Journal of Manufacturing Engineering, 2009, Vol.4, Issue.2, pp 98-104

# STUDIES ON THE EVALUATION OF EFFECTIVENESS OF PASSIVE COOLING TECHNIQUE DURING TURNING OF CAST IRON

***M S Ganesha Prasad [1], Naveen Kumar K [2], D R Kumar [3] and D N Drakashyani [4]**

[1] Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore, India
[2], Kennametal India Ltd, Bangalore, India
[3]Skanda Machine Tools Pvt. Ltd. Bangalore, India
[4]Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore, India

## ABSTRACT

Machining dry, without coolant is advantageous due to decreased costs and also because of possible negative effects of coolant on operator's health and to the environment. The chances of tool failure at higher cutting temperatures due to one or more of the reasons, like thermal cracking, chipping, micro - Chipping, built-up edge, Mechanical fracture, notching, deformation, crater and flank wear. The study is focused in creating highly controlled temperature environment for the cutting tool insert in more practical way for the small-scale industries. The special tool holder is manufactured in-house as per the requirement of the study. The heat sink material copper inside the tool holder is poured through the casting technique which has higher conductivity. Important observation made in this study is micro – chipping which is present with the conventional tool holder but not with the insert of special tool holder. The experimental results are very much comparable with computational values simulated with Ansys as analysis software.

**Keywords:** *Dry Machining, Cutting tool insert, Passive Heat Extraction Technique, Thermal Load, Heat Pipe*

## 1. Introduction

Metal cutting is an extremely complex process that cannot be described by a single simple mechanism. Even though a single mechanism may be predominant over a limited range of operating conditions, no mechanism holds in general. This accounts for the extremely wide range of views in the literature to explain cutting results supported by sound experimental data. In most cases, the relatively simple mechanism suggested by the author to explain the results fail to hold when applied to different operating conditions. Many experts suggest that no unique solution exits for optimization of entire complex machining process. Metal cutting operation leads to conversion of mechanical work to heat by plastic deformation of metal chips and also through friction between the tool and workpiece. A part of this heat conducts into the chip and is carried away by chip. Almost the same amount is conducted into the cutting tool due to continuous engagement of tool with workpiece and remaining into the workpiece itself. Due to the continuous engagement of cutting tool with the workpiece, constant thermal load is being applied on cutting tool insert. One of the main reasons for failure of cutting tool insert is because of accumulation of thermal energy into it. This thermal load on cutting tool insert reduces life by reducing the thermal resistance to plastic deformation.

Wisely falco sales, Anselmo Eduardo Diniz and Alisson Rocha Machado [1] mentioned that, to safe guard the cutting tool insert during machining, manufacturers use cutting fluids. Till the beginning of 20$^{th}$ century, use of cutting fluid was considered to be the only solution to increase the life of cutting tool insert and other machinability characteristics. But later researchers started looking at Minimum Quantity Flow (MQF) so that there is advantage of extracting the thermal load at the contact zone. The substitution of abundant oil by MQF is based among other factors on environmental issues. But it must be remembered that even MQF causes pollution, due to pulverization of oil in the air. This suspension of oil particles in the air, demands machine must be completely encapsulated with protection guards and a good exhaustion system with particle control.

Don Graham [2], P S Sreejit and B K A Ngoi [3] mentioned that dry machining is becoming increasingly popular as a means of reducing production costs and also it protects the environment. The demand for higher productivity, product quality and overall economy in manufacturing by machining, particularly to meet the challenges thrown by liberalization and global cost competitiveness requires high material removal rate.

**Corresponding Author - E- mail: msgprasad@gmail.com*

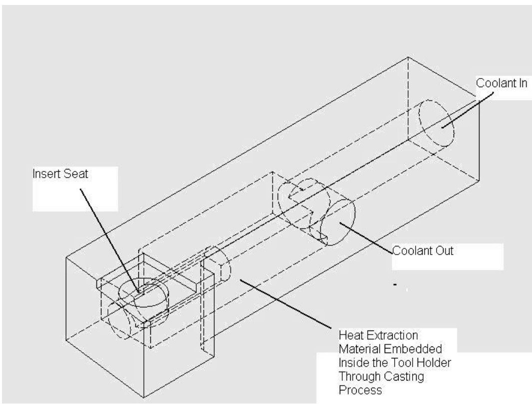



**Fig.1 Feature of the special tool holder**

To obtain higher rate of production it is necessary to increase the metal removal rate, and this leads to increase of thermal energy at the cutting tool insert edge.

