ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Thermal Analysis of Cutting Tools by Using Different Cutting Fluids

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ABSTRACT

Cutting fluids are used in machining operation for various reasons namely to improve tool life, to reduce work-piece thermal deformation and to improve surface finish. The usage of appropriate cutting fluids will not only reduces cutting tool cost but also increases production; this is concluded through Mota and Machado (1995).

Two main problems addressed by cutting fluids: Heat generation at shear zone and friction zone, friction at the tool chip and tool work interfaces. Benefits and other functions of cutting fluids such as wash away of chips for example milling and grinding, reducing temperature of work piece for easier handling and also to improve dimensional stability of work part.

In this thesis soluble oil, water and palm kernel oil were used as coolants in machining operations. Tungsten carbide and HSS cutting tools are employed as cutter with different temperatures. Thermal analysis is done on the parametric model to determine the effect of different cutting fluids on the cutters.

INTRODUCTION

Milling is the process of cutting away of material by feeding a work piece past a rotating multiple tooth cutter. Fast way of machining can be done through many teeth of the milling cutter. Through this machining the surface may be curved, angular or flat and also can be milled to any type of required shapes or any combination of shapes. The machine which grips the work piece, rotates the cutter, and feeds the work part is called as the Milling machine.

Solid materials are machined by the milling machine. The milling machines are categorized into two simple forms horizontal and vertical, which depend on the alignment of the main spindle. These types of milling machine have a collection of both small bench mounted devices to big size machines. Unlike a drill press, which holds the work piece stationary as the drill moves axially to penetrate the material, milling machines also move the work piece radically against the rotating milling cutter, which cuts on its sides as well as its tip? The movements of work piece and cutter are exactly measured to less than 0.001mm; these can be measured generally by means of precision ground slides and lead screws or analogous technology. The milling machines can be operated manually, mechanically or digitally through computer numerical control methods.

A vast number of performances can be done through milling machines from simple operation such as keyway cutting, drilling, slot, planning etc., to complex performances for example die sinking,

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contouring. The Cutting fluid is send to the cutting operation location to cool and lubricate the cut and also to wash away of the resulting scarf which forms during operation.

Milling Cutters

Milling cutters are cutting tools typically used in milling machines or machining centers (and occasionally in other machine tools). By the movement of milling cutter these remove material within the machine such as ball nose mill or directly from the cutter's shape such as a form tool eg., a hobbling cutter.

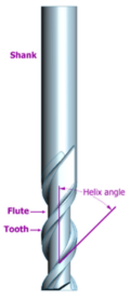

Fig1: Two Flutes Of End Mill Cutter

The milling cutters as shown in fig 1 are in numerous shapes and sizes and a option of coatings as well as rake angle and number of cutting surfaces.

Shape: Different standard shapes of milling cutters are consuming in industry.

Flutes / teeth: The flutes of the milling bit are the deep helical grooves running up the cutter, while the sharp blade along the edge of the flute is known as the tooth. The teeth are used to cut away the material and chips of the material are dragged up the flute by the rotation of the cutter. Every cutter has at least one tooth per flute and some cutters consist of two teeth per flute. The words flute and tooth are regularly used to interchangeably. Milling cutters are of 1, 2, 3 and four are regular type of milling cutters. Normally the cutter with more number of teeth will remove more amount of material. Hence the rate of removal by 4 teeth cutter will remove material double than the two teeth cutter.

Helix angle: Milling cutter has flutes of helical in shape. The impact of material by using other shape flutes will cause vibrations and eases not only accuracy but also surface quality. The angle of the flute can be settled in a way that allows the tooth to enter into the work piece to remove material regularly and also to moderate vibrations. Finishing cutters which have a high rake angle and by this the surface finish is well to other cutters.

Center cutting: The centre cuttings are used to cut at an angle of 45 degrees.

