International Journal of Manufacturing and Material Processing
Vol. 1: Issue 2
www.journalspub.com

Investigation on the Influence of Calcium Fluoride and Barium Fluoride on Cutting Performance During Hard Turning with Minimal Fluid Application

Pauliah Sam Paul[1*], Alampalam Subramanian Varadarajan[2]
[1]Department of Mechanical Engineering, Karunya University, Coimbatore (Tamil Nadu), India
[2]Nehru college of Engineering and Research Centre, Pampady, Thrissur (Kerala), India

Abstract

Recently the concept of minimal fluid application has gained attention in metal cutting industry as it has the ability to resemble pure dry turning and at the same time free from all the problems related to large scale use of cutting fluid as in conventional wet turning. Since a very small quantity of cutting fluid is doing cooling and lubrication in minimal fluid application, there must be some performance enhancers to improve the efficiency of utilization of the cutting fluid and to facilitate uninterrupted operation. In this research work, an effort is made to investigate the effect of semi-solid lubricants such as grease in pure form and as a mixture with graphite, barium fluoride and calcium fluoride on cutting performance during hard turning of AISI 4340 steel with minimal fluid application using hard metal inserts with sculptured rake face using a special semi-solid lubricant applicator developed for this purpose. Semi-solid assisted machining is a novel concept to control cutting force, cutting temperature, tool wear and to improve surface finish. From the results it was observed that the use of semi-solid lubricant grease and calcium fluoride combination applied at the tool-chip interface along with minimal fluid application provides better results when compared to other lubricant combinations. The present study illustrates the use of semi-solid lubricants along with minimal fluid application as a viable alternative for hard turning with minimal fluid application, dry and wet turning. It is also a possible environmental friendly alternative for effective control of heat generated at the machining zone.

Keywords: Calcium fluoride, barium fluoride, grease, hard turning, minimal fluid application, cutting temperature, cutting force

***Corresponding Author**
Email ID: psam_paul@rediffmail.com

INTRODUCTION

In conventional machining process, the work piece material has to be turned to the requisite shape, hardened based on the necessity and ground to the ultimate dimension to obtain high hardness condition. But in recent times, the concept of hard turning has gained considerable momentum in metal cutting as it can replace the traditional lengthy process cycle of hard wear resistant steel parts. [1] Hard turning can facilitate low process cost, low process time, better surface quality, and lower waste. But hard turning involves very large quantities of cutting fluid. Procurement, storage and disposal of cutting fluid involved expenses and it has to comply with environmental legislations such as OSHA as well. Pure dry turning is a solution to this problem as it does not require any cutting fluid at all. But pure dry turning requires Ultra Hard cutting tools, extremely rigid tools and it is difficult to implement in the existing shop floor as the machine tool may not be rigid enough to support hard turning. [2] In this circumstance, the theory of minimal fluid application provides alternative and effective solution.

In minimal fluid application, very small amount of cutting fluids were applied at critical zone with high velocity in the form of narrow pulsing slug. This method avoids larger usage of cutting fluid as compared to conventional wet turning and it also look like dry turning. A.S. Varadarajan observed that the overall performance of turning with minimal fluid application on the basis of cutting force, tool life, surface finish, cutting ratio, cutting temperature, and tool chip long length was superior to dry turning and conventional wet turning. Since a very small quantity of cutting fluid is doing cooling and lubrication purpose, there must be some performance enhancers to improve effectiveness, utilization of the cutting fluid to prevent damage to the tool and work piece. Recent advances in tribology has provided effective and efficient environment friendly concept through the application of solid and semi-solid lubricants to obtain desirable control on cutting performance in metal cutting.

