Tribology Online
Japanese Society of Tribologists
http://www.tribology.jp/trol/
Vol. 14, No. 5 (2019) 417-421.
ISSN 1881-2198
DOI 10.2474/trol.14.417

Short Communication

Development and Testing of a Modular Lathe Tribometer Tool to Evaluate the Lubricity Aspect of Cutting Fluids on Freshly Cut Surfaces

Suvin Parayantayyathu Somarajan [1)*], Jeng-Haur Horng [1)] and Satish Vasu Kailas [2)]

[1)] Department of Power Mechanical Engineering, National Formosa University, Yunlin 63201, Taiwan
[2)] Department of Mechanical Engineering, Indian Institute of Science, Bangalore 560012, India

*Corresponding author: Suvin Parayantayyathu Somarajan (suvinps@iisc.ac.in)

Manuscript received 26 June 2019; accepted 02 September 2019; published 15 December 2019
Presented at the International Tribology Conference Sendai 2019, 17-21 September, 2019

Abstract

Lubricity of cutting fluids is assessed by (i) Rubbing tests and (ii) Chip generation tests. In a rubbing test, there is very little possibility of exploring the behavior of the fluid on a nascent surface. Any method which aims to assess the lubricity of cutting fluids should be such that it tests the tribological properties on the nascent surface generated by cutting. Conventional tribological equipments like a scratch tester, pin-on-disk apparatus or a four-ball tester may not be successful in satisfying this criterion. A unique tribometer which can perform friction testing on freshly cut surfaces has been developed for experimental investigation. The lathe tribometer is set up that constitutes a cutting tool and a pin setup. The pin is independent of the tool and it is placed just below the cutting tool to ensure proper contact required to measure the component of the forces during the machining operation. The major advantage of the lathe tribometer is that it is portable and it can be used in the real-time machining operation. When the lathe tribometer is fixed on the lathe the spring in the tribometer is compressed against which the normal force is measured. The friction force comes into play when the workpiece is rotated against the tool in contact which is measured by the load cell in position. A cutting fluid (Green cutting fluid) developed in our lab and commercially available cutting fluids (CCF) were used for the experiments. Green cutting fluid (GCF) gave better machining performance in terms of COF and Roughness measurement at the 400 rpm speed (COF and *Ra* of GCF and CCF1 were 2.5/1.07 and 2.7/1.24 respectively). The performance of GCF was reliable and competent with cutting speed change. Thus the observations from the study provide an upshot for analysis, further study, and improvement of tribometer and green cutting fluid.

Keywords

tribometer, cutting fluids, coefficient of friction, surface roughness

1 Introduction

Most of the lubricants, although not all, are liquids. Liquid lubricant designed for processes, such as machining and stamping, is known as cutting fluid (CF) or metal working fluid (MWF). It is a blend of oil, emulsifier, and additives mostly derived from petroleum products. Metal cutting fluids or coolants are used in manufacturing industries to keep the work zone at a stable temperature, to lubricate chip-tool interface and to flush away chips [1]. Several types of cutting fluids are available commercially, which include neat cutting oil, water-soluble cutting fluids, synthetic, and semi- synthetic cutting fluids [2]. There are several economic advantages of using cutting fluids such as: (i) reduction in tool costs as tool life increases by reducing tool wear (ii) increase in production rate as cutting fluids reduce heat and friction between tool and work piece enabling lesser depth of cut or higher speed of cutting (iii) avoiding Built Up Edge (BUE) formation, thus reducing downtime and regrinding of tools, which reduces labor and power costs.

In general, the performance of MWFs is evaluated either by using conventional rubbing tests using tribological equipment or by the chip generation tests using tapping torque, lathe or drilling machine [3]. Rubbing tests are friction tests conducted on any of the conventional tribological equipments, and chip generation tests are tests done with an actual cutting operation. In a rubbing test, there is very little possibility of exploring the behaviour of the fluid on a nascent surface. The most common chip generation test is the lathe test, which uses an instrumented lathe to measure the forces during a cutting operation. These forces are then used to calculate the coefficient of friction based on a model which expresses the coefficient of friction for example, the Merchant circle diagram [4, 5] in terms of the forces measured. The use of such models in assessing friction during metal cutting has been debated [6]. Friction during metal cutting is not restricted to the interactions between the chip and the tool [7, 8]. Schematic representation of Chip flow and forces acting during metal cutting operation is shown in Fig. 1, where F is the frictional force, F_s the shear force, F_c the cutting force, F_t the thrust force, F_n is the normal force to the shear force, R is the resultant force, β is the friction angle and α is the rake angle of the tool associated with machining operations. Here the frictional force is determined indirectly by measuring the cutting force and thrust force during machining, using geometrical or empirical relations. Thus the calculated frictional force can be much different from the actual value.