Finishing or Roughing: There are more varieties of cutters for removing large amount material leaving with poor surface finish such as roughing and there are some cutters for removing smaller amounts of material but leaves a good surface finish such as finishing. The cutter which used for roughing has notched teeth for flouting up the chips to smaller pieces. This kind of teeth leaves rough surface but the cutter used for finishing process has four teeth or more to eliminate material with care. However, the large number of flutes leaves little room for efficient swarf removal, so they are less appropriate for removing large amounts of material.

Types

Fig 2: End mill and ball nose cutters

In figure 2 end mills are on the middle row and these have cutting teeth at one end and also on the sides. The words end mill are referred as flat bottomed cutters and also these includes rounded cutters and radiuses cutters such as bull nose and torus cutters. They are usually made from high speed steel (HSS) or carbide, and have one or more flutes. The end mill is a best collective tool which is used in vertical milling.

Slab mill

Fig 3: High Speed Steel slab mill

Slab mills as shown in fig 3 are used either themselves or in milling, to quickly machine surfaces of large broad on manual horizontal or in universal milling machines. These are superseded by the usage of carbide-tipped face mills which are used in vertical mills or in machining centers

Side and face cutter

Fig 4 -Side and face cutter

The side and face cutter as in fig 4 have cutting teeth on cutter side and on its circumference. Side and face cutter are in erratic widths and diameters which determined by their application. The teeth which are on side of the cutter makes unbalanced cuts which are so formed without deflecting the cutter as that occurs by a slitting saw or slot cutter which have no side teeth. Cutters of this type were settled on the earlier milling cutters. From 1810 to 1880's, these are the mostly used milling cutters, but nowadays merit perhaps goes to end mill cutters.

Modular principle

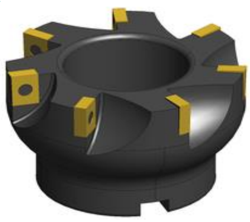

Fig 5 - Shell Mill

Shell mill have a rectangular cutout region on the rear side there is a pocket which is involves in the lugs or tangs of the arbor. A shell mill is similar to various milling cutters namely a face mill or end mill whose construction takes place in a modular form with help of the shank made separately from the body of the cutter known as "shell" and assigns to the shank through any of several standardized joining methods.

USING A MILLING CUTTER

Chip Formation

As there are many kinds of milling cutters, it is vital to understand chip formation to use of any of it. As milling cutter rotates a small chip of material is removing from the material by the tooth of the cutter. It is important to succeed the correct size of chip. The size of this chip is determined by many things namely:

Surface cutting speed (Vc): Surface cutting speed is a speed at which every tooth cuts into the material as the tool spins. This is restrained either in meters per minute or in metric countries or surface feet per minute in USA. Important values for cutting speed are 10m/min to 60m/min for some type of steels and for aluminum it is 100m/min and 600m/min. This should not be disorganized with the feed rate. This value is also known as "tangential velocity."

Spindle speed (S): This is the rotation speed of the tool, and is measured in revolutions per minute (rpm). Typical values are from 100's to 1000's of rpm.

Feed per tooth (Fz): This is the distance the material is fed into the cutter as each tooth rotates. Deepest cut which so formed depends on the depth of the tooth.

Feed rate (F): Material is fed at this speed into the cutter. Typical values are from 20mm/min to 5000mm/min.

Depth of cut: This depends on depth of the tool which is on the surface of the workpiece. This will be the level of the chip so formed. Normally the depth of cut will be less or equal to the diameter of the cutting tool.

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One needs three values such as Speed, Feed and Depth are key things, how to cut a new material with a new tool. Machinist will maybe given such values of Vc and Fz from the tool manufacturer. S and F can be calculated from them:

Spindle Speed	Feed rate
$S = \frac{1000V_c}{\pi D}$	$F = zSF_z$
Looking at the formula for the spindle speed, S, it can be seen that larger tools require lower spindle speeds, while small tools may be able to go at high speeds	In above formula feed rate, F displays that increasing Speed or Z, depth gives a higher feed rate. Hence machinists can choose a tool with the utmost number of teeth that can quiet manage with the sward load.

Table 1- Difference between spindle speed and feed rate.