The process of using graphite based grease along with oil during milling process was done by Lathkar *et al.* and they observed that cutting performance for the process with semi-solid lubricant was far superior when compared to dry milling. [3] Shaji and Radhakrishnan used graphite as a lubricating medium to reduce the heat generated in the grinding zone during surface grinding and it is reported that the introduction of semi-solid lubricant reduced cutting force, cutting temperature and improved surface finish during grinding of EN31steel. [4] Suresh and Rao studied the effect of graphite and molybdenum disulphide lubricants on surface quality and cutting forces during end milling of AISI 1045 steel. [5] From the results it can be seen that there was considerable improvement in cutting performance when compared to conventional cutting fluids. Deshmukh and Basu used solid lubricants like MoS_2, MoS_2 based grease, graphite based grease and silicon compound mixed with SAE20 oil during turning and observed better surface quality. [6] Dilbarg and Rao investigated the effect of graphite and molybdenum disulphide during hard turning of bearing steel with ceramic inserts at different cutting conditions and tool geometry and the results indicated considerable improvement in the surface finish when compared to dry hard turning.[7] Krishna V. *et al.* used solid lubricant mixture like Graphite in SAE 40 oil and boric acid in SAE 40 oil in turning of EN8 steel and found encouraging results with reduction in tool wear and surface roughness as compared to dry and wet machining. [8] In another study, they reported improvement in cutting performance when solid lubricant like graphite and boric acid were applied on the back side of the chip. [9]

Indium was used as solid lubricant during turning of AISI 4340 steel along with TiN coated and patterned carbide inserts and it was found that tool wear was reduced considerably[10]. Abhang and Hameedullah considered various turning parameters like cutting speed, feed rate, tool nose radius and concentration of solid-liquid lubricants. From the experimental results, it was clearly shown that surface finish and chip thickness has been improved considerably for the composition having 10% boric acid by weight mixed with base oil SAE 40 and this composition was identified as the most significant parameter. [11] Deng Jianxin *et al.* developed turning tool embedded with MoS_2 solid lubricant and observed that cutting forces and cutting temperature were reduced as compared to that of the conventional tool. [12] Sam Paul and Varadarajan investigated the effect of semi-solid lubricant such as silicon grease in pure form and as a mixture with 10% graphite on cutting performance during hard turning of AISI 4340 steel with minimal fluid application using hard metal inserts with sculptured rake face and it was observed that silicon and graphite offers better cutting performance. [13] From the literature review, it was observed that the researchers have attempted and used many solid lubricants to improve cutting performance. In the light of the review of literature, it was decided in this investigation, to study the effect of semi-solid lubricants like calcium fluoride, barium fluoride, grease and graphite on cutting performance during turning of hardened AISI 4340 steel along with minimal fluid application.

DESIGN AND FABRICATION OF SEMI-SOLID LUBRICANT APPLICATOR

In metal cutting, semi-solid lubricant assisted machining is a novel technique which aims to improve cutting performance with economical and technical benefits. In turning process, this semi-solid lubricant has the tendency to act as coolant and lubricant when applied properly at specific location or critical zones. In this semi-solid lubricant application, heat transfer is predominantly in the evaporative mode which was more efficient than the conventional heat transfer prevalent in wet turning. Semi-solid lubricant applicator of pneumatic type was used in the present investigation to deliver grease in desired locations. It consists of a cylinder, a piston and a nozzle as shown in Figure 1. When compressed air from the compressor enters into the inlet tube, piston will move forward against the force of a stabilizing spring and subsequently grease will be delivered through the nozzle to the tool-chip interface. Control valve is provided in the apparatus to control the rate of delivery of the grease. Relief valve is installed to protect the system from accidental overloads in the event of block in the nozzle. The line sketch consisting of different parts of semi-sold lubricant applicator is shown in Figure 1. Figure 2 represents the photograph of the fabricated semi-solid lubricant applicator. Based on the information available in the literature, semi-solid lubricant was applied at the tool-chip interface. [13]