It can be seen that in a metal cutting operation nascent surfaces get generated and sliding occurs between the newly generated surface against the cutting tool in the presence of a MWFs. The formation of a chemically bound interfacial film on the cut surface is considered to govern the lubricity under cutting conditions. The conventional testing methods limited scope in exploring the behaviour of the fluid on nascent surfaces. It can be seen that most of the previous work the performance of MWF was evaluated by conventional tribological tools.

In order to overcome this difficulty a new equipment called "tool chip tribometer" was used, where the experiments were done by carrying out cutting process inside a tank containing a pool of the cutting fluid and friction force was measured *in-situ* [9]. Here the tool chip tribometer performs sliding tests on freshly cut surfaces generated inside a pool of the metal cutting fluid. The cut track is generated by engaging a knife-edged tool against a rotating disc immersed in the pool, and a separate pin with ball attached to it slides on the cut surface so generated. The friction between this ball pin and the newly reacted layer is found [10]. Few drawbacks of tool chip tribometer is that, it needs special sample preparation (disc, pin etc) and setting time is around an hour for conducting one experiment, further cutting operation is performed with parting tool in submerged condition. But actual machining operation uses single point cutting tool and involves flushing of cutting fluid to the machining zone. The present work demonstrates a new design to evaluate friction on a nascent surface following the same methodology of tool chip tribometer. In this work a portable- modular lathe tribometer is developed overcoming the drawbacks of tool chip tribometer to evaluate the efficiency of cutting fluids in machining. Further, its performance was tested on a highly stable coconut oil based MWF termed as GCF [11] and two commercial cutting fluids CCF1 and CCF2. All these cutting fluids used for testing are oil in water emulsion in the ratio 1: 20.

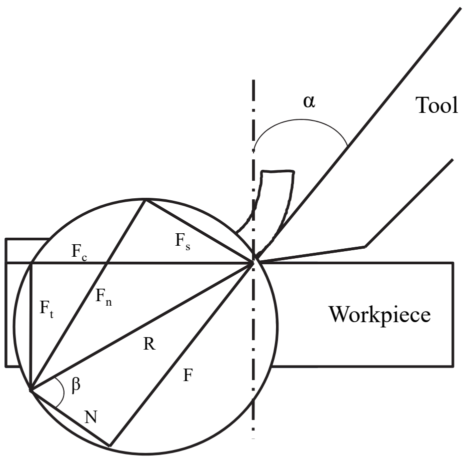


Fig. 1 Schematic representation of chip flow and forces acting during metal cutting operation

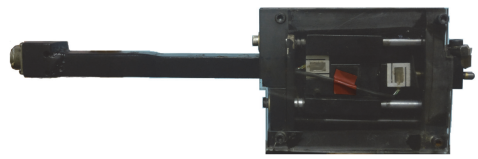
2 Lathe tribometer

A unique tribometer which can perform friction testing on freshly cut surfaces has been developed for experimental investigation. A few drawbacks of tool chip tribometer such as cutting in flooded condition, introducing oblique cutting etc are addressed with the newly developed novel tribometer. Schematic representation of lathe tribometer is given in Fig. 2. In this paper we propose a new lathe tribometer. While this paper illustrates the design and development of Lathe tribometer overcoming the few drawbacks of tool chip tribometer (TCT) [12], it also discusses how the technique can be adopted to measure friction during lathe turning operation.

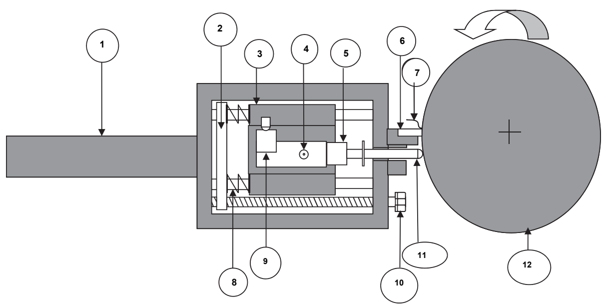
3 Principle of operation and experimental setup

A new method to evaluate the ability of MWFs in forming lubricious layers during metal cutting was designed and developed to result in a new tribological set-up called Lathe Tribometer (LT). This tribometer measures friction *in situ* by means of a pin placed in close proximity to the cutting tool in a lathe and would slide against the new surface generated by the tool. During metal cutting with the MWF supply on, the tangential and normal forces acting on this pin is measured by suitable instrumentation, which are used to evaluate the coefficient of friction.