Some of the technologies, which promote clean environment were developed by researchers like Nikhil R Dhar, M Kamruzzaman, M M A Khan and A B Chattopadhyay [4] They used cryogenic cooling for metal cutting operations to improve the life of cutting tool insert. The feasibility factors for the small-scale manufacturers should be taken into consideration before commercializing such initiatives.

The passive cooling techniques through heat pipe was first introduced by R L Judda, S Mackenzie and M A Elbestawi[5]. Researchers like Richard Y Chiou, Jim S J Chen, Lin Lu and Ian Cole [6] developed computational model for use of heat pipe during dry machining, Noorul Haq et al [7] optimized the process parameters and parameters of heat pipe during dry machining. The present study is a derived version of heat pipe during dry machining.

**Table 1: Material property of different materials**

| Material | Thermal conductivity (W /m-k) | Density (Kg/m$^3$) | Specific Heat (J/Kg- K) |
|---|---|---|---|
| **Cutting Tool Insert** – Uncoated Tungsten Carbide | 75 | 14900 | 443.77 |
| **Cutting Tool Holder** – Mild Steel | 46.7 | 7850 | 419 |
| **Heat Sink Material** – Copper | 401 | 8960 | 110 |

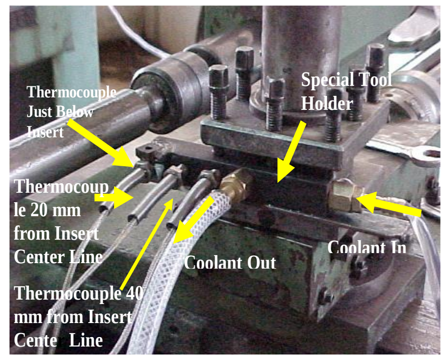



**Fig.2 Experimental Setup**

Instead of heat pipe, a solid metallic conductor of material pure cupper is used to divert the thermal load from the cutting tool insert.

The test is conducted for brittle and hard workpiece material cast iron, with inserts in conventional tool holder and tool holder with copper as heat sink material. The coolant circulation is inside the tool holder as shown in figure 1 and 2. The special tool holders used in this study is modified from the conventional tool holder. The estimation of thermal loads on cutting tool insert during dry machining through computational technique is also carried out. The study is taken up to develop an economical tool holder that augments the life of cutting tool insert. The computational model is developed by Autodesk Inventor and analyzed through Ansys for conventional as well as modified tool with tool holder setup. The instruments used for the experimental work includes thermocouple and lathe tool dynamometers, which are computer data logger types.

## 2. Computational Model

The computational model is developed by AutoDesk Inventor modeling software from AutoDesk Inc. The 3D compatible file (*.sat) is exported to Ansys, through Cartesian coordinate system in both the software to match the assembly of holder, cutting tool insert and heat sink material. The conventional model and the model with heat sink material are having 47,129 nodes each. The simulation is based on a constant time step of 900 seconds with sub step of 300 seconds. The total simulation time is 3600 seconds. For the hybrid model the boundary conditions are used from experimental data. The material property of the cutting tool insert, insert holder and heat sink material are mentioned in Table 1.

