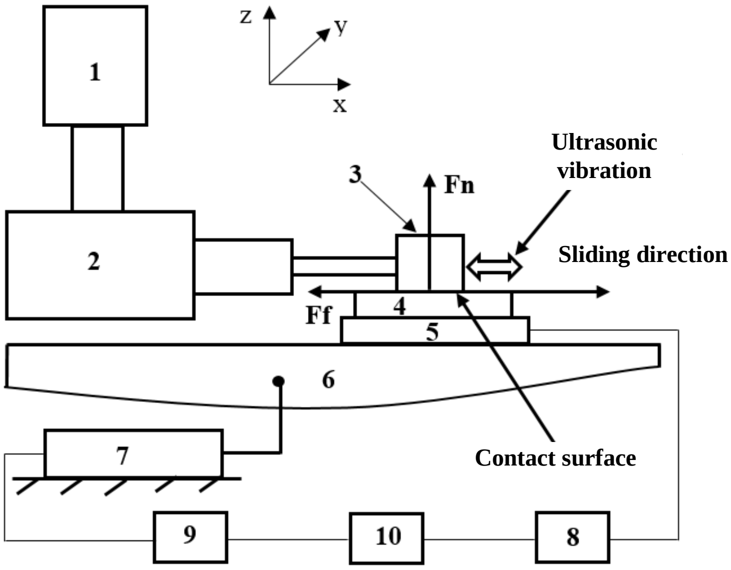

Figure 1: The experimental scheme

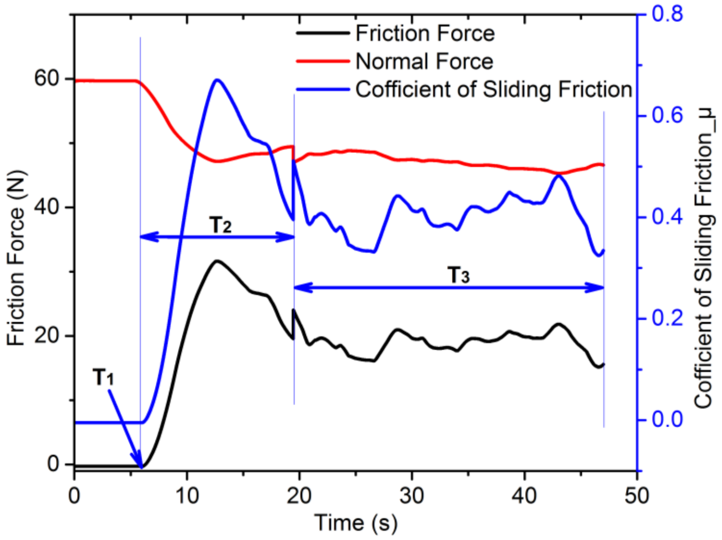

Figure 2: The experimental scheme

The experiment was carried out with two values of normal force, 40 N and 60 N. Assuming the friction obeys Coulomb's law, then:

$$\mu = F_f/F_n \quad (1)$$

Figure 2 shows the typical time histories of friction force F_f and normal force (F_n). The contact process between the two surfaces of the pair of materials is divided into 3 stages as shown in the figure 2. T1 is the time at which there is no displacement, the normal force is adjusted to the survey value and the friction force at this moment is equal to zero. At the stage T2, there is a shift in the value of friction here, which is static frictional magic. The interval T3 is the time when there is relative displacement between the two contact surfaces with a steady sliding velocity. The values of the friction force and the normal force in this moment are taken to calculate the coefficient of friction. Displacement sensor allows determining that the contact range surveyed on all experiments is the same. The graph shows that the value of the normal force decreases compared to the initial time, the cause of this phenomenon is due to the non-parallelism between the sliding slider (3) and the plate (4). Observation of the time histories show that the variation of coefficient of friction divides into three distinct intervals: It gradually increases in the T1 interval, then increases to the maximum value at the T2 interval and tends to be stable for the rest. The influence of the contact surface conditions and properties is responsible for the variation of the coefficient of friction in the range T3.

III. RESULTS AND DISCUSSION

Statistical results are presented in Table 1 and Table 2, in which μ_{mean}, μ_{min}, μ_{max} are the average, minimum and maximum values of the coefficient of friction, respectively. The average value is taken to compare the coefficient of sliding friction between two cases with and without vibration.

Table 1. The coefficient of friction corresponds to the normal force 40 N

Sliding speed (m/s)	With ultrasonic vibration			Without ultrasonic vibration			Ratio reduction of frictional coefficient (%)
	μ_{mean}	μ_{min}	μ_{max}	μ_{mean}	μ_{min}	μ_{max}	
0.0003333	0.27037	0.12859	0.46114	0.60421	0.46697	0.7961	55.25
0.0005333	0.23007	0.11147	0.42212	0.58006	0.42556	0.75981	60.33
0.00075	0.21116	0.10465	0.3648	0.57445	0.42071	0.68576	63.24
0.00115	0.18743	0.09197	0.40084	0.55666	0.383	0.76139	66.32
0.0018	0.15815	0.03964	0.3792	0.53344	0.36769	0.72989	70.35