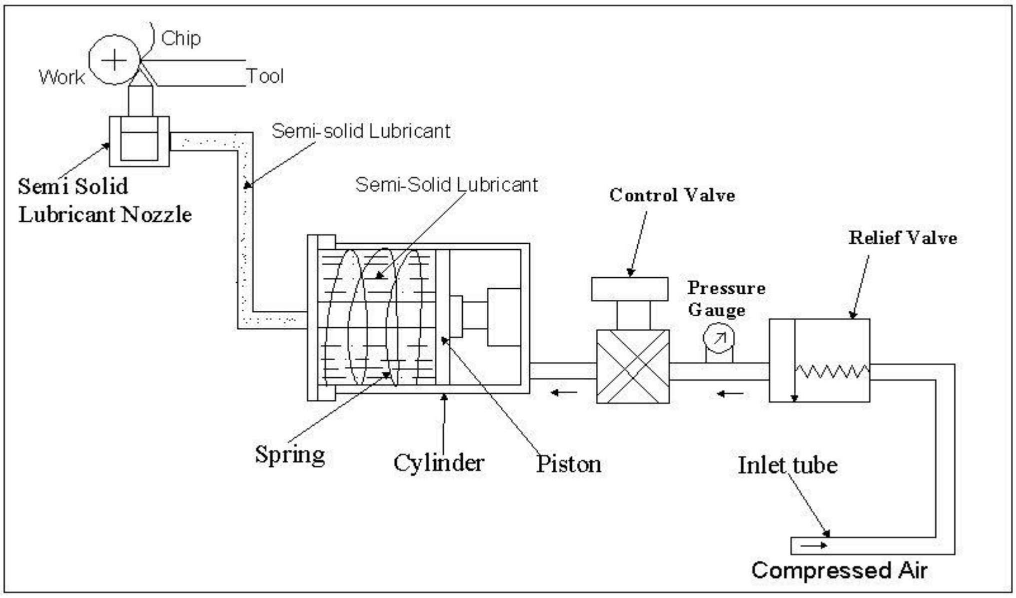

***Fig.1**: Line Sketch Indicating Parts of Semi-Solid Lubricant Applicator.*

Design of Applicator

Aluminum alloy (6063-T5) which has a tensile strength of 220 N/mm^2 has been selected for fabricating different lubricator parts due to its light weight, high tensile strength, anti-rust properties, and ease of fabrication, cost effectiveness, high pressure and availability. The capacity of the compressor was 1-18 bar. The thin walled cylinder shell was designed based on circumferential (or) hoop stress pd / 2t. For piston rod having diameter 56 mm and pressure acting on the piston 10 bar, thickness of the thin walled cylindrical shell was calculated to be 3 mm. The volume of the applicator was calculated based on the required flow rate, operation time of the applicator and the available pressure and it was found to be 250 cm^3. Fixtures are used for holding the semi-solid lubricant applicator at lathe. In the present investigation, grease in pure form and grease impregnated with graphite, calcium fluoride, and Barium fluoride were used. Semi-solid lubricants were applied using a nozzle, which applies the grease to the part under pressure, forcing the solid grease into the spaces at the tool-chip interface.