Different Modules in Pro/Engineer

- Part design
- Assembly
- Drawing
- Sheet metal
- Mould design
- Manufacturing

Model of Cutting Tool

Sketch

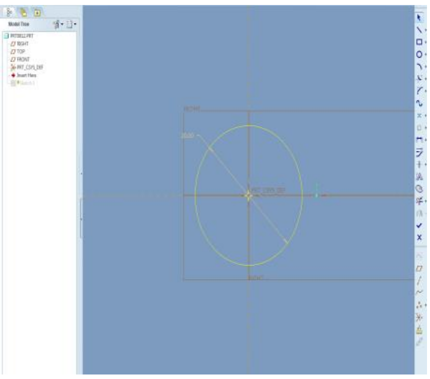

Fig6: Sketch of Cutting Tool

Extrude

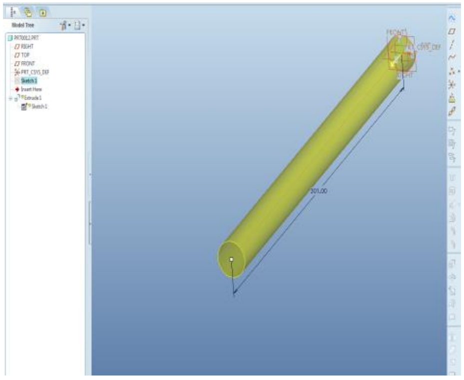

Fig 7: Extrusion

WORKPIECE

Sketch

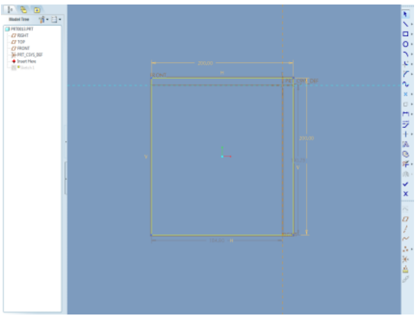

Fig8: Sketch of a work piece

Solid part

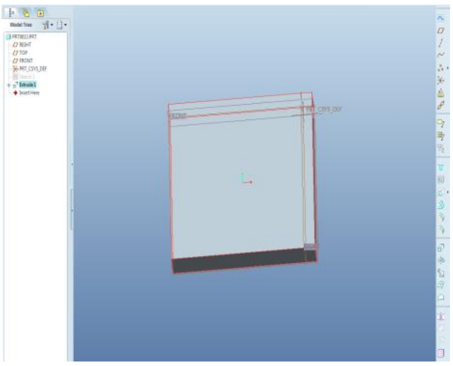

Fig 9: Solid part of work piece

Finite element analysis (FEA)

Finite element analysis (FEA) is a fairly recent discipline crossing the boundaries of mathematics, physics, and engineering and computer science. This technique has extensive use and relishes widespread consumption in the structural, thermal and fluid analysis zones. The finite element method is comprised of three major phases:

(1) Pre-processing, in which the analyst develops a finite element mesh to divide the subject geometry into sub domains for mathematical analysis, and applies material properties and boundary conditions

(2) Solution, during which the program derives the governing matrix equations from the model and solves for the primary quantities.

(3) Post-processing, in which the specialist checks the validity of the result, observes the values of principal quantities namely displacements, stresses and derives and it also surveys further quantities namely specialized stresses and error pointers.

The benefits of Finite element analysis are abundant and significant. A fresh design idea can be displayed to define its actual world activities under several load environments and can hence be refined former to the formation of drawings, once limited dollars have been committed and changes are inexpensive. As soon as a complete Computer aided design model has been advanced, Finite element analysis may study the design in detail and also saves time and money by decreasing the quantity of prototypes essential. Present product which is undergoing a field problem or it is just developed, may be studied to speed an engineering modification and ease its cost. Moreover, FEA can be performed on increasingly affordable computer workstations and personal computers, and professional assistance is available.

