HEAT PIPE ASSISTED DRY TURNING

Project Report

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HEAT PIPE ASSISTED DRY TURNING

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MECHANICAL ENGINEERING

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INDIAN INSTITUTE OF TECHNOLOGY BHUBANESWAR

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INDIAN INSTITUTE OF TECHNOLOGY BHUBANESWAR CANDIDATES' DECLARATION

We hereby certify that the work which is being presented in the project entitled "**Heat pipe assisted dry turning**", in the partial fulfilment of the requirement for the award of the Degree of Bachelor of Technology in Mechanical Engineering and submitted in the School of Mechanical Sciences, Indian Institute of Technology Bhubaneswar, is an authentic record of our own work carried out during a period from July 2015 to April 2016 under the supervision of **Dr. Mihir Kumar Das and Dr. V Pandu Ranga,** IIT Bhubaneswar.

The matter presented in the project has not been submitted by us for the award or any degree of this or any other Institute/ University

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CERTIFICATE

This is to certify that the thesis entitled "**Heat Pipe Assisted Dry Turning"** submitted by **AKARSH VARRE** and **HAREESH PAREPALLI** to Indian Institute of Technology Bhubaneswar is record of bona fide research work under our supervision and we consider it worthy of consideration for the award of degree of Bachelor of Technology (Mechanical) of the institute.

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ABSTRACT

The purpose of this project is to determine the effectiveness of the use of heat pipe in turning operations on reducing cutting temperature. The temperature of a tool plays an important role in thermal distortion and the machined part's dimensional accuracy, as well as the tool life. The heat pipe has been used to effectively remove the heat generated at the tool chip interface in machining, thereby, reducing tool wear and prolonging tool life. In particular, the technique can effectively minimize pollution and contamination of the environment caused by cutting fluids, and the health problems of skin exposure and particulate inhalation in manufacturing. Experiments were conducted to determine the temperatures of the cutting tool under various conditions. Numerical simulations were carried out using finite element methods in ANSYS on the cutting tool and the obtained results were compared to determine the effectiveness. Also, a new method has been proposed i.e. to make a hole in the insert (at an optimum position whose center is 3.5mm away from the nose of the insert) rather than in the tool holder to increase the effectiveness of heat pipe without disturbing the quality of machining.

CONTENTS

1. Introduction

A large amount of heat is generated during machining process as well as in different process where deformation of material occurs. The temperature that is generated at the surface of cutting tool (insert) when cutting tool comes in contact with the work piece is termed as cutting tool temperature. Heat is a parameter which strongly influences the tool performance during the operation. We know the power consumed in metal cutting is largely converted into heat. Several experimental attempts have been made to predict and measure the temperatures involved in the process .Though it was found that there was no precised experimental method to check the analytical parameters. Temperature being developed during cutting it is of much concern as a result heat are mainly dependent on the contact between the tool and chip, the amount of cutting force and the friction between the tool and chip. Almost all the heat energy produced is transferred into the cutting tool and work piece material while a portion is dissipated through the chip. During machining the deformation process is highly concentrated in a very small zone and the temperatures generated in the deformation zone affect both the work piece and tool. Tool wear, tool life, work piece surface integrity, chip formation mechanism are strongly influenced at high cutting temperatures and contribute to the thermal deformation of the cutting tool which is considered as the largest source of error in the machining process. Thus machining can be improved by monitoring and controlling of cutting tool temperature.

HEAT PIPES:

A heat pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces.

At the hot interface of a heat pipe a liquid in contact with a thermally conductive solid surface turns into a vapor by absorbing heat from that surface. The vapor then travels along the heat pipe to the cold interface and condenses back into a liquid – releasing the latent heat. The liquid then returns to the hot interface through either capillary action, centrifugal force, or gravity, and the cycle repeats. Due to the very high heat transfer coefficients for boiling and condensation, heat pipes are highly effective thermal conductors. The effective thermal conductivity varies with heat pipe length, and can approach 100 kW/(m·K) for long heat pipes, in comparison with approximately 0.4 kW/(m·K) for copper.

Structure, design and construction:

A typical heat pipe consists of a sealed pipe or tube made of a material that is compatible with the working fluid such as copper for water heat pipes, or aluminum for ammonia heat pipes. Typically, a vacuum pump is used to remove the air from the empty heat pipe. The heat pipe is partially filled with a working fluid and then sealed. The working fluid mass is chosen so that the heat pipe contains both vapor and liquid over the operating temperature range.

Below the operating temperature, the liquid is too cold and cannot vaporize into a gas. Above the operating temperature, all the liquid has turned to gas, and the environmental temperature is too high for any of the gas to condense. Whether too high or too low, thermal conduction is still possible through the walls of the heat pipe, but at a greatly reduced rate of thermal transfer.

Working fluids are chosen according to the temperatures at which the heat pipe must operate, with examples ranging from liquid helium for extremely low temperature applications (2–4 K) to mercury (523–923 K), sodium (873–1473 K) and even indium (2000–3000 K) for extremely high temperatures. The vast majority of heat pipes for room temperature applications use ammonia (213–373 K), alcohol (methanol (283–403 K) or ethanol (273–403 K)) or water (298–573 K) as the working fluid. Copper/water heat pipes have a copper envelope, use water as the working fluid and typically operate in the temperature range of 20 to 150 °C. Water heat pipes are sometimes filled by partially filling with water, heating until the water boils and displaces the air, and then sealed while hot.

For the heat pipe to transfer heat, it must contain saturated liquid and its vapor (gas phase). The saturated liquid vaporizes and travels to the condenser, where it is cooled and turned back to a saturated liquid. In a standard heat pipe, the condensed liquid is returned to the evaporator using a wick structure exerting a capillary action on the liquid phase of the working fluid. Wick structures used in heat pipes include sintered metal powder, screen, and grooved wicks, which have a series of grooves parallel to the pipe axis. When the condenser is located above the evaporator in a gravitational field, gravity can return the liquid. In this case, the heat pipe is a thermosiphon. Finally, rotating heat pipes use centrifugal forces to return liquid from the condenser to the evaporator.

Heat pipe materials and working fluids:

Heat pipes have an envelope, a wick, and a working fluid. Heat pipes are designed for very long term operation with no maintenance, so the heat pipe wall and wick must be compatible with the working fluid. Some material/working fluids pairs that appear to be compatible are not. For example, water in an aluminum envelope will develop large amounts of non-condensable gas over a few hours or days, preventing normal operation of the heat pipe.

Since heat pipes were rediscovered by George Grover in 1963, extensive life tests have been conducted to determine compatible envelope/pairs, some going on for decades. In a heat pipe life test, heat pipes are operated for long periods of time, and monitored for problems such as non-condensable gas generation, material transport, and corrosion.

The most commonly used envelope (and wick)/fluid pairs include:

- Copper envelope/Water working fluid for electronics cooling. This is by far the most common type of heat pipe.
- Copper or Steel envelope/Refrigerant R134a working fluid for energy recovery in HVAC systems.
- Aluminum envelope/Ammonia working fluid for Spacecraft Thermal Control.
- Super alloy envelope/Alkali Metal (Cesium, Potassium, Sodium) working fluid for high temperature heat pipes, most commonly used for calibrating primary temperature measurement devices.

Vapor chamber or flat heat pipes:

Thin planar heat pipes (heat spreaders) have the same primary components as tubular heat pipes: a hermetically sealed hollow vessel, a working fluid, and a closed-loop capillary recirculation system. In addition, a series of posts are generally used in a vapor chamber, to prevent collapse of the flat top and bottom when the pressure is lower than atmospheric, which is 100 °C for water vapor chambers.

Variable Conductance Heat Pipes (VCHPs):

Standard heat pipes are constant conductance devices, where the heat pipe operating temperature is set by the source and sink temperatures, the thermal resistances from the source to the heat pipe, and the thermal resistances from the heat pipe to the sink. In these heat pipes, the temperature drops linearly as the power or condenser temperature is reduced. For some applications, such as satellite or research balloon thermal control, the electronics will be overcooled at low powers, or at the low sink temperatures. Variable Conductance Heat Pipes (VCHPs) are used to passively maintain the temperature of the electronics being cooled as power and sink conditions change.