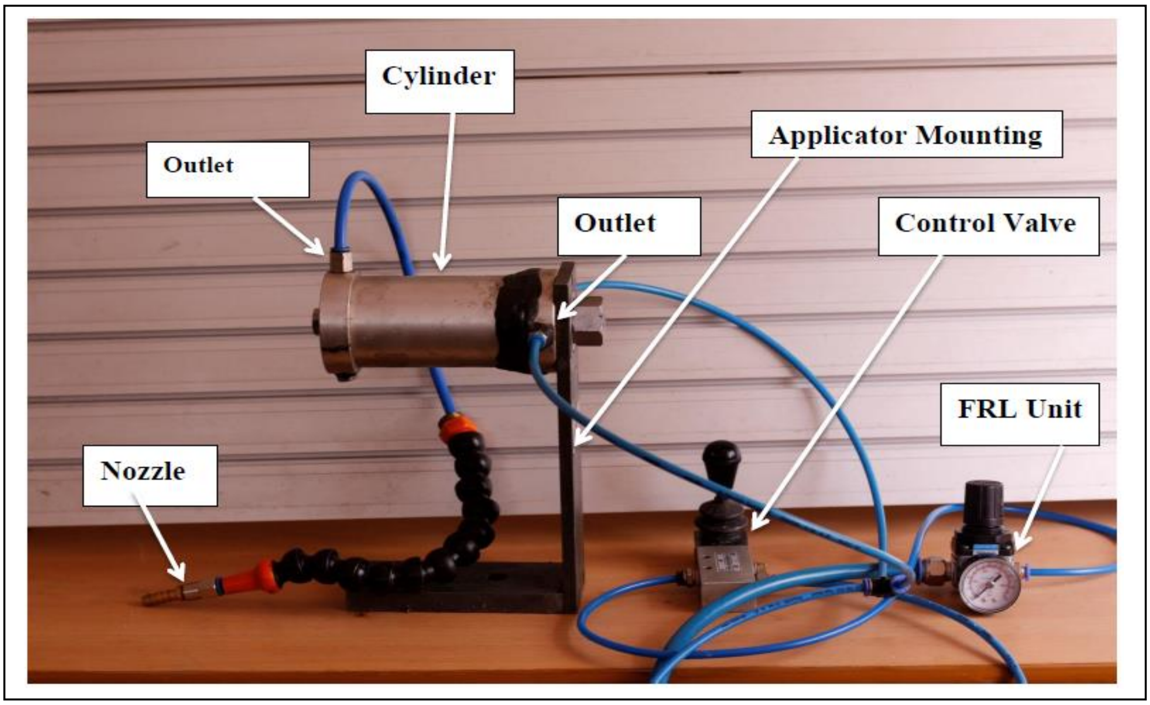

Fig. 2: *Photograph of Fabricated Semi-Solid Lubricant Applicator Setup.*

Grease used in this study consists of a soap emulsified with mineral oil and has the specification of LGWA 2 (DIN 51825). This grease can support much heavier load at lower speed. Also in metal cutting, where liquid lubricants cannot be retained, grease which do not easily leak out of a machine, do not migrate away and form an effective seal against contaminants can be used as an alternative. Lubrication at high temperature is a major issue in metal cutting where liquid lubricants and greases cannot meet the requirements for their easy sticking onto the mould surface, which results in the deterioration of mould working condition. To widen the operating temperature range of lubrication coating, one of the approaches is to combine low temperature and high temperature lubricant materials into a composite structure. Alkali fluorides (CaF_2, BaF_2) are alternative choices for their low shear strength and stable thermo-physical and thermochemical properties at elevated temperature.[14] In the present investigation, silicon grease in pure form and that impregnated with different weight percentage of graphite, calcium fluoride, and Barium fluoride were used.

EXPERIMENTATION

Cutting experiments were conducted on a Kirloskar turn master and the photograph of the experimental setup with semi-solid lubricant applicator is shown in Figure 3. The main cutting force which is acting in tangential direction was measured using a Kistler type 9257B dynamometer. Surface roughness was measured using Mahr TR100 surface roughness tester of type MarSurf GD 25. The average flank wear was measured using a tool maker's microscope and the amplitude of tool vibration was measured using a piezoelectric vibrometer pickup mounted at the top of the tool holder. The experiments were replicated twice to improve the accuracy of the results and the parameters which were kept constant during each experiment are shown in Table 1. The parameters mentioned in Table 1 were arrived at based on the results of preliminary experiments and these ranges are prescribed for turning in semi finish range for the tool-work combination.

Table 1: *Parameters Kept Constant during Experimentation.*

Parameters	**Values**
Depth of cut	1.2 mm
Feed rate	0.08 mm/rev.
Cutting velocity	100 m/min.
Rate of fluid application	8 ml/min.
Frequency of pulsing	500 pulses/min.
Pressure at the fluid injector	80 bar
Rate of application of semi-solid lubricant	8 gm/min.
Cutting fluid composition	10% + rest water
Type of cutting fluid	Specially formulated mineral oil based cutting fluid
Mode of fluid delivery	Cutting fluid application in minimal fluid application mode
Direction of semi-solid lubricant	Tool chip interface