BASIC STEPS TO SOLVING ANY PROBLEM IN ANSYS

Similar to solving any problem systematically, one wants to define the following aspects (1) solution purview, (2) physical model, (3) boundary conditions and (4) physical properties. Later one need to solve the problem and need to show the results. The main difference in numerical methods is an additional step is known as mesh generation. This is the step that splits the difficult model into small components hence it can be simply solved or else it is excess complex situation.

The following defines the methods in terminology somewhat additional adjust to the software.

Build Geometry

Create 2D or 3D representation of the object to be modeled and tested by means of the work plane coordinate system in ANSYS.

Define Material Properties

Explain a collection of the essential materials that comprise the object being modeled. This comprises both thermal &mechanical properties.

Generate Mesh

ANSYS knows the makeup of part and defines how it should be broke into pieces.

Apply Loads

As soon as the system is completely designed, the former task is to burden the system with restrictions namely physical loadings or boundary conditions.

Obtain Solution

This is in fact a step, since ANSYS must understand within what state (steady state, transient… etc.) the problem needs to be solved.

Present the Results

As the final solution has been attained, there are several means to present ANSYS solutions, choose from many options such as tables, graphs, and contour plots.

Specific capabilities of ANSYS:

Static Analysis–Need to define displacements and stresses in static loading circumstances. ANSYS can compute both linear static analyses and also nonlinear static analyses. Nonlinear static analysis includes properties such as creep, great strain plasticity, stress stiffening, huge deflection, hyper elasticity and contact surfaces.

Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings, naval, aeronautical, and

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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mechanical structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

Transient Dynamic Analysis–Need to define the response of a structure to arbitrarily time variable loads. Totally nonlinear analysis stated under Static Analysis beyond is permitted. Buckling Analysis - Need to estimate the buckling loads and define the buckling type shape. Both linear buckling and nonlinear buckling studies are potential. Besides of above analysis types, numerous superior purpose features are offered such as Fracture mechanics, Composite material analysis, Fatigue both p-Method and Beam analyses. ANSYS is proficient of both steady state thermal analysis and transient analysis of any solid by means of thermal boundary conditions.

Such loads comprise the following:

- Convection
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates such as heat flow per unit volume and
- Perpetual temperature boundaries.

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of best material differ with temperature. This temperature dependency being substantial, the analysis turns into nonlinear. Radiation boundary circumstances also create the analysis nonlinear. Transient calculations are time dependent and ANSYS will together solve distributions in addition to make video for time incremental displays of models.

Fluid Flow

The ANSYS/FLOTRAN CFD (Computational Fluid Dynamics) offers comprehensive tools for analyzing two-dimensional and three-dimensional fluid flow fields. ANSYS is capable of modeling a vast range of analysis types such as: airfoils for pressure analysis of airplane wings (lift and drag), flow in supersonic nozzles, and complex, three-dimensional flow patterns in a pipe bend. In addition, ANSYS/FLOTRAN could be used to perform tasks including:

- Calculating the gas pressure and temperature distribution in an engine exhaust manifold
- Studying the thermal stratification and breakup in piping systems.
- Using flow mixing studies to evaluate potential for thermal shock.
- Doing natural convection analyses to calculate the thermal performance of chips in electronic fields.
- Conducting heat exchanger survey comprising different fluids parted by solid regions.

ANALYSIS OF MILLING CUTTER

TRANSIENT ANALYSIS FOR HSS MATERIAL

Coolant - Kernel oil

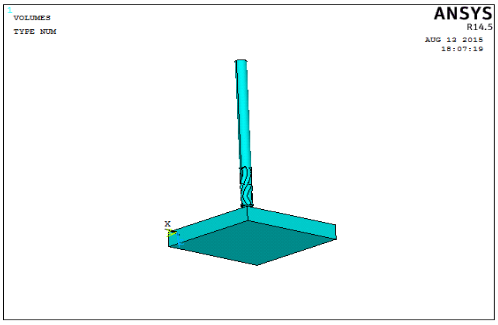

Fig 10: Imported model of HSS for transient thermal analysis

Material Properties

Cutting Tool – HSS

Thermal conductivity =0.019 W/mm K
Specific Heat – 460J/Kg K
Density = 0.0000081 Kg/mm3