Diode heat pipes:

Conventional heat pipes transfer heat in either direction, from the hotter to the colder end of the heat pipe. Several different heat pipes act as a thermal diode, transferring heat in one direction, while acting as an insulator in the other.

Thermosyphons:

Most heat pipes use a wick and capillary action to return the liquid from the condenser to the evaporator. The liquid is sucked up to the evaporator, similar to the way that a sponge sucks up water when an edge is placed in contact with a water pool. The wick allows the heat pipe to operate in any orientation, but the maximum adverse elevation (evaporator over condenser) is relatively small, on the order of 25 cm long for a typical water heat pipe.

Heat transfer:

Heat pipes employ evaporative cooling to transfer thermal energy from one point to another by the evaporation and condensation of a working fluid or coolant. Heat pipes rely on a temperature difference between the ends of the pipe, and cannot lower temperatures at either end beyond the ambient temperature (hence they tend to equalize the temperature within the pipe).

When one end of the heat pipe is heated the working fluid inside the pipe at that end evaporates and increases the vapour pressure inside the cavity of the heat pipe. The latent heat of evaporation absorbed by the vaporization of the working fluid reduces the temperature at the hot end of the pipe.

The vapour pressure over the hot liquid working fluid at the hot end of the pipe is higher than the equilibrium vapour pressure over the condensing working fluid at the cooler end of the pipe, and this pressure difference drives a rapid mass transfer to the condensing end where the excess vapour condenses, releases its latent heat, and warms the cool end of the pipe. Non-condensing gases (caused by contamination for instance) in the vapour impede the gas flow and reduce the effectiveness of the heat pipe, particularly at low temperatures, where vapour pressures are low. The speed of molecules in a gas is approximately the speed of sound, and in the absence of noncondensing gases (i.e., if there is only a gas phase present) this is the upper limit to the velocity with which they could travel in the heat pipe. In practice, the speed of the vapour through the heat pipe is limited by the rate of condensation at the cold end and far lower than the molecular speed.

The condensed working fluid then flows back to the hot end of the pipe. In the case of vertically oriented heat pipes the fluid may be moved by the force of gravity. In the case of heat pipes containing wicks, the fluid is returned by capillary action.

Applications

- **Spacecraft**

Heat pipes on spacecraft typically use a grooved aluminum extrusion as the envelope.

- Permafrost cooling
- Cooking

Ventilation heat recovery

In heating, ventilation and air-conditioning systems, HVAC, heat pipes are positioned within the supply and exhaust air streams of an air handling system or in the exhaust gases of an industrial process, in order to recover the heat energy.

Limitations

- Heat pipes must be tuned to particular cooling conditions. The choice of pipe material, size and coolant all have an effect on the optimal temperatures at which heat pipes work.
- When heated above a certain temperature, all of the working fluid in the heat pipe vaporizes and the condensation process ceases; in such conditions, the heat pipe's thermal conductivity is effectively reduced to the heat conduction properties of its solid metal casing alone. As most heat pipes are constructed of copper (a metal with high heat conductivity), an overheated heatpipe will generally continue to conduct heat at around 1/80 of the original flux via conduction only rather than conduction and evaporation.
- Most manufacturers cannot make a traditional heat pipe smaller than 3 mm in diameter due to material limitations (though 1.85 mm thin sheets with embedded, flattened heat pipes can be fabricated, as well 1.0 mm thin vapor chambers). Experiments have been conducted with micro heat pipes, which use piping with sharp edges, such as triangular or rhombus-like tubing. In these cases, the sharp edges transfer the fluid through capillary action, and no wick is necessary.

SINGLE POINT CUTTING TOOL:

Basic Terms and Definitions

The geometry and nomenclature of cutting tools, even single-point cutting tools, are surprisingly complicated subjects. It is difficult, for example, to determine the appropriate planes in which the various angles of a single-point cutting tool should be measured; it is especially difficult to determine the slope of the tool face. The simplest cutting operation is one in which a straight-edged tool moves with a constant velocity in the direction perpendicular to the cutting edge of the tool. This is known as the two-dimensional or orthogonal cutting process illustrated in the below figure (1). The cutting operation can best be understood in terms of orthogonal cutting parameters.

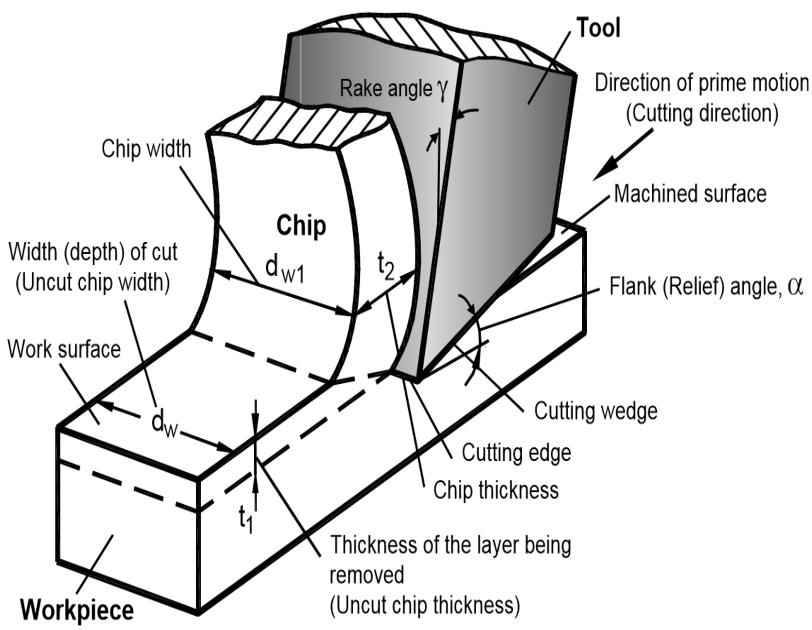

Figure 1

Tool Surfaces and Elements:

The design components of the cutting tool are defined as follows:

- *Rake face* is the surface over which the chip, formed in the cutting process, slides

- *Flank face* is the surface(s) over which the surface, produced on the workpiece
- *Cutting edge* is a theoretical line of intersection of the rake and the flank surfaces
- *Cutting wedge* is the tool body enclosed between the rake and the flank faces
- *Shank* is the part of the tool by which it is held

Geometry Parameters of Indexable Inserts:

The following parameters of the cutting tool geometry are distinguished by these standards:

- The shape of inserts, this may give only a very vague idea of the tool cutting edge angle because this angle is mainly determined by the tool holder. However, the shape of insert indicates a possible range of the tool cutting edge angle and the tool cutting edge angle of the minor cutting edge variations which is the starting point in the selection of a particular shape.

Figure 1.2

Geometry Parameters of Tool Holders for Indexable Inserts:

Out of nine compulsory and one optional symbols in this designation, only one directly and one conditionally relate to the tool geometry. Tool style symbol defines the tool cutting edge.

Insert clearance symbol relates to the insert flank angle. It is not clear, however, how the tool holder supports or modifies this angle. Although, as mentioned above, indexable inserts with zero flank angle (N) are the most popular in practice, it does not follow from the tool holders standard designation what the flank angle (if any) they provide in this most common case. The next section that deals with the tool geometry of the assemblage “insert tool holder” aims to clarify this important issue.

Geometry Parameters of Single Point Tools with Indexable Inserts:

The above-discussed process of selection of indexable inserts and tool holders defines the following parameters of the tool geometry:

- The tool cutting edge angles of the major and minor cutting edges
- The nose radius
- The shape of the cutting edge and particularities of edge preparation if used
- The shape of the chipbreaker if used

Three other major parameters of the tool geometry (when the insert is mounted into the toolholder), namely, the rake, flank, and cutting edge inclination angle, are not defined. The next sections are clarify the issue.

Rake Angle

Tools manufacturers made distinction between the so-called negative and positive insert geometry. According to this perception, a negative insert has the normal wedge angle of 90 degrees while this angle is of less than 90 degrees for a positive insert. The negative insert has to be inclined negatively in the toolholder so as to provide a suitable flank angle (clearance) while the positive insert has this clearance built-in.