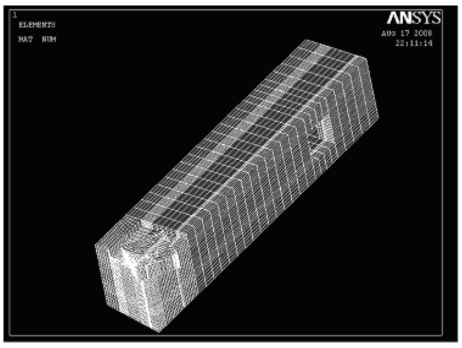



**Fig.3 Computational Model**

The thermal load i.e. heat (Watts) is applied at the cutting edge of the cutting tool insert. It is considered for sharp cutting edge tool, with only the edge of cutting tool insert in contact with the work piece. The load is calculated by considering frictional contact of the cutting tool insert with the work piece. The machining parameters for the turning are mentioned in the table 2. For calculation of the thermal load between the tool and the work piece, the cutting forces measured with dynamometer is used as input dataThe heat generation $q$, in Watts, at the interface between cutting tool and work piece, is estimated by Sata and Takeuchi [17 ] as

$$q = 1.68\, d\; f^{0.15}\, V^{0.85}$$

where d is the depth of cut in mm, f is the feed rate in mm/rev and V is the cutting speed in m/min. During cutting of brittle material, the thermal load on the cutting tool insert from the shear zone is very less due to discontinuous chips. The thermal load on the cutting tool insert is mainly due to rubbing action of the cutting tool edge on to the work piece surface.

The figure 4 gives the temperature details at the tool tip of the cutting tool insert and the figure 5 indicates temperature at the thermocouple point just below the cutting tool insert. The graphs 4 & 5 shows that the cutting tool insert present in the holder with copper as heat sink material behaves very much similar to the R L Judd [5] model for heat pipe as heat extracting technique during transient period of cutting. The temperatures on the cutting tool insert starts decreasing before 600 seconds in R L Judd model and at 800 seconds after start of test for the present model indicates temperature at the thermocouple point just below the cutting tool insert. The graphs 4 & 5 shows that the cutting tool insert present in the holder with copper as heat sink material behaves very much similar to the R L Judd [5] model for heat pipe as heat extracting technique during transient period of cutting.

The temperatures on the cutting tool insert starts decreasing before 600 seconds in R L Judd model and at 800 seconds after start of test for the present model.

## 3. Experimental Setup and Procedure

The experimental setup consists of turning centers from Mysore Kiroloskar Ltd with speed range of 45 rpm to 2000 rpm & the power capacity of motor is 2.2 kW. The cutting tool insert is from Kennametal of specification SNMA 12 – 04 – 12 and un-coated

**Table 2: Machining parameters**

| | Speed m/min | Feed mm/rev | Dept of Cut (mm) |
|---|---|---|---|
| 1st Trail | 27.14 | 0.355 | 2 |
| 2nd Trial | 27.14 | 0.45 | 2 |
| 3rd Trail | 42.22 | 0.355 | 2 |
| 4th Trial | 42.22 | 0.45 | 2 |

type (Lathe Tooling Kennametal Product Catalogue and Corokey® - Sandvik, 2006). It is specially made for medium to rough machining work of cast iron. The cutting tool holders are manufactured in-house according to the test requirements. The final modified tool holder for the study is shown in the figure1

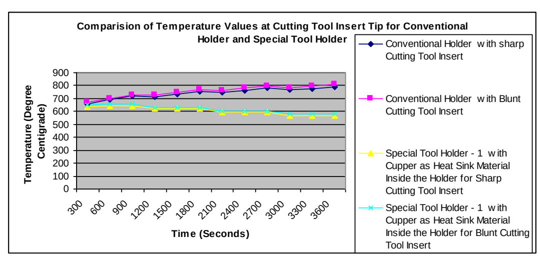



**Fig.4 Computational model for speed of 180 rpm and feed of 0.45 mm / revolution**

The work piece material is of cast iron (Machinability Grade) with 3.97% of Carbon, 1.75% of Manganese, 0.29% of Silica with less then 0.5% of Sulphur, Chromium, Molybdenum and Nickel (Workpiece tested As per IS 8811 – 1998 & Spectra Manual Test Method). The thermocouple used in this study is Ferrite Constantan K Type with capacity of 600 Degree Centigrade. These thermocouples are fixed to the toolholder and are very close to cutting tool insert by using M6 type screw These thermocouples are fixed close to the cutting zone where it will experience temperature of cutting tool insert just below it and, the second one at 20 mm from insert center line and third at 40 mm from insert center line.The software used for the study plots the variation of temperature values with respect to time. These graphs are shown in