Work Piece – Aluminum alloy 6063

Thermal conductivity =0.2 W/mm K
Specific Heat – 900J/Kg K
Density = 0.0000027 Kg/mm3

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Boundary Conditions

Temperature

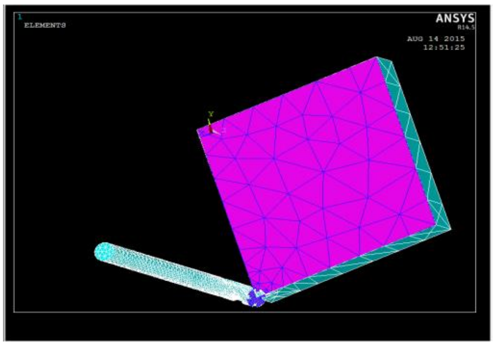

Fig 11 Boundary condition- Temperature of HSS tool

Convection

Film co-efficient of Kernel =0.080 W/mm^2 K

Bulk Temperature – 303K1

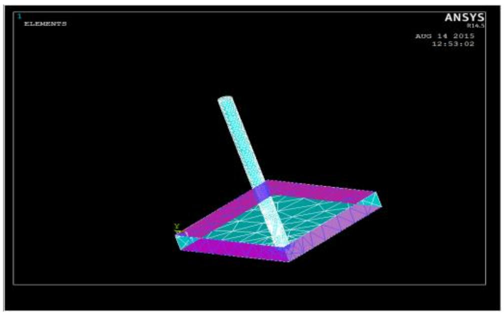

Fig 12 Boundary condition convection of HSS

Soluble Oil as Coolant

Temperature - 410k

Convection

Film co-efficient =0.09 W/mm2 K

Bulk Temperature – 303K

Nodal temperature

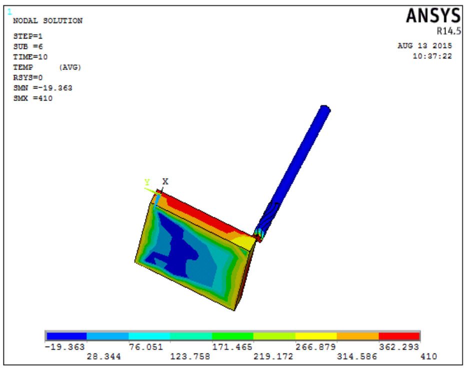

Fig 13 Nodal temperature of HSS Tool at 410k for coolant as soluble oil

Coolant – Water

Temperature – 410k

Nodal temperature

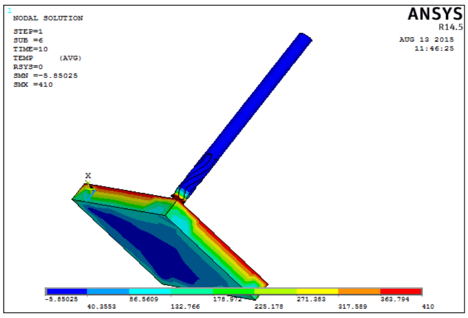

Fig 14 Nodal temperature of Carbide tool at 410k for coolant as Water

Temperature – 460k

Nodal temperature

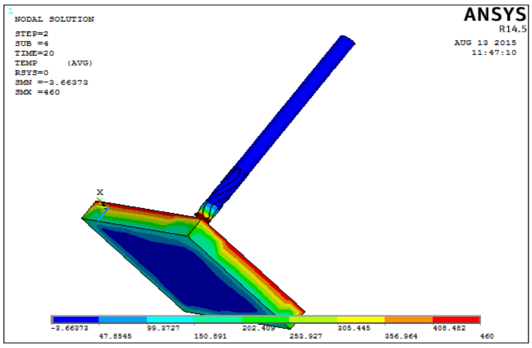

Fig 15 Nodal temperature of Carbide tool at 460k for coolant as Water

Temperature – 510k

Nodal temperature