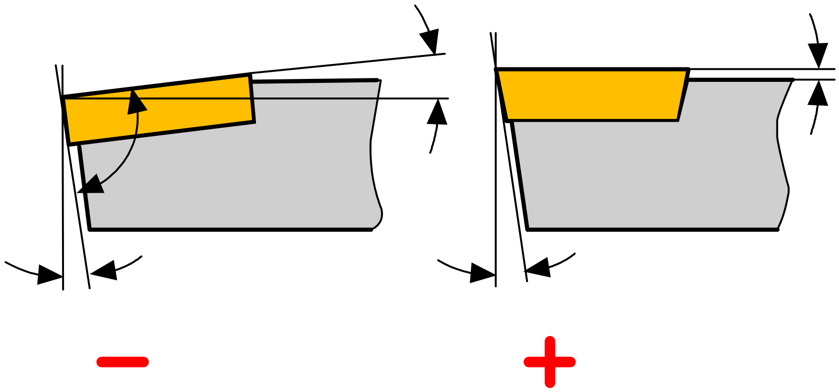

Figure 1.3

Flank Angle

Apart from the rake angle, the actual value of the flank angle (clearance) should be known exactly as this angle strongly affects tool performance. Obtaining this real value for a single-point tool with an indexable insert may present some challenge because this value does not appear in the tool holder designation or in its specifications in the catalogs of tool and toolholder manufacturers. Not only are there no explanations provided on the selection of this important angle in these catalogs and in other training/advertisement brochures, materials, flyers, but also this angle is not even mentioned. Therefore, a need is felt to clarify the issue.

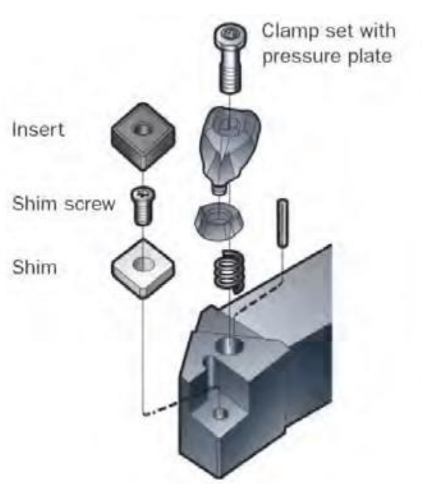

Figure 1.4

Carbide Inserts

Carbide inserts are replaceable and usually indexable bits of cemented carbide used in machining steels, cast iron, high temperature alloys, and nonferrous materials. Carbide inserts allow faster machining and leave better finishes on metal parts. Carbide inserts can withstand higher temperatures than high speed steel tools.

Cemented carbides are composed of a metal matrix composite where carbide particles act as the aggregate and a metallic binder serves as the matrix. The process of combining the carbide particles with the binder is referred to as sintering. During this process, the binder eventually will be entering the liquid stage and carbide grains (much higher melting point) remain in the solid stage. The binder is embedding/cementing the carbide grains and thereby creates the metal matrix composite with its distinct material properties. The naturally ductile metal binder serves to offset the characteristic brittle behavior of the carbide ceramic, thus raising its toughness and durability. Such parameters of carbide can be changed significantly within the carbide manufacturer's sphere of influence, primarily determined by grain size, cobalt content, dotation, and carbon content.

Carbide is more expensive per unit than other typical tool materials, and it is more brittle, making it susceptible to chipping and breaking. To offset these problems, the carbide cutting tip itself is often in the form of a small insert for a larger tipped tool whose shank is made of another material, usually carbon tool steel. This gives the benefit of using carbide at the cutting interface without the high cost and brittleness of making the entire tool out of carbide. Most modern face mills use carbide inserts, as well as many lathe tools and endmills.

Figure 1.5

To increase the life of carbide inserts, they are sometimes coated. Four such coatings are TiN (titanium nitride), TiC (titanium carbide), Ti(C)N (titanium carbide-nitride), and TiAlN (titanium aluminum nitride). Most coatings generally increase a tool's hardness and/or lubricity. A coating allows the cutting edge of a tool to cleanly pass through the material without having the material gall or stick to it. The coating also helps to decrease the temperature associated with the cutting process and increase the life of the tool. The coating is usually deposited via thermal CVD and, for certain applications, with the mechanical PVD method at lower temperatures.

2. Theory and Literature review

During metal cutting, the magnitude of the temperature on the cutting edge is a function of the cutting parameters. Temperature estimation is one of the most difficult and complicated procedures in metal cutting operations. Due to the complexity of the various events taking place at the point of contact between the tool and workpiece, developing a model for measuring the temperature is an extremely difficult process.

Lowen and Shaw developed an analytical prediction model for the measurement of cutting temperatures during machining. They concluded that the cutting temperature is the function of cutting speed and feed rate. They specified the average cutting speed as:

$$\Theta_t = V^{0.5} f^{0.3} \qquad \text{……………… (2.1)}$$

Where θ_t is the average cutting temperature, V is the cutting speed and f is the feed rate.

Temperature measurement techniques include thermocoupling, measurement of infrared radiation (pyrometers, infrared photography, *etc*.) and the use of thermo-sensitive paint, as well as metallography based on metal microstructure or microhardness variations, measurement of temper colour. Each technique has its own advantages and limitations depending on the physical measurement.

Thermocouples are one of the most widely used experimental methods for measuring the temperature in machining. Thermocouples are conductive, inexpensive, can be operated over a wide temperature range and can be easily applied; however, they only measures the mean temperature over the entire contact area of the tool and the workpiece. Thermocouples are one of the most widely used experimental methods for measuring the temperature in machining. Thermocouples are conductive, inexpensive, can be operated over a wide temperature range and can be easily applied; however, they only measures the mean temperature over the entire contact area of the tool and the workpiece.

Type K thermocouple is chosen to measure the interface temperatures in our experimentation. Type K (chromel- alumel) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C range (−330 °F to +2460 °F).

Figure 2.1: Type K thermocouple

Ay and Yang used a technique with K-type thermocouples to analyze the temperature variations in carbide inserts along the cutting edge when cutting various materials such as copper, cast iron, aluminum 6061 and AISI 1045 steel.

Abdil Kus made a thermocouple based temperature measurement in metal cutting process using K-type thermocouple on PVD AlTiN insert. On the other hand temperature measurement using K type thermocouple on High Speed Steel tool is performed by S H Rathod.

One way of improving the cutting performance is increasing the life of the cutting tool. This can be achieved by reducing the average cutting temperature and reduction in cutting temperature may be brought about by introducing heat pipes at specified locations near the cutting tools. Extraction of heat from the cutting zone using heat pipe is an alternative to conventional method of removing heat from the cutting zone using cutting fluid and has become an emerging area of interest recently. In the literature review there are reports highlighting the application of heat pipes as a means of extracting heat from the cutting tool. Heat pipe assisted cooling systems can reduce or eliminate the need for cutting fluids and contamination of the environment by cutting fluids. In the literature review there are report of heat pipe assisted cooling of cutting tools in various machining operations such as turning and drilling. On a similar line an alternate cooling technique consisting of installing heat pipe in contact with cutting inserts was explored in the present investigation to cool and thereby improve the life of the cutting tool during turning of AISI 1045.