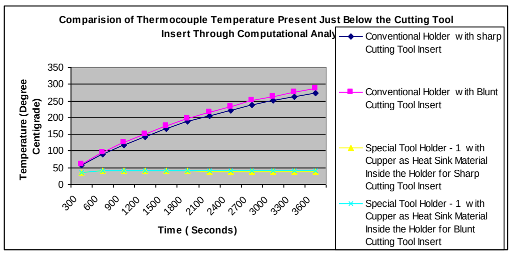



**Fig.5 Computational Model for speed of 180 rpm and feed of 0.45 mm / revolution**

figure 6 and 7 for conventional tool holder and figure 8 and 9 for special tool holder with copper as heat sink material for different machining parameters. The top most curves in all the four graphs (Figure 6 to figure 9) gives the direct measurement of temperature just below the cutting tool insert, the second and third curve plots the temperature value at a distance of 20 mm and 40 mm from insert center line in horizontal direction.

. Even though the cutting activity involves lot of process parameters during machining, only speed and feed are varied with other parameters kept constant for the study. These parameters are considered as per manufacturer's specifications of cutting tool inserts. The 2 mm depth of cut is selected, which would adequately serve the present purpose. The experiments are conducted for all the four trials with new inserts at the beginning of each trail, for conventional tool holder and special tool holders with copper as heat sink material separately. The duration of the test for each trial is approximately 60 minutes. At the end of cutting test the photograph of inserts on nose, rake and flank face is taken through Nikon Measuring Microscope, which is shown in figure-10 with a magnification of 30X (from Kennametal India Ltd.- Bangalore) .

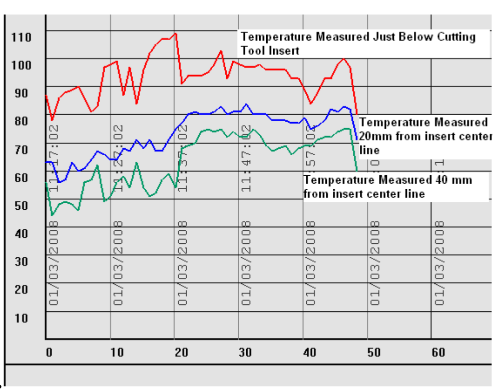



**Fig.6 Thermocouple Readings with Conventional Tool Holder with speed 180 rpm and feed of 0.355mm / rev**

The cutting force is measured through lathe tool dynamometer of CSM make with maximum capacity 500 Kgf (model DTL – 01), and recorded in computer through data logger system. The average value of cutting forces are recorded and tabulated in Table 3.

## 4. Experimental Results and Discussion

The interrupted cutting process of the turning operation causes thermal shocks since the cutting insert repeatedly heats up when in contact with the workpieceand cools when removed from contact with the workpiece. In the turning of cast iron the magnitude of these thermal shocks is especially severe because of the typically high temperatures, which will not be carried by the chips, as in the case of ductile material D. Mari and D. R. Gonseth, [16] mentioned that the wear mechanism of edge chipping, carbide tools begin to exhibit some plasticity at a temperature of about 550° C at the cutting tool insert edge. Above 550° C, cracks can initiate and grow in a less catastrophic manner. Turning of cast iron and its alloys at greater speeds, which results in higher temperatures of the cutting inserts, generates cyclic mechanical and thermal stresses that produce cracks. That result in the micro chipping of the cutting edge of the cutting insert. It is observed in this study that the thermal loads are comparatively more for the increase of cutting speed