The tribometer can be fixed to a lathe tool post holder. The surface that needs to be tested is mounted on the chuck of the lathe. A carbide insert tool will cut the material and generate a new surface. The friction measuring pins are made of carbide. The surface profile of the pin (6 mm spherical radius)



(A)



(1) fixed part to be fixed on to lathe tool post, (2) slider for compressing the spring, (3) moving sensor holding part, (4) pivot with bearing, (5) load cell I (LCI), (6) Insert tool, (7) chip flow, (8) Spring, (9) load cell II (LCII), (10) screw, (11) pin and (12) cylindrical specimen/workpiece

(B)

Fig. 2 A) Developed lathe tribometer, B) Schematic diagram of the lathe tribometer rig is machined to form a sphere. The surface thus generated gets rubbed by the pin. The friction between the cut surface and the spherical pin is measured, with the pin positioned 19 mm below the cutting tool insert. The friction pin is mounted on block which is pivoted on bearings and the tractional resistance experienced by the arm due to friction at the pin work piece interface is measured by a load cell [LCII]. The pin can move in and out horizontally. Normal force on the pin-workpiece interface can be applied by adjusting a screw-spring mechanism, which in turn gets measured using another load cell [LCI]. Normal load can be varied from 0 to 50 N.

The location of the pin is not exactly on the axis centre. Therefore, conversion of the measured force to the actual force for normal and frictional force has to be done. Further, this sets a limit to the minimum diameter (75 mm or more) of the workpiece that can be tested with this design. Figure 3 shows the free body diagram of actual forces acting between pin workpiece interface and the calculations to be used in calculating normal force (N) and frictional force (F_f).

Frictional force [F_f]
Normal Force [N]
r = Radius of workpiece (known)
H = distance between tool and pin (known)
Sinθ = H/r; Hence θ also known
F_m will be frictional force measured from load cell II [LCII]
L will be normal force input measured from load cell I [LCI]
Coefficient of Friction $\mu = F_f / N$

$F_L . a = F_m . b$
$F_L = F_m . b/a$
Equilibrium equation
$F_f \cos\theta + F_L - N \sin\theta = 0$ (1)
$F_f \sin\theta - L + N \cos\theta = 0$ (2)

Multiply by Cosθ and Sinθ to the above Eqs. (1) and (2) to get Eqs. (3)-(6).
$F_f \cos^2\theta + F_L \cos\theta - N \sin\theta\cos\theta = 0$ (3)
$F_f \sin^2\theta - L \sin\theta + N \sin\theta\cos\theta = 0$ (4)
Add 3 & 4
$F_f + F_L \cos\theta - L \sin\theta = 0$
Frictional Force [F_f] = $L \sin\theta - [F_m . b/a] \cos\theta$ **(A)**

Similarly,
$F_f \sin\theta\cos\theta + F_L \sin\theta - N \sin^2\theta = 0$ (5)
$-F_f \cos\theta\sin\theta + L \cos\theta - N \cos^2\theta = 0$ (6)
Add 5 & 6
$F_L \sin\theta + L \cos\theta - N = 0$
Normal Force [N] = $[F_m . b/a] \sin\theta + L \cos\theta$ **(B)**