When the heat pipe was not installed, let T_1 be the average cutting temperature of the face ABCD of the insert and T_2 that of the face EFGH. If K is the thermal conductivity of the material of the insert, A is the area of cross section and x is the distance between the faces ABCD and EFGH, the rate of heat (Q_1) transferred from the face ABCD to EFGH is given by

$$Q_1 = KA\left[\frac{T_1 - T_2}{x}\right] \qquad (2.2)$$

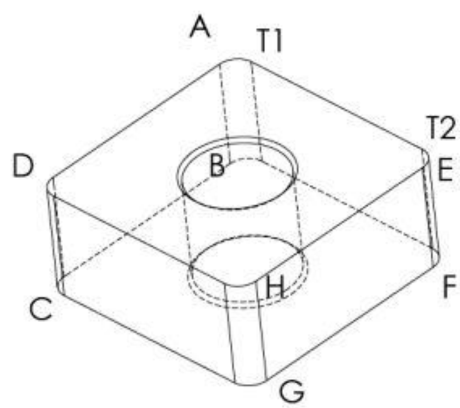

Figure 2.2 Carbide insert

But when the heat pipe was installed, let T_3 be the average temperature of the surface EFGH. The rate of heat (Q_2) transferred is given by

$$Q_2 = KA\left[\frac{T_1 - T_3}{x}\right] \qquad (2.3)$$

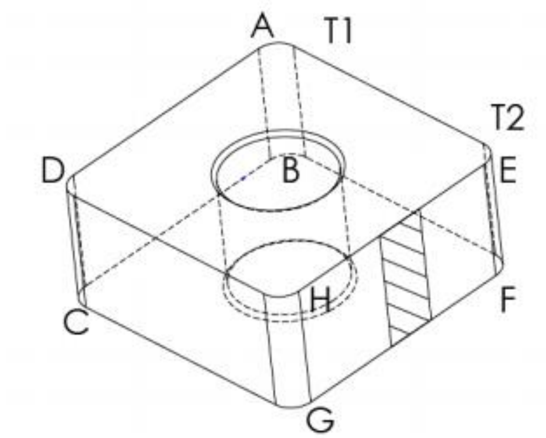

Figure 2.3

But because of the presence of the heat pipe, the face EFGH will be cooled and hence $T_3<T_2$ and from the equations (2.2) and (2.3), It can be seen that $Q_2>Q_1$. When more heat is transferred from the face ABCD, the thermal stress and the severity of temperature related damages of the tool tip reduces. Average cutting temperature is considered as the factor that accelerates all forms of tool wear. Hence when heat generated on the tool is removed at faster rate, the mechanisms responsible for tool wear of different forms become less active leading to the reduction in tool wear. Rapid removal of heat from the contact zone made possible by the presence of heat pipe leads to overall reduction of average cutting temperature and this can also reduce the thermal degradation of the cutting fluid which helps in preserving its lubricating ability. This causes the conditions in the contact zone to change from sticking to one of sliding. This leads to reduction in tool chip contact length and associated reduction in main cutting force. Better rake face lubrication and reduction in tool wear results in better surface finish.

Cutting Force Analysis - Merchant's Circle

Forces experienced by a tool during cutting is detrimental in design of mechanical structure of cutting machine, predicting power consumption, determining the tool life and increasing the productivity.

Why Cutting Force Analysis is Important?

Most of the time cutting force acting on a tool is measured experimentally. But it is also important to predict quantity of cutting force and how different cutting parameters are affecting cutting force even before setting up the machining operation due to following reasons.

1. In order to design of mechanical structure of cutting machine which will withstand cutting force and thrust force effectively.
2. To determine power consumption during machining process. This will help in selecting suitable motor drive.
3. To predict tool life.
4. To increase productivity

Cutting Terminology

The following figure 2.4 describes important terminologies used in cutting force analysis.

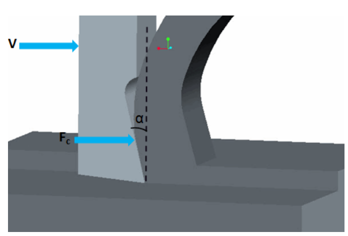

Figure 2.4

The figure shows a case where tool velocity (V) and cutting edge are perpendicular to each other, this is known as orthogonal cutting. Here we are analyzing cutting force for an orthogonal cutting operation. Cutting force (Fc) is the force parallel to cutting tool velocity. Rake angle of cutting tool is represented by 'alpha'

Forces acting on the chip

If you make a free body analysis of the chip, forces acting on the chip would be as follows.

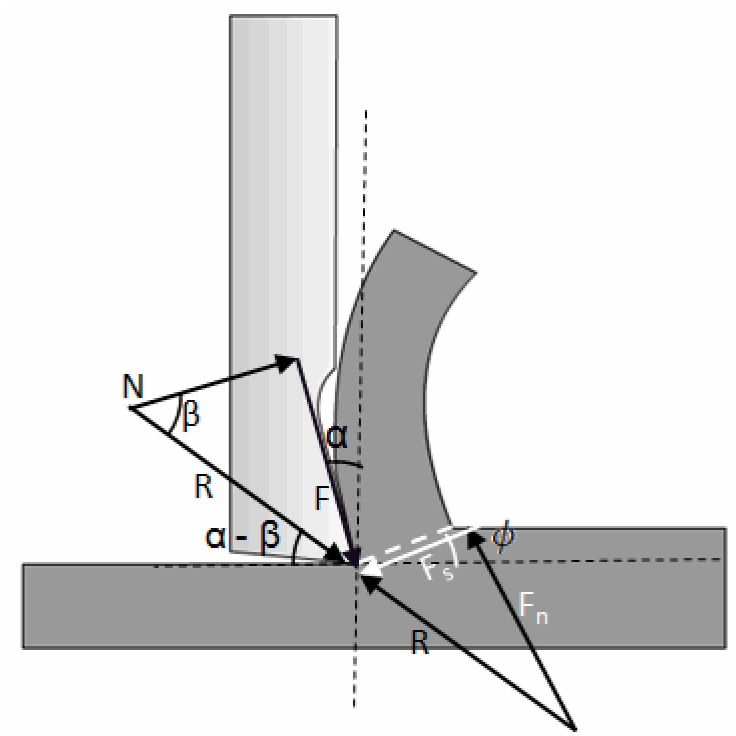

Figure 2.5: Free body diagram of orthogonal cutting

At cutting tool side due to motion of chip against tool there will be a frictional force and a normal force to support that. At material side thickness of the metal increases while it flows from uncut to cut portion. This thickness increase is due to inter planar slip between different metal layers. There should be a shear force (Fs) to support this phenomenon. According to *shear plane theory* this metal layer slip happens at single plane called shear plane. So shear force acts on shear plane. Angle of shear plane can be approximately determined using *shear plane theory* analysis. It is as follows

$$\phi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2} \qquad \text{............ (2.4)}$$

Shear force on shear plane can be determined using shear strain rate and properties of material. A normal force (F_n) is also present perpendicular to shear plane. The resultant force (R) at cutting tool side and metal side should balance each other in order to make the chip in equilibrium. Direction of resultant force, R is determined as shown in the above figure.

Merchant's Circle Analysis

Steps involved in Merchant's circle analysis is as follows. Since we know angle of resultant force at tool side, draw a line parallel to this. On one end of this line draw shear force (Fs), magnitude and direction of which is known. Now draw a line perpendicular to shear force line, it will meet resultant force line at one point. You can draw a circle assuming the intersected line as diameter of the circle, this is known as Merchant's circle. It is shown in figure 2.6 below.

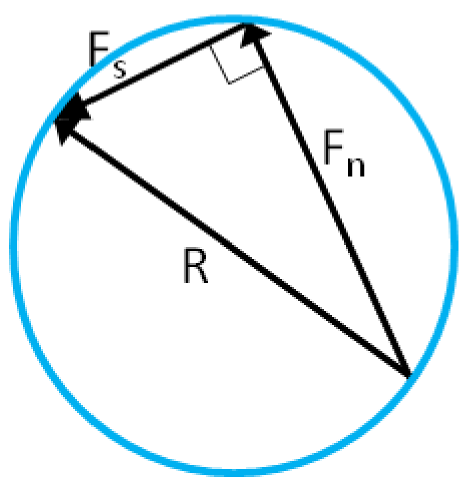

Figure 2.6: normal force and shear force

In order to determine cutting force (Fc) one can draw a line parallel to tool motion in Merchant's circle, starting from end of diameter. The chord so obtained will give magnitude of cutting force. If you draw a line perpendicular to Fc that will give thrust force acting on the tool (F_t). So resultant force, **R** at tool side also can be considered as a summation of cutting force and thrust force. The diagram so obtained is shown in following figure2.7.