**Table 3: Lathe Tool Dynamometer output**

| | Cutting Force (Kgf) at the Beginning of Machining | | | | Cutting Force (Kgf) After 60 minutes of Machining | | | |
|---|---|---|---|---|---|---|---|---|
| Speed | 180 RPM | | 280 RPM | | 180 RPM | | 280 RPM | |
| Trial Number | 1st Trial | 2nd Trial | 3rd Trial | 4th Trial | 1st Trial | 2nd Trial | 3rd Trial | 4th Trial |
| 1. Insert in Conventional Tool Holder | 97.5 | 152.84 | 120.25 | 138.89 | 135.58 | 190.23 | 147.63 | 166.55 |
| 2. Insert in Special Tool Holder With Copper Heat Sink | 106.3 | 152.30 | 118.24 | 147.90 | 136.3 | 160.32 | 124.5 | 151.00 |

with the use of conventional tool holder. The reduction of temperature in the cutting tool insert with copper as heat sink material inside the cutting tool holder is mainly due to creation of thermal channel from in-convenient zone to convenient zone for heat dissipation.

These thermal loads are of lower order with special tool holders. Formation of micro chipping on insert edge present in conventional tool holder is because of peeling off of the built up edge from the tool material. This effect is more with higher temperature. Faster removal of heat from the cutting tool insert, results in reducing abrasion wears by retaining tool hardness and also adhesion and diffusion type of wears which are considered highly sensitive to high temperature. Due to this thermal load diversion technique there will be reduction in growth of flank wear. Also the tool life will be much higher, if heat sink material is more in the tool holder. But with more amount of heat sink material, the tool holder may loose its stability. The micro chipping which is observed more with inserts of conventional tool holder is not present with special tool holder. The built up edge formed on all the inserts also indicate that the speed of the machining process can be increased to a still higher value. The lower temperature values with special tool holder clearly indicate that the process parameters can also be increased still to higher values The lathe tool dynamometer is used to determine the cutting force values coming on insert due to metal cutting activity. The table 3 shows the values of cutting force before and after 60 minutes of cutting test

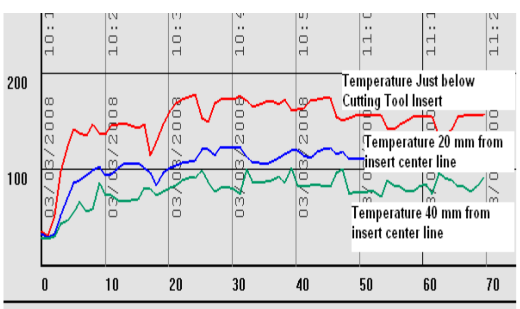



**Fig.7 Thermocouple Readings with Conventional Tool Holder with speed 280 rpm and feed of 0.45 mm / rev**

It is observed in this study, that the wear land on the cutting tool insert as well as the micro chipping on the cutting edge increases the cutting force. The change in percentage of cutting force value is observed more with insert present in the conventional tool holder.

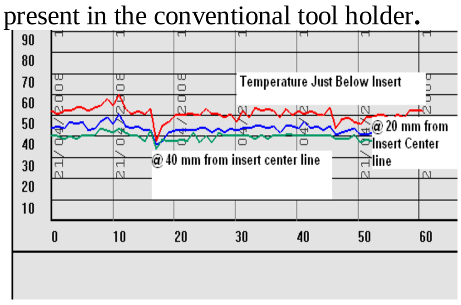



**Fig.8 Thermocouple Readings for Special Tool Holder speed of 180 rpm and feed of 0.45 mm / revolution**

Increase of cutting force value is mainly due generation of chipped edge of cutting tool insert. The maximum percentage increase of cutting forces in case of conventional tool holder is of the order of 30 percent, and that of the special tool holders is 22 percent. Thus there is almost 26 percent reduction of cutting force with inserts of special tool holder. The reduction of cutting force is mainly because of reduced wear on nose (Figure 10.5) as well as on the flank surface (Figure 10.4) of the cutting tool insert. Even though there may not be drastic reduction of cutting force with inserts of special tool holder, it is certain that the condition of cutting tool insert is better for the given cutting process parameters. The built-up edge is appeared for all trials mainly because of lower cutting speed for given workpiece – tool combination Surface roughness is another important index of machinability. The machining environment influences this for given cutting tool insert with that of workpiece pair and also machining parameters like speed and feed conditions. The maximum roughness value for insert present in conventional tool holder is ranging from 9.23 to 10.68 µm and for the workpiece machined by special tool holder with copper as heat sink material it is 6.72 to 9.27 µm. These surface conditions of the workpiece highlights that there is a correlation between the condition of cutting tool insert and that of the roughness value on the workpiece. The micro chipping which is major reason for failure of cutting tool insert present with conventional tool holder, on its flank as well as on the nose reveals that there is an enhanced surface roughness value of workpiece. The same is not true for the inserts present in special tool holder.