Equations (A) and (B) gives the actual Frictional force and Normal force, In turn we can calculate the coefficient of friction associated with the pin rubbing on the newly generated surface while machining. Specifications of the tribometer and Machining Parameters to evaluate machining performance of cutting fluids are as given in Tables 1 and 2 respectively. To study the performance of lathe tribometer machining test was done for dry, green cutting fluid [GCF] and two commercial cutting fluids [CCF1 and CCF2]. Properties of the cutting fluid/emulsion samples are given in Table 3. The parameters that are measured are (i) the frictional force acting on the pin (ii) the normal force applied. Load cell used in the lathe Tribometer is S type load cell with full bridge (Make: Sensortronics, India, Range: 0-5 kg). The full bridge arrangement makes the system more sensitive. In this type, two strain gauges are used for tension and two for compression. The spring used at the bottom provides restoring force which is normal force. With Newton's third law of motion, this normal force is equal and opposite to the reaction force while in operation. This reaction is measured by the load cell. Another load cell is used to measure the frictional force during the machining operation. The ratio of frictional force to the normal force gives the coefficient of friction. Output from the sensors passes through a low pass filter and a signal conditioner before the analogue to digital (A/D converter) conversion. An Emant 300 data acquisition module then sends this data for display as well as for recording in a PC. Data logging at a rate of ten data points per second was employed. Preliminary experiments were conducted in the test-rig to establish the reliability of the system to perform tribological tests. Calibration done for the two load cells is given in Fig. 4. The load cell was loaded from 1 N to 30 N, in increments. It can be seen that the measured force varies with

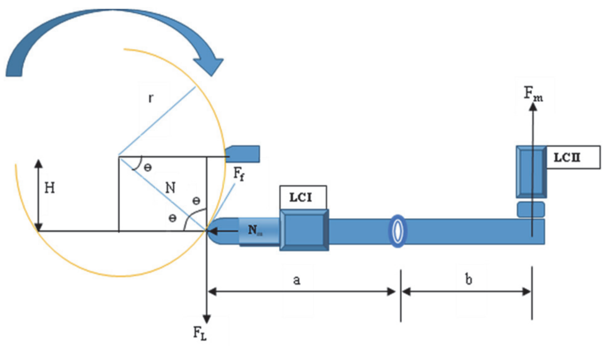


Fig. 3 Free body diagram of forces acting at pin-workpiece interface

Table 1 Specifications of the tribometer

Specifications	**Range**
Normal load	0-50 N
Frictional Force	0-50 N
Radius of pin surface (Spherical)	6 mm
Cutting Tool	Triangular carbide insert
Minimum Work piece diameter	75 mm

Table 2 Machining Parameters to evaluate machining performance of cutting fluids

Insert tool	**Triangular Carbide insert**
Insert Signature	TNMG100508
Workpiece Material	Mild steel (Cylindrical rod)
Workpiece Diameter	120 mm
Workpiece Hardness	Hv 307 for a load of 100 kgf
Cutting speed	5 m/sec
Cutting fluid flow rate	1.2 L/min (Flushing)

Table 3 Properties of cutting fluid samples [10]

Sl NO	Property	Value		
		GCF	CCF1	CCF2
1	pH value	7.5	8.6	9.0
2	Viscosity (at 30°C)	1.41 mPa.s	1.08 mPa.s	1.06 mPa.s
3	Stability	Stable	Stable	stable
4	Colour	Whitish	Milky white	Whitish

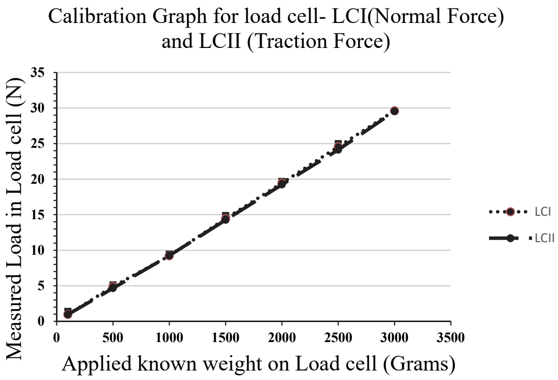


Fig. 4 Load cell calibration data points

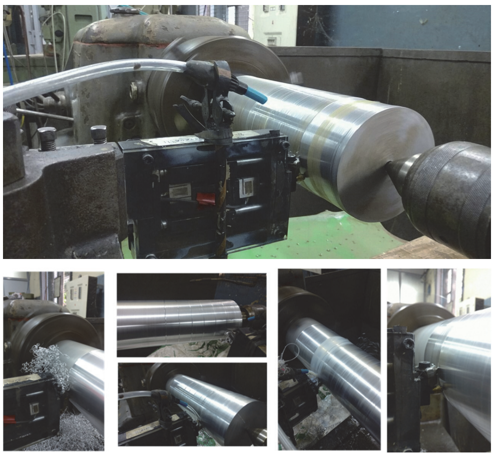


Fig. 5 Experimental setup for performance testing of cutting fluids using lathe tribometer

near linearity with respect to applied load. Repeatability study was done and the variations were less (+/-0.5 N variations in force).