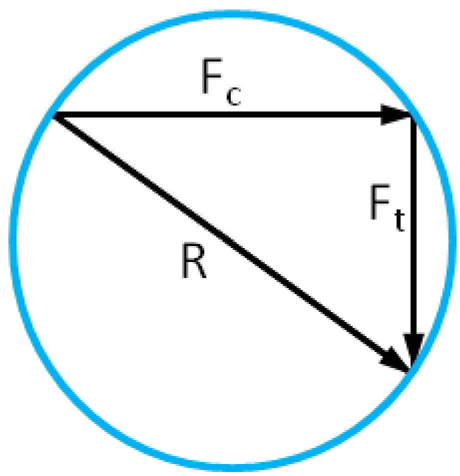

Figure 2.7: Cutting force and thrust force

3. Analytical analysis

HEAT GENERATION AND CUTTING TOOL TEMPERATURE

When a material is deformed elastically, some energy is spent to increase its strain energy which is returned during unloading. But in plastic deformation, most of th energy thus spent is converted into heat. During machining, the plastic deformation is large and takes place at a very high rate, and under such conditions, almost 99% of the energy is converted into heat. For cutting a low strength material, heat generation and the consequent increase in temperature of the tool at the cutting zone is not a big problem. However, when ferrous and other high strength materials are machined, the temperature rises with the speed and the tool strength decreases, leading to a faster wear and failure. So, though machining at a high speed is desirable, for higher productivity, the faster tool wear due to high temperature puts a limit to the cutting speed. Thus, an understanding phenomena of heat generation and temperature rise during machining is very important.

The sources of heat generation during machining is shown in the below figure 3.1.

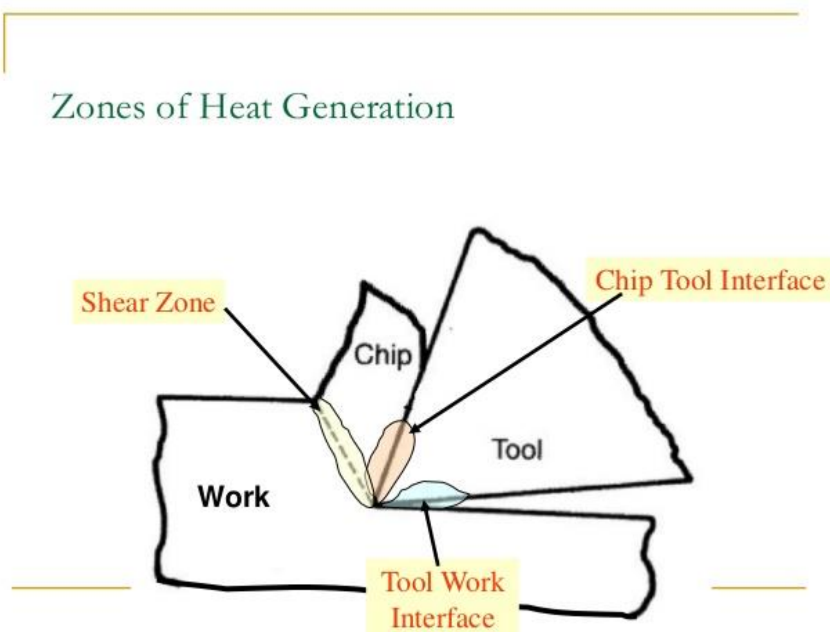

Figure 3.1

The major plastic deformation takes place in the shear zone and this heat source is the primary heat source. A large fraction of this heat goes to the chip. The sliding motion of the chip on the rake surface of the tool also generates heat, and this is secondary heat source. From this source also, the chip takes away major portion of the heat. There is another source of heat where the job rubs against the flank surface of the tool. But with sharp tools, the contribution of this source to the heating phenomenon is insignificant.

Now, the total power consumption during machining is $W=F_cV$. If the rates of heat generation in the primary and secondary are W_p and W_s, respectively, then

$W=W_p+W_s$ ………………… (3.1)

And $W_s= FV_c=FrV$ where V_c is the chip velocity.

Thus, when enough information is available, the rate of heat generation in the primary deformation zone and the secondary deformation zone can be found out.

When a material particle moves across the primary deformation zone, the temperature rise is given by

$\theta_p= (1-\Pi)\ W_p /\rho vct_1w$ ………………… (3.2)

where

Π= fraction of primary heat which goes to the work

ρ=density of the work

c=specific heat

t_1= uncut thickness

w=width

Since the computation of Π needs an elaborate analysis, we will give here only the result which agrees well with the experimental results. It has been found that Π is a function of the shear angle.

$$\Pi = 0.15 \ln(27.5/(\rho v c t_1/k)\tan\phi) \quad \text{.............................. (3.3)}$$

Hence if shear angle is known, Π can be calculated. The maximum temperature rise in the secondary deformation zone along the rake surface of the tool can be approximately expressed as

$$\Theta_s = 1.13\,(1/\,\rho v c t_1 k(1+\tan(\phi-\alpha))^{0.5}\,(W_s/w) \quad \text{..................... (3.4)}$$

And the final temperature is given by

$$\Theta = \theta_0 + \theta_p + \theta_s \quad \text{......................... (3.5)}$$

Where θ_0 initial temperature of the workpiece. This maximum temperature is along the rake surface of the tool.

And the total heat generation in watts is given by

$$Q = 1.68 d f^{0.15} V^{0.85} \quad \text{........... (3.6)}$$

Where

Q= heat generation rate in watts

F= feed rate (mm/rev)

V=cutting velocity (m/min)

And out of this total heat flow only a portion Q_c flows to the tool.

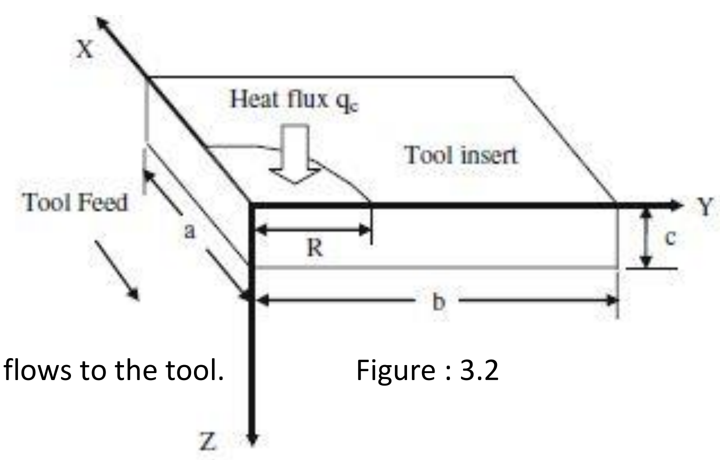

Figure : 3.2

4. Experimentation and results

Preliminary experiments were conducted to determine the influence of heat pipe on cutting performance in turning operation. Cutting experiments were conducted on a Turn master- 35 lathe. AISI 1045 steel was used as work material. Cutting tool consisted of hard metal inserts with a specification DNMG 130508 – TT 9080 grade and tool holder with a specification HDJNR 2525 M1305. High Speed steel single point cutting tool is also used to conduct used some experiments on heat pipe. All the input parameters that includes cutting speed (V), depth of cut (d), feed rate (f) were kept constant and are mentioned in the table below. A K-type digital thermometer was affixed on the flank face of the insert at a point whose horizontal distance is 2mm from nose radius and 1mm vertical distance from cutting edge. Cutting experiments were conducted during dry turning. A series of experiments were conducted on HSS tool and carbide insert tool without heat pipe and temperatures are noted. A similar experiments were conducted with installation of heat pipe and temperatures are noted. Specifications of the cylindrical heat pipe used are mentioned in the table below. Holes are drilled in both HSS tool and tool holder to accommodate heat pipe by using milling machine.

Figure 4.1 : Drilling a hole in the tool holder for the installation of heat pipe

Table 4.1: List of parameters that were kept constant

Parameter	Value
Cutting velocity (V)	37.6 m/min
Feed (f)	0.1 mm/rev
Depth of cut (d)	1 mm

Table 4.2: Specifications of heat pipe

Items	Description
Container material	Copper
Coolant	De-ionized water
Pipe diameter	3 mm
Wick type	Groove

Figure 4.2: Carbide insert tool with heat pipe

In the above mentioned figure 4.2 heat pipe is inserted in the drilled hole and thermal cement is applied so as to make a proper contact and good conductivity between the heat pipe and insert.

Machining was performed for 45sec and temperature readings were noted and are mentioned in the following table 4.3.