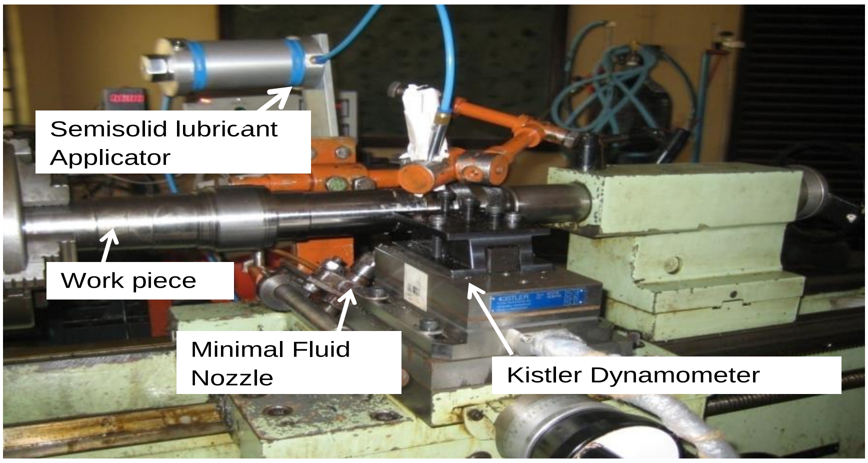

Fig. 3: *Photograph of Semi-Solid Lubricant Applicator and Minimal Fluid Application Setup Attached in Lathe.*

Selection of Tool and Work Piece Material

AISI 4340 steel which has a wide range of application in automobile and allied industries by virtue of its good hardenability was used as work piece material in this study. Cutting experiments were performed on a cylindrical bar of 80 mm diameter and 380 mm length having hardness of 46HRc. The Chemical composition in weight % of AISI 4340 Steel is available in Table 2. The tool holder used had the specification of PSBNR 2525 M12. Multicoated carbide inserts with specification SNMG 120408 MT TT5100 having sculptured rake face geometry was used as cutting tools in this investigation. The selection of cutting tool and the tool holder was done according to the information available in the literature.[13] and the recommendations of the cutting tool manufacturers, M/s Taegutec India (P) Ltd.

Table 2: *Composition of AISI4340 Steel.*

Elements	**C**	**Mn**	**Si**	**Ni**	**Cr**	**Mo**	**Fe**
% Composition	0.41	0.87	0.28	1.83	0.72	0.20	rest

RESULTS AND DISCUSSION

To study the effect of lubricants on cutting performance during turning of AISI 4340 steel with a hardness of 46 HRc, cutting experiments were conducted and the observations made during the experiment are summarized in Table 3.

Table 3: *Summary of Experimental Results.*

S. No	**Lubricant used**	**Cutting Temperature (ºC)**	**Main Cutting Force (N)**	**Surface Roughness R_a (µm)**	**Average Flank Wear VB_B(mm)**	**Amplitude of tool vibration (mm)**
1	Dry turning	175.61	257.346	1.384	0.0427	0.157
2	Minimal cutting fluid application (MCFA)	170.92	250.113	1.219	0.0375	0.148
3	MCFA+ Grease	166.03	241.885	1.006	0.0342	0.141
4	MCFA + Grease (90%) + Graphite (10%)	162.45	230.412	0.992	0.0312	0.135
5	MCFA + Grease (50%) + Graphite (10%) + Barium Fluoride (40%)	160.04	226.181	0.938	0.0297	0.129
6	MCFA + Grease (50%) + Graphite (10%) + Calcium Fluoride (40%)	157.28	220.814	0.902	0.0275	0.121
7	MCFA + Grease (40%) + Barium Fluoride (30%) + Calcium Fluoride (30%)	153.28	215.042	0.851	0.0251	0.110
8	MCFA + Grease (50%) + Barium Fluroide (50%)	150.97	210.913	0.878	0.0247	0.102
9	MCFA + Grease (50%) + Calcium Fluoride (50%)	144.89	190.871	0.787	0.0214	0.085

Based on the experimental results shown in Figures 4 and 5, it is observed that application of semi-solid lubricants along with minimal cutting fluid application form the most significant parameter influencing Surface Finish, tool wear, tool vibration, cutting force and cutting temperature. Among the rate of semi-solid lubricants used in this study, it is seen that the application of semi-solid lubricant impregnated with calcium fluoride in accompaniment with minimal fluid application brought forth better cutting performance.