The lathe tribometer is set up as a cutting tool as shown in Fig. 5. The pin is below the cutting tool for proper contact required to measure the component of the forces during machining operation. The major advantage of the lathe tribometer is that it is portable and it can be used in the real time machining operation. When the lathe tribometer is fixed on the lathe the spring in the tribometer is compressed against which the normal force is measured. The friction force comes into play when the work piece is rotated against the tool in contact. This is measured by the load cell in the horizontal position.

4 Results and discussion

The Green cutting fluid shows better performance as compared to the commercial cutting fluids. This could be attributed to the influence of tribofilm formed by different cutting fluids. GCF which has vegetable oil (coconut oil) as the base oil which has got better lubricity and wetting/lubricating properties than the other cutting fluids which has mineral oil as the base oil [10, 11]. Further it will aid in reducing friction in cutting tool and work piece interface. The traction force is reduced to around 10 N with GCF. Thus the tool life and the surface finish are enhanced. The observed values will be closer to the real frictional force values. Performance results from lathe tribometer with dry cutting and different cutting fluids is shown if Figs. 6 and 7 respectively. The experiment has shown that the operation is more efficient with cutting fluids when compared to dry cutting. The GCF performance is better than the commercial fluids. The cutting fluid used in the machining operation significantly reduces the frictional forces. This results are in terms with the results from tool chip tribometer [10]. Figure 8 shows the coefficient of friction variation with speed and Table 4 shows the roughness values

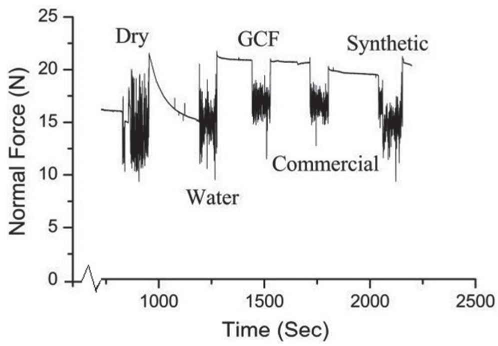


Fig. 6 Graph showing normal force variation with time for dry machining and machining using different cutting fluids

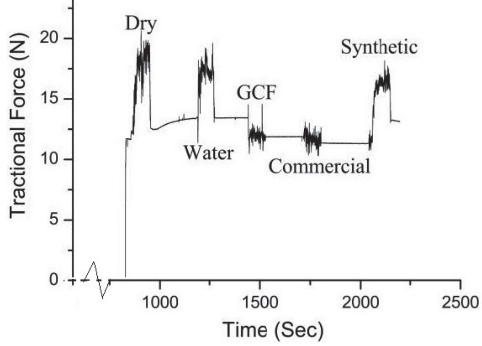


Fig. 7 Graph showing tractional force variation with time for dry machining and machining using different cutting fluids

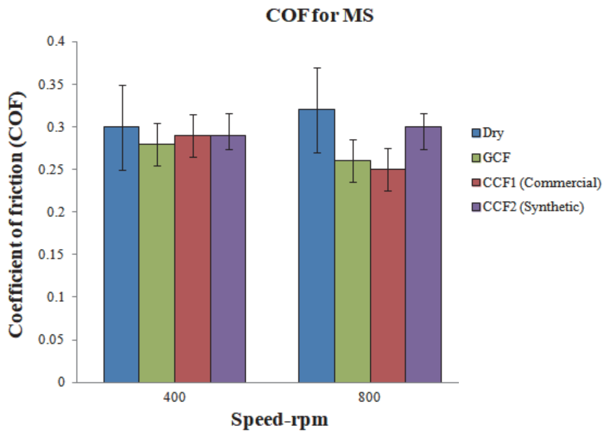


Fig. 8 Consolidated results showing coefficient of friction variation with speed for mild steel workpiece using GCF, commercial, and synthetic cutting fluid

Table 4 Roughness observations from Lathe tribometer experiments for mild steel [MS] sample