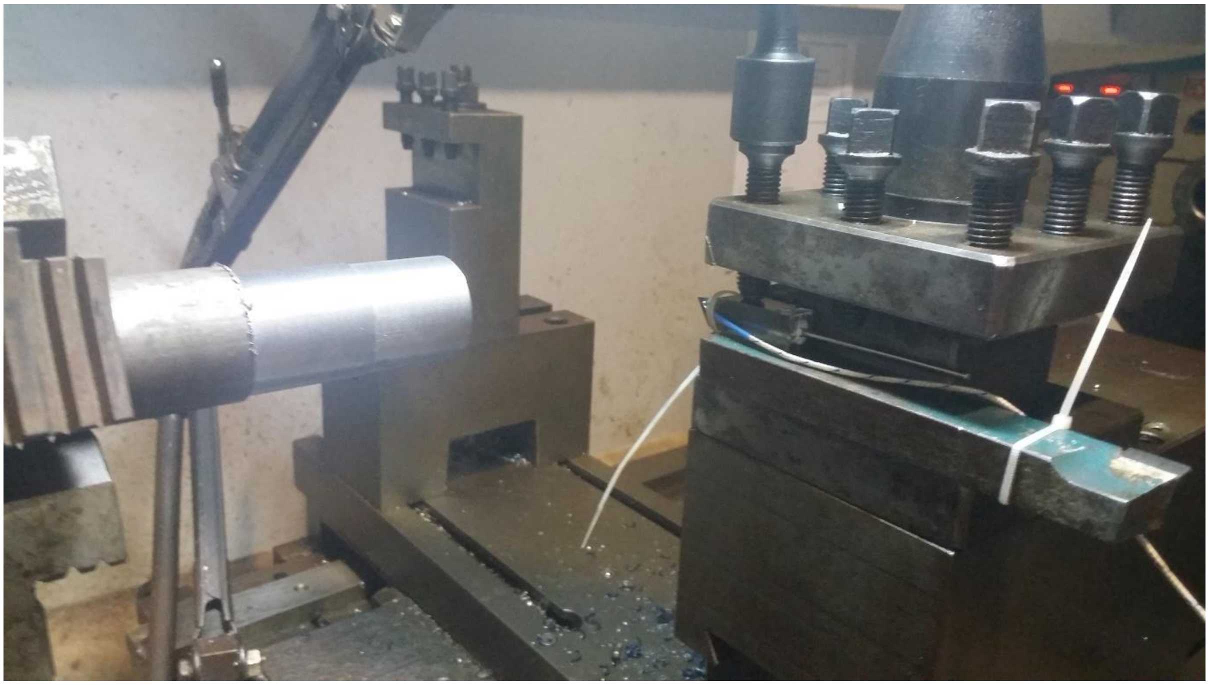

Figure 4.3: Machining of AISI 1045 with HSS tool with heat pipe installed

Thermocouple end is fixed at the required position (2mm - horizontal distance, 1mm – vertical distance) using nylon belts.

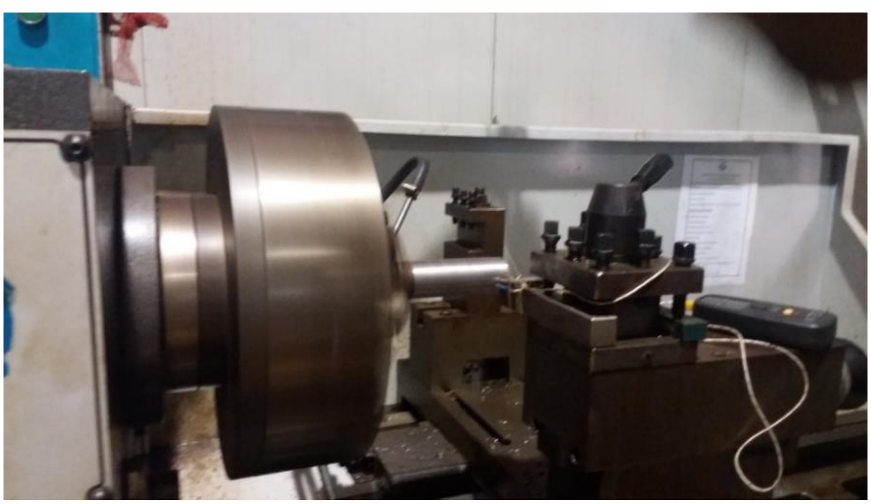

Figure 4.4: Machining of AISI 1045 using carbide insert tool without heat pipe

Figure 4.5: Temperature reading on digital thermometer while machining AISI 1045 with heat pipe installed in carbide insert

Table 4.3: Temperature readings on digital thermometer in various machining conditions

Experiment trial	Cutting tool	Without heat pipe	With heat pipe
1	HSS	118^0C	109^0C
2	HSS	117^0C	106^0C
3	HSS	118^0C	108^0C
4	Insert	86^0C	86^0C
5	Insert	83^0C	83^0C

5. Simulations and results

Specifications of Insert:

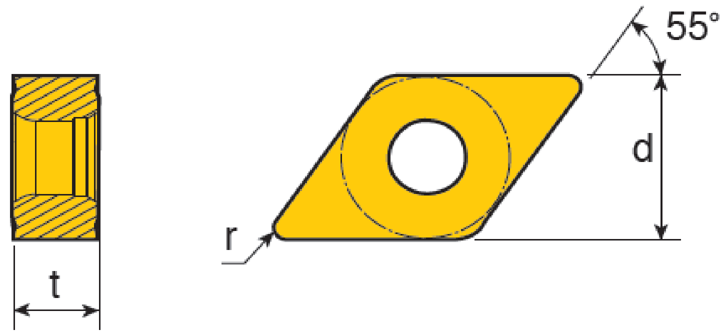

Figure 5.1

Table 5.1

Insert type	d (mm)	r (mm)	t (mm)
DNMG 130508	11.11	5.56	0.8

Static structural analysis of insert:

Based on the analytical results, normal cutting face that acts on the rake face of the tool is applied on the cutting edge to find the deformations and stress distribution in the insert. A cutting tool insert is developed in Solid works design software. Static structural analysis is performed with the help ANSYS (FEM technique). The force that was applied is 400N as per the typical machining conditions mentioned in the previous chapters.

Structural properties of the insert are given as:

Young's Modulus: 200 GPa

Poisons ratio : 0.2

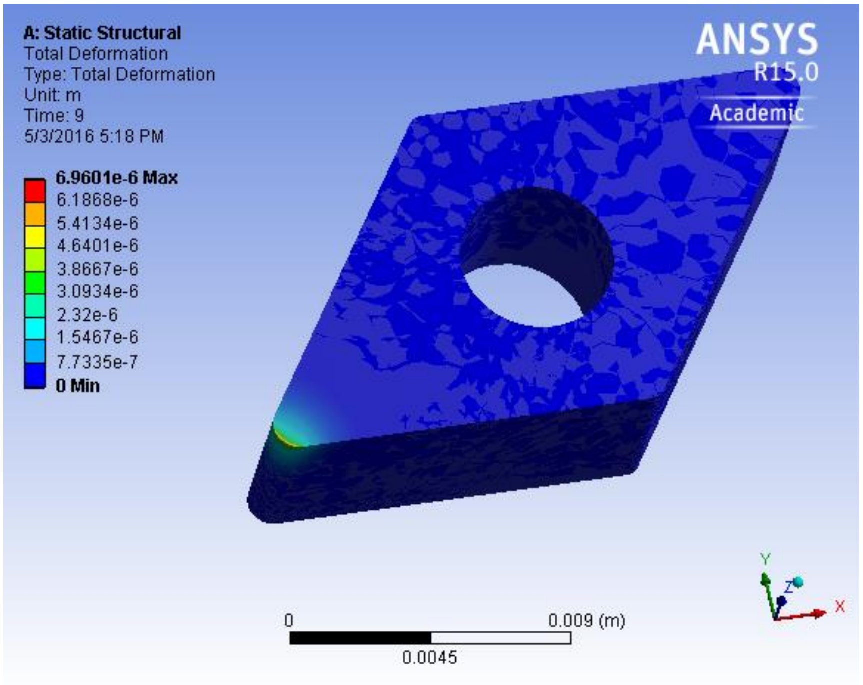

Figure 5.2: tool insert without hole

The purpose of creating a hole in the insert is to install the heat pipe as close as possible to the cutting zone without causing any damage to the tool and the heat pipe. The main aim of this static structural analysis is to determine whether the stresses (Von-misses) induced are exceeding the ultimate strength of the tool.