Table 2. The coefficient of friction corresponds to the normal force 60 N

Sliding speed (m/s)	With ultrasonic vibration			Without ultrasonic vibration			Ratio reduction of frictional coefficient (%)
	μ_{mean}	μ_{min}	μ_{max}	μ_{mean}	μ_{min}	μ_{max}	
0.0003333	0.29494	0.15146	0.42875	0.58866	0.39079	0.74488	49.89
0.0005333	0.23981	0.12631	0.38321	0.56303	0.44348	0.70111	57.40
0.00075	0.21009	0.07632	0.41465	0.55142	0.42346	0.74883	61.90
0.00115	0.16181	0.05505	0.30792	0.5343	0.36649	0.75241	69.71
0.0018	0.14448	0.06451	0.283	0.51376	0.38329	0.70222	71.87

The results, as described on Table 1 and Table 2, shown that the coefficient of sliding friction almost depends on the sliding speed and is independent of the normal force. The higher the sliding speed, the lower the coefficient of friction, both in with and without vibration. Besides, it is clearly shown that, friction coefficient with ultrasonic vibration assisted is significantly reduced comparing to that without ultrasonic vibration. Moreover, the greater the sliding speed, the greater the reduction in coefficient of friction.

Figure 3 and figure 4 illustrate some experimental results of measuring sliding friction coefficient with 02 values of normal force (40 N and 60 N) at 05 different sliding speed values (m/s): 0.0003333, 0.0005333, 0.00075, 0.00115 and 0.0018, respectively. Where, the relationship between the coefficient of sliding friction and the sliding speed is described by the function as below:

$$\mu = a + b*exp\verb|^|(x*c) \quad (2)$$

where x is the sliding speed; a, b and c are the coefficient of freedom [7].

(a) with ultrasonic vibration (b) without ultrasonic vibration

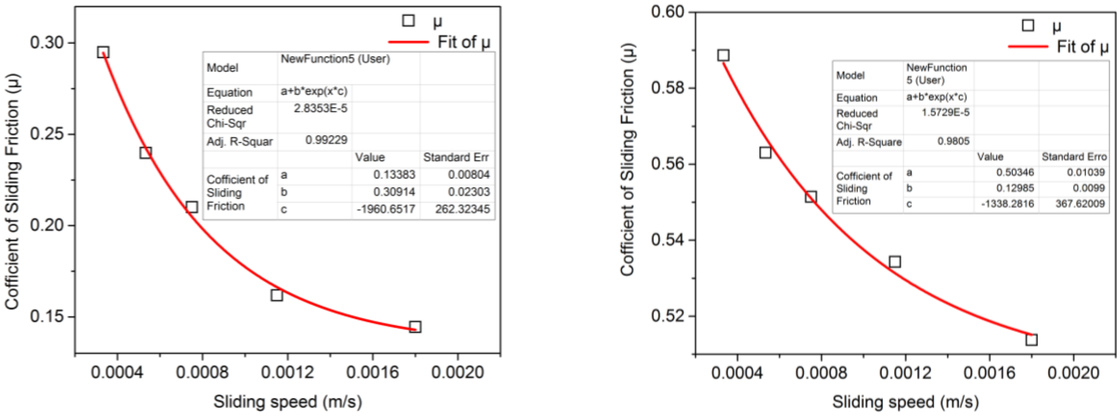

Figure 3: Relationship between coefficient of friction and sliding speed.

(a) with ultrasonic vibration (b) without ultrasonic vibration

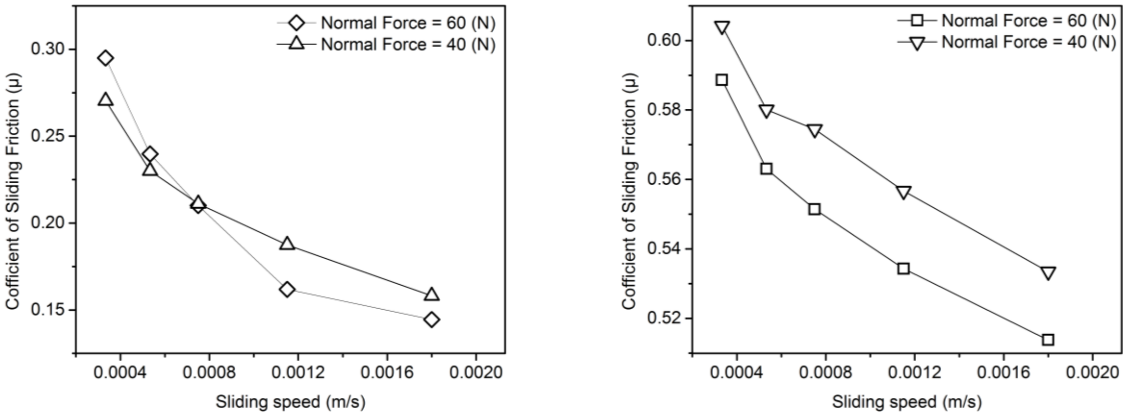

Figure 4: Effect of normal pressure on coefficient of friction

IV. CONLUSION

In this work, experiments were carried out to determine the effects of ultrasonic vibration on sliding friction coefficient and reduction of friction coefficient between aluminum alloy and high speed steel (HSS) cutting materials. Two cases were investigated and compared with each other: with ultrasonic vibration and without ultrasonic vibration. The experimental results revealed that:

- The coefficient of sliding friction almost depends on the sliding speed. The higher the sliding speed gets, the lower the coefficient of friction is, both in with and without vibration. The greater the sliding speed, the greater the reduction in coefficient of friction.

- Friction coefficient with ultrasonic vibration assisted is significantly reduced comparing to that without ultrasonic vibration.

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