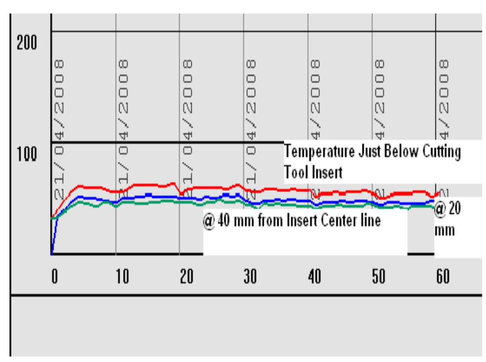
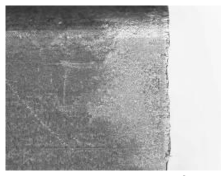



**Fig.9 Thermocouple Readings for Special Tool Holder with Copper as heat sink material for speed of 280 rpm and feed of 0.45 mm / revolution**

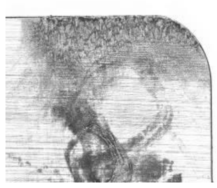
However it is evident that heat sink materials present in the tool holder provides a heat channel for the thermal load on the cutting tool insert. And this arrangement substantially im0070roves surface finish, from the figure 4 it is clear that the initial temperature

Inserts with Conventional tool Holder



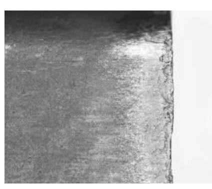
10. 1 Flank Surface

10.2 Nose



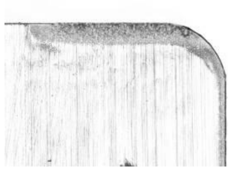
10.3 Rake Surface

Inserts with Special Tool Holder



10.4 Flank Surface

10.5 Nose



10.6 Rake Surface

**Fig.10 Status of cutting tool insert from Nikon Measuring Microscope with 30X**

at the cutting tool insert is around 640ºC. This temperature is getting increased in case of conventional tool holder where as this temperature will be reduced to 540 ºC in special tool holder. This gives direct evidence for the heat diversion technique. The final temperature in case of conventional tool holder from the thermocouple output is 190 ºC (Figure 7) and that of special tool holder is 65 ºC (Figure 9).

## 5. Conclusion

The concept of diverting the heat from high temperature cutting zone is a derived version of use of heat pipe technique. But an effort is made in this study to develop a product that actually augments the life of cutting tool inserts, in more simple way. This is very much apparent in the temperature verses time graphs as shown in figures 4 to 9 The passive heat extraction technique through, copper as a heat sink material can provide environment friendly manufacturing without cutting fluid.

i. The passive heat extraction technique reduces the cutting temperature by almost 100 degree centigrade at the tool tip.

ii. Passive heat extraction technique reduces the maximum average cutting force by almost 26 percent and safe guards the cutting edges of the insert.

iii. The flank, nose and crater wear on the inserts with special tool holders are considerably less. Therefore the process parameters can be increased for high rate of production.

iv. More built up edge on the cutting tool inserts with conventional tool holder is mainly because of higher temperature in the cutting zone. This effect is considerably less with inserts in special tool holders.

v. Due to very high temperature resulting from cutting and rubbing action at the tool tip and workpiece interface the cutting tool insert present in conventional setup experiences more damage as can be seen in figure 10.1, 10.2 and 10.3. This effect is comparatively less in case of insert present with special tool holder as observed in the figure 10.4, 10.5 and 10.6.