The following figure shows the deformation of the tool insert in which a 3mm hole is made at a distance of 4mm from extreme point of insert. Similar analysis is performed on the insert with the holes made at different positions so as to determine their structural rigidity and failure.

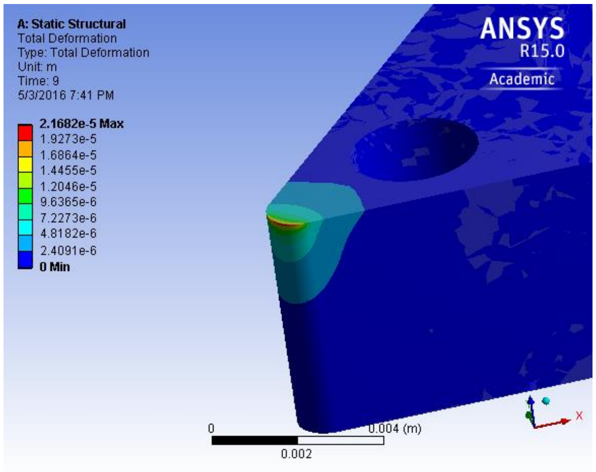

Figure 5.3: Tool insert with a hole at 4mm distance

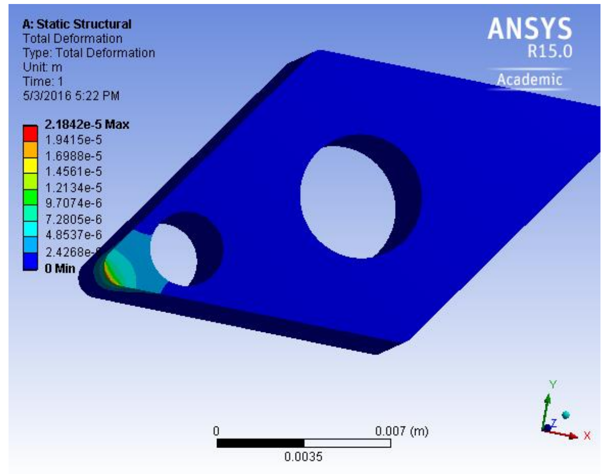

Figure 5.4: Tool insert with a hole at 3.5mm distance

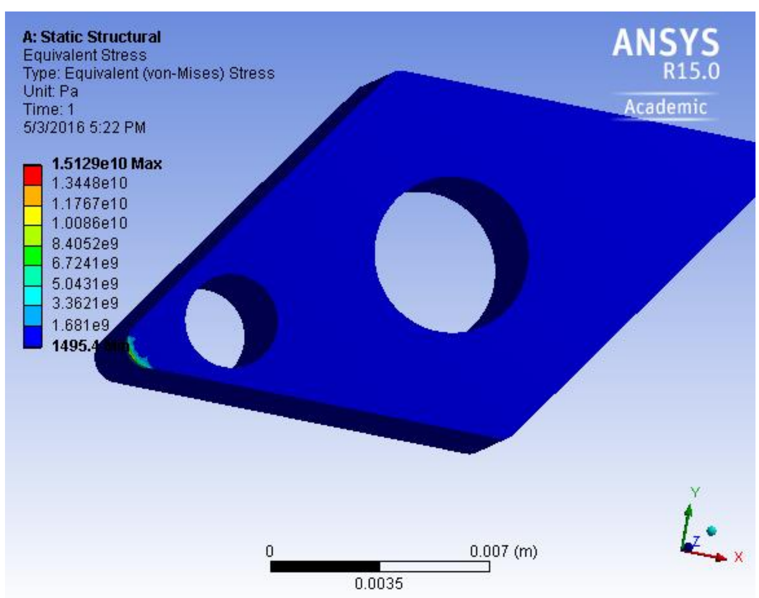

Figure 5.5: tool insert with a hole at 3.5mm distance

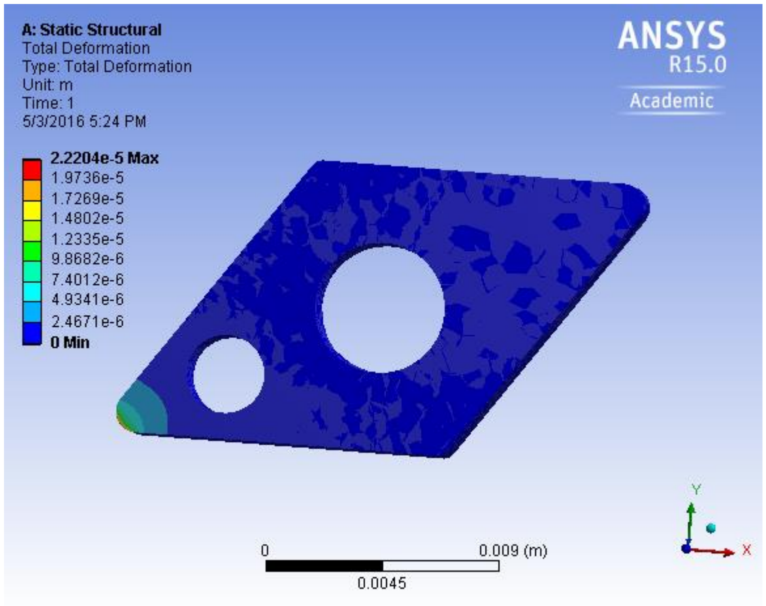

Figure 5.6: tool insert with a hole at 4.5mm distance

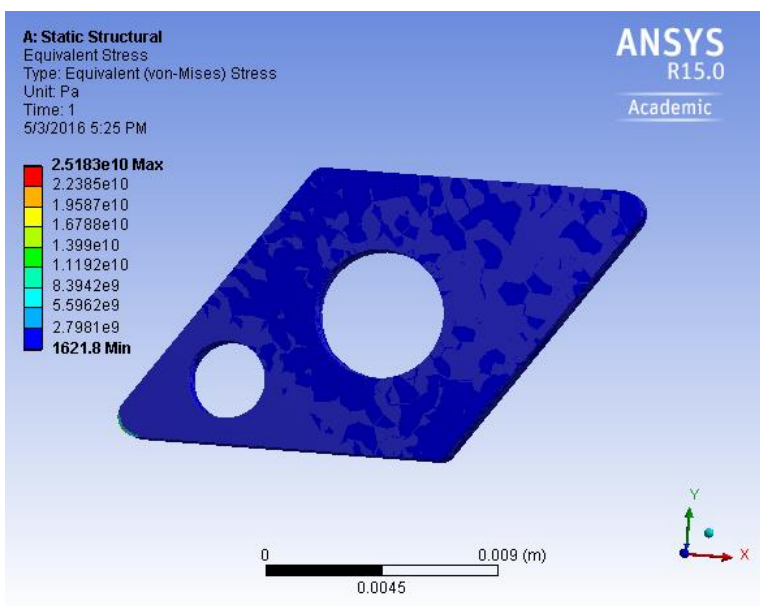

Figure 5.7: tool insert with a hole at 4.5mm distance

Thermal analysis of cutting tool insert:

A 3D model of the cutting insert is developed for the simulation of temperature based on the estimated machining heat flux over the tool-chip contact area on a tool insert of the cutting tool. Heat is generated at the tool-chip interface in the quarter-circular area of the tool insert rake surface, and a portion of it flows into the tool. The temperature distribution on the insert is obtained by the transient thermal analysis. The real geometry of the cutting tool insert is chosen as the computational domain. The typical FEM used in this cutting simulations assumed that the total power required to perform the machining is converted to heat. A simulation is based on a constant time step of 1sec for a cutting time of 40sec. The material properties of the tool insert are mentioned in the following table:

Table 5.2: Input values of FEA model for cutting tool

1.	Density of insert	14900 kg/m^3
2.	Thermal conductivity of insert	36 W/m K
3.	Specific heat of insert	302 J/Kg K

The convective heat transfer coefficients for the cutting tool top surface and the side surface are set to 20 W/m^{2} ^{0}C and 15 W/m^{2} ^{0}C respectively, with the one for the shim seat set at 5 W/m^{2} ^{0}C. A typical simulation for a cutting tool without heat pipe for heat flow of Q = 15.7 W is performed. All these boundary conditions were based on Y. Chiou.