	Sample Name	RPM	Cutting velocity (m/sec)	*Ra* for machined surface [μm]
MS	Dry	400	2.5	4.55
	GCF			1.07
	CCF1			1.24
	CCF2			2.07
	Dry	800	5	2.45
	GCF			1.56
	CCF1			1.73
	CCF2			2.66

of the surface measured from talysurf profiler. Green cutting fluid gave better machining performance in terms of COF and Roughness measurement at lower speed. The performance of GCF was reliable and competent with cutting speed change. Thus, the observations from the study provide a upshot for analysis, further study and improvement of green cutting fluid and lathe tribometer. Similar to the results from the Tool-Chip-Tribometer, results from experiments using this set-up (Lathe Tribometer) also confirmed the ability of the GCF in forming lubricious layers was on par with that of the CCFs. Thus a portable lathe tribometer,ie, A tribometer testing setup to evaluate the lubricity aspect of cutting on freshly cut surfaces was developed successfully overcoming few of the drawbacks of tool chip tribometer. These are preliminary experimental results and extensive tests has to be carried out to study the efficiency in evaluating direct oils as cutting oils and other lubricants in machining industry. In turn lathe tribometer could be effective in studying different lubricants used in machining.

5 Conclusion

The evaluation of formulated green cutting fluid and commercial cutting fluid on in house developed lathe tribometer has been reported. Tribological evaluation of newly generated surface is critical in evaluating the performance of any cutting oil. As nascent surface generated during machining is influenced by the type and concentration of the cutting fluid used. With the obtained results, the performance of lathe tribometer device has been validated and thus in turn shows promising capabilities in assessing friction during machining and further scopes.

Acknowledgement

This work is a part of two research projects funded by the Department of Biotechnology (DBT DBT0/370/SVK-DC) and Coconut development board-India. The authors appreciate the support of Indian Institute of Science and National Formosa University.

References

[1] Brinksmeier, E., Meyer, D., Huesmann-Cordes, A. G. and Herrmann, C., “Metalworking Fluids—Mechanisms and Performance,” CIRP Annals, 64, 2, 2015, 605–628.

[2] Abdalla, H. S. and Patel, S., “The Performance and Oxidation Stability of Sustainable Metalworking Fluid Derived from Vegetable Extracts,” Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 220, 12, 2006, 2027–2040.

[3] Ozcelik, B., Kuram, E., Demirbas, E. and Sik, E., “Effects of Vegetable-Based Cutting Fluids on the Wear in Drilling,” Sadhana - Academy Proceedings in Engineering Sciences, 38, 4, 2013, 687–706.

[4] Zemzemi, F., Rech, J., Salem, W. B., Dogui, A. and Kapsa, P., “Identification of a Friction Model at Tool/Chip/Workpiece Interfaces in Dry Machining of AISI4142 Treated Steels,” Journal of Materials Processing Technology, 209, 8, 2009, 3978–3990.

[5] Claudin, C., Rech, J., Grzesik, W. and Zalisz, S., “Characterization of the Frictional Properties of Various Coatings at the Tool/Chip/Workpiece Interfaces in Dry Machining of AISI 4140 Steel,” International Journal of Material Forming, 1, 1, 2008, 511–514.

[6] Boyd, J., “Tribometer-Based Quantifying of Friction in Metal Cutting,” Thesis, 2012, 89.

[7] Smolenicki, D., Boos, J., Kuster, F., Roelofs, H. and Wyen, C. F., “In-Process Measurement of Friction Coefficient in Orthogonal Cutting,” CIRP Annals - Manufacturing Technology, 63, 1, 2014, 97–100.

[8] Childs, T. H. C. and Rowe, G. W., “Physics in Metal Cutting,” Reports on Progress in Physics, 36, 3, 1973, 223–288.

[9] Pottirayil, A., Kailas, S. V. and Biswas, S. K., “Experimental Estimation of Friction Force in Lubricated Cutting of Steel,” Wear, 269, 7–8, 2010, 557–564.

[10] Somarajan, S. P. and Kailas, S. V., “Study and Comparison of Lubricity of Green and Commercial Cutting Fluid Using Tool-Chip Tribometer,” Tribology Online, 13, 6, 2018, 340–350.

[11] Somashekaraiah, R., Suvin, P. S., Gnanadhas, D. P., Kailas, S. V. and Chakravortty, D., “Eco-Friendly, Non-Toxic Cutting Fluid for Sustainable Manufacturing and Machining Processes,” Tribology Online, 11, 5, 2016, 556–567.

[12] Pottirayil, A., Kailas, S. V. and Biswas, S. K., “Lubricity of an Oil in Water Emulsion in Metal Cutting: The Effect of Hydrophilic/Lypophilic Balance of Emulsifiers,” Colloids and Surfaces A: Physicochemical and Engineering Aspects, 384, 1–3, 2011, 323–330.