## References

1. *Wisley Falco Sales, Anselmo Edurdo Diniz, and Alissonm Rocha Machdo. "Application of Cutting fluids in Machining Processes", Journal of Brazilian Society of Mechanical Sciences, Vol. 23(2), 2001*

2. *Don Graham "Going Dry", Manufacturing Engineering, Vol.124(1), 72 – 78, 2000*

3. *P. S. Sreejith and B. K. A. Ngoi "Dry machining: Machining of the future" International Journal of Machine Tools and Manufacture, vol. 46,287 –29, 2000*

4. *Nikhil Ranjan Dhar, M Kamruzzaman, M M A Khan and A B Chattopadhyay " Effects of Cryogenic Cooling by*

*Liquid Nitrogen Jets on Tool Wear, Surface Finish and Dimensional Deviation in Turning Different Steels" Int. J. Machining and Machinability of Materials Vol. 1, No1, 115 – 131, 2006*

5. *R L Judd, H S Mackenzie and M A Elbestawi, "An investigation of a heat pipe cooling system for use in turning on a lathe", International Journal of Advance Manufacturing Technology, 357 – 366. 1995*
6. *Richard Y Chiou, Jim S J Chen, Lin Lu and Ian Cole,, "Prediction of Heat Transfer Behavior of Carbide inserts with Embedded Heat pipes for Dry Machining", Proceedings of IMEC, ASME International Mechanical Engineering Congress & Exposition, Nov 17 – 22, New Oreans , LA,PP, 2002*
7. *A Noorul Haq & T Tamizharasan, "Investigation of the effects of cooling in hard turning operations", Int. Journal of Advanced Manufacturing Technology, V 30, 808 – 816, 2006*
8. *Dr. B J Ranganath, "Text Book: Metal Cutting and Tool Design", Vikas Publication Pvt. Ltd, 36-40, 2004*
9. *M C Shaw, "Text Book: Metal Cutting Principles", CBS Publications & Distributors, 251 – 270, 2003*
10. *Corokey by SANDVIK – CORAMAT, 44-45, 2006*
11. *Lathe Tooling Hand Book by WIDIA, A product of Kennametal Inc, 27 - 28*
12. *T A Sadashivan and D Saraty, "Cutting tools for productive machining", WIDIA (India) Ltd. , 6.1 – 6.16, 6.45., 1999*
13. *Edward M. Trent and Paul K. Wright, "Chapter 5: Heat in Metal Cutting", Text Book Metal Cutting pp 97-131, 2007*
14. *F. Klocke and G. Eisenblätte, "Dry Cutting", CIRP Annals - Manufacturing Technology Volume 46, Issue 2, 519-526, 2007*
15. *M S Ganesha Prasad, D R Kumar, D N Drakashyani, "Studies on Computational Analysis of Cutting Tool Insert and Insert Holder for Augmentation of Cutting tool Insert Life", Proceedings of international Conference on Applications and Design in Mechanical Engineering University Malaysia, Perlis, Malaysia. 25$^{th}$ – 26$^{th}$ October 2007, ISBN: 978-983-42358-3-3, 331 – 335*
16. *D. Mari and D. R. Gonseth, "A New Look at Carbide Tool Life", Wear, Vol. 165(1), 9 – 17. 1993*
17. *Sata T, Takeuchi Y "Improvement of working accuracy of NC lathe by compensation for the thermal expansion of the tool. Annals CIP, 30 (1), 445 - 449, 1981*

## Acknowledgement

This research work is funded by All India Council for Technical Education ( A I C T E ) New Delhi, India (File No 8023 / BOR / RID / RPS -12 / 2007 – 08) under Research Promotion Scheme and support given by R & D and Testing Department of Kennametal India Ltd, Bangalore, India in using wear Measuring Microscope is sincerely acknowledged. The authors are also grateful to the Department of Mechanical Engineering, Sir M Visvesvaraya Institute of Technology, Bangalore, India for providing the facilities to carry out the project.