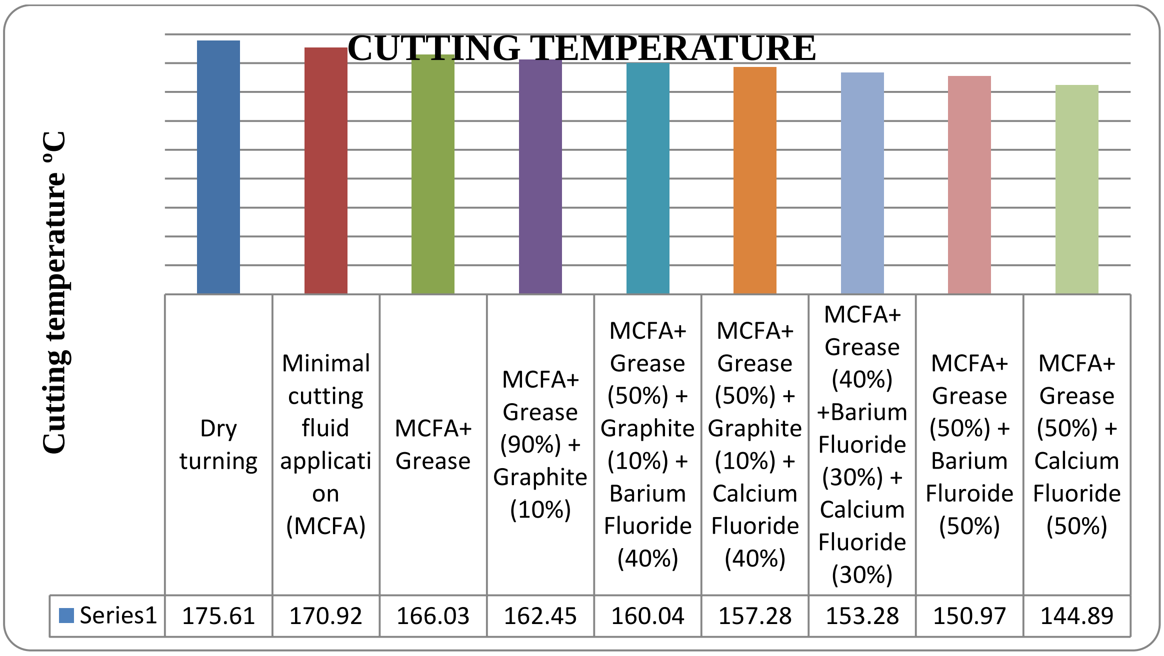

Fig. 4: *Comparison of Cutting Temperature during Dry Turning, Turning with Minimal Fluid Application and Composition of Lubricants with Minimal Fluid Application.*

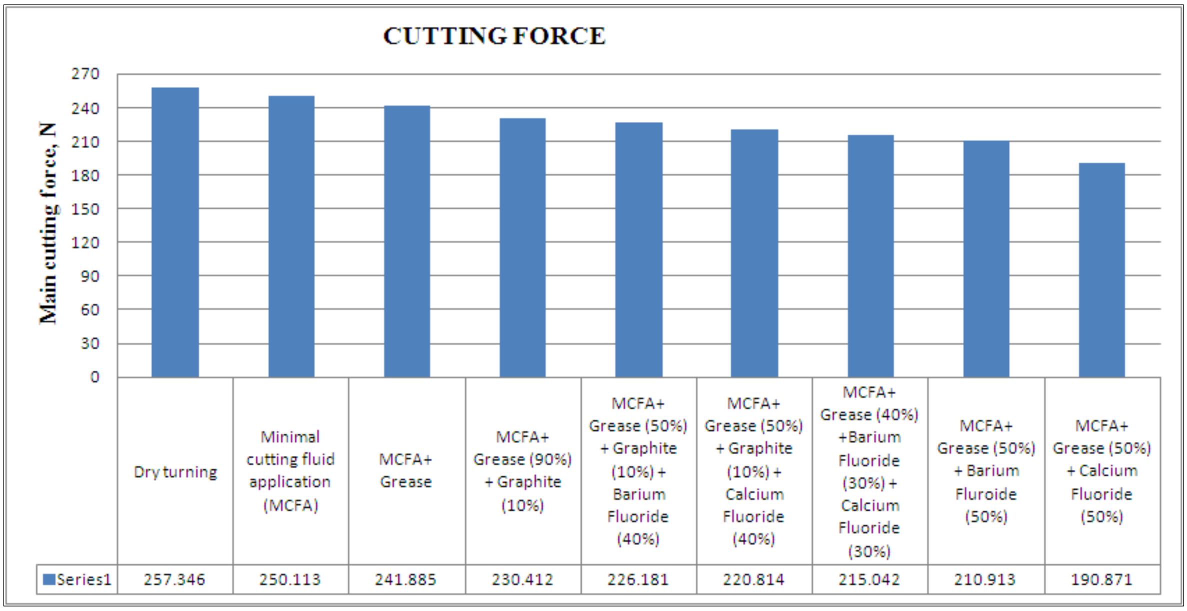

Fig. 5: *Comparison of Cutting Force during Dry Turning, Turning with Minimal Fluid Application and Composition of Lubricants with Minimal Fluid Application.*