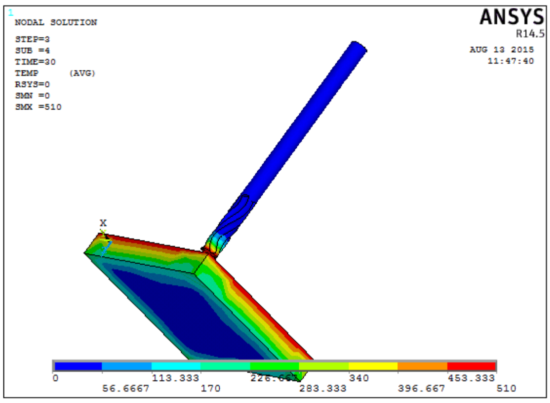

Fig 16 Nodal temperature of Carbide tool at 510k for coolant as Water

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RESULT TABLES

HSS Material

	Nodal temperature (K)	Thermal gradient (K/mm)	Thermal flux (W/mm²)
KERNEL	410	149.914	2.84836
	460	220.051	4.18097
	510	290.153	5.51291
SOLUABLE OIL	410	162.111	3.08011
	460	237.448	4.51152
	510	312.965	5.94633
WATER	410	87.744	1.66714
	460	72.801	1.38322
	510	68.8123	1.30743

Table 2 Properties of HSS material

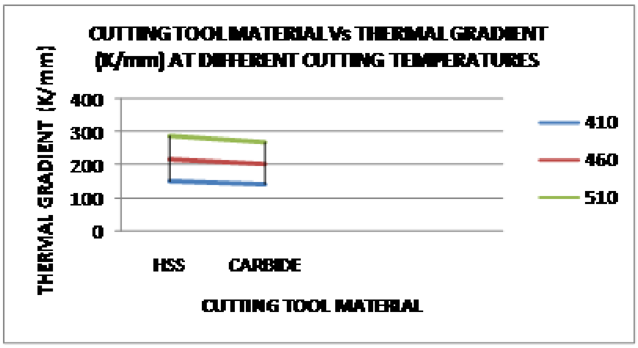
Carbide Material

	Nodal temperature (K)	Thermal gradient (K/mm)	Thermal flux (W/mm²)
KERNEL	410	140.703	3.9397
	460	206.209	5.77386
	510	271.814	7.61086
SOLUABLE OIL	410	145.858	4.08402
	460	213.781	5.98588
	510	281.802	7.89016
	410	66.4684	1.86111
WATER	460	55.1176	1.54329
	510	52.1571	1.4604

Table 3 Properties of Carbide material

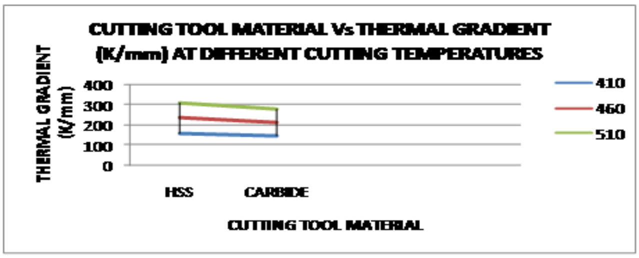
GRAPHS

Cutting Fluid – Kernel



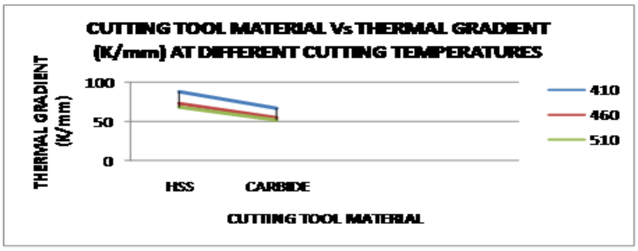
Graph 1 Cutting Tool Material Vs Thermal gradient for Cutting Fluid Kernal