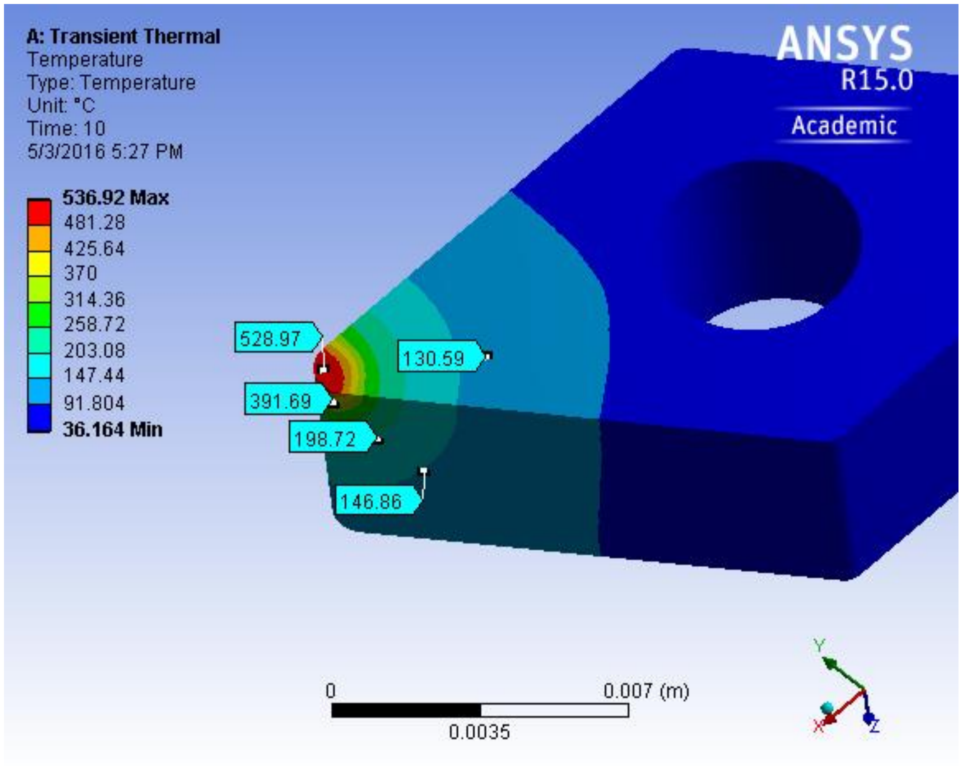

Figure 5.8: Temperature distribution of insert

As mentioned before, a hole is made in the insert to install the heat pipe. Transient thermal analysis is performed on various inserts with similar conditions to determine the temperature distribution.

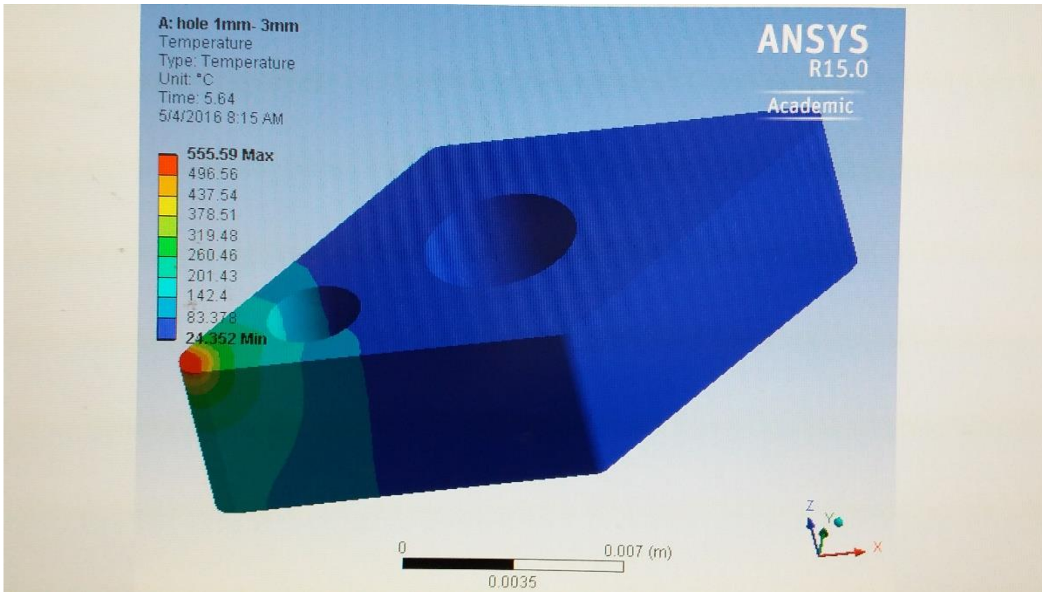

Figure 5.9: Temperature distribution on the insert with a hole at 4.5mm distance

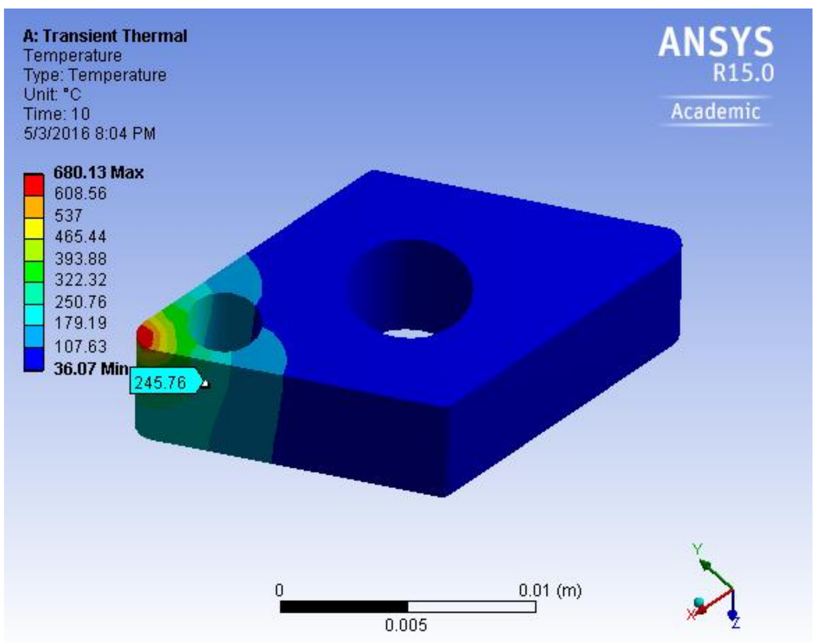

Figure 5.10: Temperature distribution on the insert with a hole at 3.5mm distance

6. Discussion

Temperature obtained from digital thermometer while machining AISI 1045 using carbide insert is compared with the temperature obtained from the transient analysis in ANSYS at the position where thermocouple is placed. It was found that both the readings are almost similar with a difference of 21^0C.

Temperature difference is not observed while machining AISI 1045 using carbide insert with and without heat pipe. The main reason is that heat distribution is not happening upto the face where heat pipe is in contact. So machining is done using high speed steel with and without heat pipe. A noticeable change of 9^0C is observed.

To utilize the heat pipe efficiently, it has to be installed near the heating zone. Therefore hole of 3mm diameter is made in the insert 3D model near the cutting zone. Static structural analysis is performed for various inserts in which holes are drilled at various positions and it was found that Von – misses stress induced are below the ultimate strength.

Transient thermal analysis is performed on the inserts with holes at different positions. In the first case where the hole is made far away from the cutting zone a temperature rise of 19^0C is observed. In the other case where the hole is made much nearer to the cutting zone a temperature rise of 130^0C is observed. This increase in temperature is observed because of reduction in the volume which leads to the decrease in the conduction. Therefore the hole which is at 4.5mm distance is chosen to install the heat pipe.

7. References

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