In metal cutting, whenever high cutting temperatures were encountered it can be presumed that there is degradation of the lubricating ability of the cutting fluid and this degradation is marked by an increase in the main cutting force component. This increase in the cutting force can be considered as a measure of the deterioration of the lubricating ability of the cutting fluid. Also when higher cutting forces are acting on the machine tool than the usual, more vibration will be induced in the cutting tool which in turn increases tool wear and surface roughness.

From Figure 4 and 5, it can be seen that during dry turning cutting temperature and main cutting force was found to be 175.61°C and 257.36 N. But this cutting force and cutting temperature parameters started decreasing and reaches a minimum value of 144.89°C and 190.871 N when minimal fluid application was applied along with 50% grease and 50% calcium fluoride. At room temperature, Calcium Fluoride does not have the property to mist polished surfaces when exposed to 100% relative humidity and the polished surfaces will not degrade in normal working condition. But in moisture condition, calcium fluoride surfaces will degrade when temperature exceeds 600°C and in dry condition it can be used up to 1000°C. Also calcium fluoride (CaF_2) has the property to reveal self-lubrication properties when coated as bonded thin surface film and during the rise in temperature it will experience brittle to ductile transformation and form ductile phase with lower shear strength. [15] In general, when solid lubricant is applied at the tool chip interface, it takes the latent heat of fusion from the tool chip interface which reduces the severity of the thermal conditions that prevail at the tool chip interface and prevents the complete degradation of the lubricating properties of the cutting fluid particles present at the tool chip interface.

Moreover a mixture comprising of cutting fluid particles, molten solid lubricant grease and calcium fluoride particles act as a dielectric that prevents intermolecular and interatomic interaction between the chip and the tool surfaces. This prevents adhesion of the chip to the tool surface and changes the conditions prevailing at the tool-chip interface from sticking to one of sliding leading to drastic reduction in cutting force. Also when tiny droplets of cutting fluid get adsorbed on the top side of the chip owing to their small size and high velocity, they dope the nascent surfaces generated and prevent the coalesce of crack tips. This leads to the weakening of the back side of the chip and the chip tends to bend away from the tool rake face resulting in reduction of cutting force, tool wear, tool vibration, cutting temperature and better surface finish.

Calcium Fluoride exhibits high degree of plasticity with low yield strength in shear direction and its frictional coefficient decreases with increase in temperature.When semi-solid lubricant impregnated with calcium fluoride in accompaniment with minimal fluid application is applied during machining, the formation of thin film of lubrication on the rake face of the tool reduces the frictional forces between the tool and chip, which subsequently reduces the temperature developed and prevents the tool wear which further leads to substantial improvement in cutting performance.

Also in minimal fluid application along with semi-solid lubricants, due to cooling by convective as well as evaporative heat transfer and formation of thin film lubrication, cutting temperature and tool wear reduces marginally when compared to turning with minimal fluid application, which is not possible in case of dry turning.

CONCLUSION

In this study, an attempt was made to investigate the effect of semi-solid lubricants such as calcium fluoride, barium fluoride and as a mixture with grease and graphite on cutting performance during hard turning of AISI 4340 steel with minimal fluid application using hard metal inserts with sculptured rake face.

From the present study, the following conclusions were drawn:

1. Hard turning with minimal fluid application in the presence of calcium fluoride, barium fluoride, grease and graphite provides better cutting performance as compared with dry and turning with Minimal fluid application.
2. In order to reduce cutting force, cutting temperature, tool wear, surface roughness and tool vibration, semi-solid lubricants having 50% calcium fluoride that impregnated with 50% grease by weight should be applied at the tool chip interface along with the minimal fluid application
3. The present study illustrates that if semi-solid lubricant is properly applied along with minimal fluid application it would be an effective alternative for dry and wet turning.