Cutting Fluid - Soluble Oil



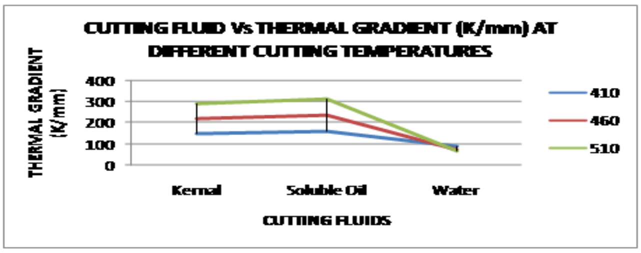
Graph2 Cutting Tool Material Vs Thermal gradient for Cutting Fluid Soluble oil

Cutting Fluid – Water



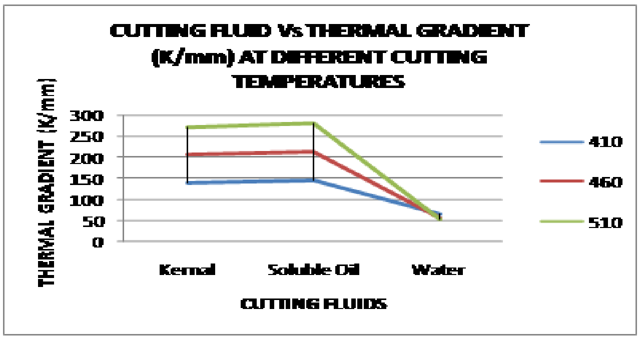
Graph3 Cutting Tool Material Vs Thermal gradient for Cutting Fluid Water

Cutting Tool – HSS



Graph 4 Cutting fluid Vs Thermal gradient of HSS

Cutting Tool – Carbide



Graph 5 Cutting fluids Vs Thermal gradient of Carbide tool

LITERATURE SURVEY

In the paper by L. B. Abhang[1], In metal cutting, the heat generated on the cutting tool is important for the performance of the tool and quality of the work piece. During machining at interface of tool and chip extreme heat is generated. By good knowledge on temperatures used for cuttings on the tool the machining can be improved. In this survey, the temperature produced on the cutting tool and experimental techniques for the extent of temperatures are revised. Exceptional consideration has been paid to tool and work thermocouple process and an experimental arrangement fabricated to measure the temperature on the cutting tool and work piece junction in the course of metal cutting is termed. The average temperature at the tool and chip crossing point is measured by this method. The yield of the thermocouple is in the mill volt range and restrained by a digital milli-voltmeter. The voltmeter is mainly current sensitive device and therefore the meter reading will be in need of on the emf generated by tool and work-thermocouple. The thermoelectric power of the circuit is generally small and expected by calibrating the circuit in contrast to a reference thermocouple namely Alumel-Cromel K type. Here in this work the whole setup for calibration and the process is explained.

In the paper by M. Dogra[2], The effect of cutting tool geometry has long been an issue in understanding mechanics of turning. Tool geometry has substantial impact on chip creation, heat generation, tool wear, surface finish and surface reliability through turning. This article shows a study on dissimilarity in tool geometry that is namely tool nose radius, rake angle, wiper geometry, groove on the rake face, variable edge geometry and curvilinear edge tools and their effect on machined surface roughness, tool wear and surface integrity of the machined surface. Additional modeling and simulation methods on tool geometry together with one approach advanced in a recent survey, on variable micro-geometry tools, is deliberated in brief.

CONCLUSION

In this thesis soluble oil, water and palm kernel oil were used as coolants in machining operations. Tungsten carbide and HSS cutting tools are employed as cutter with different temperatures. Thermal analysis is done on the parametric model to determine the effect of different cutting fluids on the cutters. Parametric Modeling is done in Pro/Engineer and analysis is done in Annoys. By observing the analysis results, the heat transfer rates are more when the fluid soluble oil is used since thermal flux is more than Kernel and water. Kernel also has good heat transfer rates, but using water is not preferable. When compared the values for tool materials, the heat transfer rates are more for carbide tool than HSS tool.

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