ACKNOWLEDGEMENT

The authors are grateful to the Centre for Design and Manufacturing Engineering (CRDM) of School of Mechanical Sciences, Karunya University for providing the facilities to carry out this research work.

The authors would like to thank the Karunya university Mechanical department staff members Mr J.Jones Robin, Mr. Devamanoharan and Mr.Siva Sankaran for their assistance and help. The authors also thank M/s Taegu Tec for supporting this research work.

REFERENCES

1. Byrne G., Dornfeld D. Denkena B. Advancing Cutting Technology. STC "C" Keynote. *CIRP Annals*. 2003; 52(2):483–507p.
2. Varadarajan A.S., Philip P.K., Ramamoorthy B. Investigations on hard turning with minimal cutting fluid application (HTMF) and its comparison with dry and wet turning. *International Journal of Machine Tools and Manufacture*. 2002; 42(2): 193–200p. doi: 10.1016/S0890-6955(01)00119-5
3. Lathkar G.S., Kharde R.R., Basu S.K. Some experiments in machining grease based solid lubricants. *Journal of the Institution of Engineers (India)* 2001; 82:1–6p.
4. Shaji S., Radhakrishnan V. An investigation of surface grinding using graphite as lubricant. *International. Journal of Machine Tools & Manufacture*. 2002; 42(6): 733–40p.
5. Reddy N.S.K., Rao PV. Experimental investigation to study the effect of solid lubricants on cutting forces and surface quality in end milling. *International Journal of Machine Tools and Manufacture*. 2006; 46: 189–98p.
6. Deshmukh S.D., Basu S.K. Significance of solid lubricants in metal cutting. *Proceedings of the 22nd AIMTDR Conference on Manufacturing Technology Design Research*, IIT Roorkee, India, India: AIMTDR. 2006. 421–7p.
7. Singh D., Rao P.V. Performance improvement of hard turning with solid lubricants. *International Journal of Advanced Manufacturing Technology*. 2008; 38(5–6): 529–35p.
8. Krishna P. V., Rao D. N. Performance evaluation of solid lubricants in terms of machining parameters in turning. *International Journal of Machine Tools and Manufacture* 2008; 48: 1131–7p.

doi:10.1016/j.ijmachtools.2008.01.012
9. Krishna P. V., Srikant R.R., Rao D.N. Experimental investigation to study the performance of solid lubricants in turning of AISI 1040 steel. *Proceedings of the Institute Mechanical Engineers. Part J Journal of Engineering Tribology*. 2010; 224: 1273–81p. doi: 10.1243/13506501JET794
10. Guleryuz C.G., Krzanowski J.E., Veldhuis S.C., *et al.* Machining performance of TiN coatings incorporating indium as a solid lubricant. *Surface and Coatings Technology*. 2009; 203(22): 3370–6p. doi: 10.1016/j.surfcoat.2009.04.024
11. Abhang L.B., Hameedullah M. Experimental Investigation of Minimum Quantity Lubricants in Alloy Steel Turning. *International Journal of Engineering Science and Technology*. 2010; 2(7): 3045−53p.
12. Deng J., Song W., Zhang H., *et al*. Friction and wear behaviors of the carbide tools embedded with solid lubricants in sliding wear tests and in dry cutting processes. *Wear*. 2011; 270(9-10): 666–74p. doi:10.1016/j.wear.2011.01.031
13. Paul P.S., Varadarajan A.S. Performance evaluation of hard turning of AISI 4340 steel with minimal fluid application in the presence of semi-solid lubricants. *Journal of Engineering Tribology*. 2013; 227(7):739–48p.
14. Wang L., Wang B., Wang X., *et al.* Tribological investigation of CaF_2 nanocrystals as grease additives. Tribology International 2007; 40: 1179−85p. doi: 10.1016/j.triboint.2006.12.003
15. Wang H.M., Yu Y.L., Li S.Q. Microstructure and tribological properties of laser clad CaF2/Al2O3 self-lubrication wear-resistant ceramic matrix composite coatings. *Scripta Materialia*. 2002; 47: 57−61p.