Experimental Investigation Of Convective Heat Transfer During Turning For Different Machining Conditions

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Abstract- *Heat has critical influences on machining. To some extent, it can increase tool wear and then reduce tool life, get rise to thermal deformation. But due to the complexity of machining mechanics, it's hard to predict the intensity and distribution of the heat sources in an individual machining operation. This study deals with heat generation during machining process and the experimental investigation of temperature. Elevated temperatures generated in machining operations significantly influence the process efficiency and the surface quality of the machine part. Heat transfer between the chip, the tool, and the environment during the metal machining process has an impact on temperatures, wear mechanisms and hence on tool-life and on the accuracy of the machined component. This study deals with experimental study of different cooling methods for different machining conditions. In this presented work cooling has been determined by calculating the heat transfer coefficient. Experiments on work piece cooling conducted on a lathe provided reference temperature data for a model of a cylindrical work piece, which was solved for temperature using a Control-Volume Finite Difference method. Heat transfer coefficients were obtained for various convective boundary conditions existing on a work piece when cooling in VTJA air and in coolant. Cooling characteristics calculated using these heat transfer coefficients showed good agreement with the experiment. Presented approach can be used to obtain the convective heat transfer coefficients for studies on modelling thermal behavior of a work piece in other conditions.*

Keywords: *Dry machining, wet machining, VTJA, Heat transfer, Heat transfer coefficient, Reynolds number, cutting speed etc.*

I. 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 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. Prediction and measurement of machining forces, temperatures, tool wear, residual stresses and many other characteristics are performed with substantial care, and many good agreements are found between numerical/analytical solutions and experimental data. Temperature field is one of the most important properties of a machining process; since the field can affect other characteristics such as residual stresses and tool wear.

Thermal expansion affects the machining accuracy, hence the latter interest can be attributed to the demand for higher accuracy there has been a growing interest in modeling of metal cutting process in recent years.so it has been also accompanied by the interest in modeling of thermal behavior of the work piece. Machining error caused by the thermal expansion of the work piece is expressed by the convective heat transfer coefficients. However, the literature search did not reveal any convection data for water cooling in conditions corresponding to turning [1].

Different approaches were carried out to predict quantitatively the temperature level and heat flux at the interface with cutting speed, feed rate, rake angle, tool geometry, tool material and work piece materials [2].

First, almost all (90%-100%) of the mechanical energy consumed in a machining operation finally convert into the thermal energy. Second, there are three major sources of thermal in orthogonal cutting with a sharp tool: plastic deformation in the so-called primary zone and secondary zone, and the frictional dissipation energy generated at the interface between tool and chip [6].

II. MODELLING OF HEAT GENERATION

Heat balance for the machining process can be written from First law of thermodynamics helps to calculate the heat balance. It is the summation of rate difference that thermal and mechanical energy enters and exits the control volume, and rate of heat generation is equal to the rate of energy stored within the control volume [4].

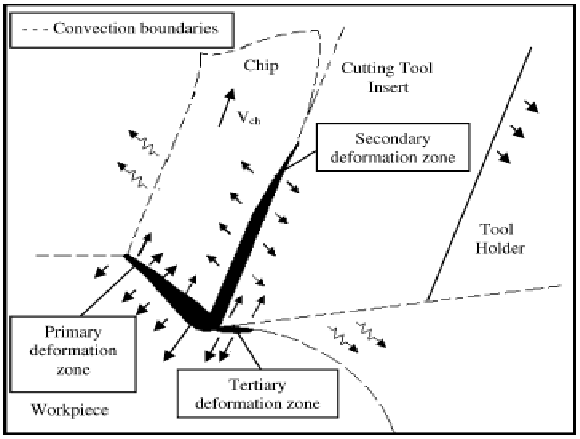


Figure 1 Heat transfer model in the orthogonal cutting process

E_{in}	Energy entered in control volume [Watt]
E_{out}	Energy exited in control volume [Watt]
$E_{generat}$	Energy generated in control volume [Watt]
E_{stored}	Energy stored within the control volume
$\frac{\partial T}{\partial x}, \frac{\partial T}{\partial y}, \frac{\partial T}{\partial z}$	Temperature gradient in X, Y and Z direction respectively
K	Thermal conductivity [Watt/mK]
A	Exposed surface area to heat conduction [m$^{2]}$
$Q_{z,c}$	Convection rate directed to surrounding [Watt]
h	Coefficient of convective heat transfer [Watt/m^{2}K]
T	Temperature [ºC]
ρ	Density of material [Kg/m^3]
C_p	Specific heat of material [kJ/KgK]
f_r	Feed rate [mm/sec]
l_m	Axial distance of machining [mm]
t	Time for machining [sec]
v	*Cutting velocity [m/min]*
d	*Diameter of work piece [mm]*
n	*Spindle speed [rpm]*
SUBSCRIPT	
VTJA	*Vortex tube jet assisted*
MQL	*Minimum quantity lubrication*
DOC	*Depth of cut*

A. Heat Balance for the Work piece and tool

According to the above energy balance equation if we define Q_x $Q_y and$ Q_z as the conduction of heat entering the control volume from x, y and z directions d_x d_y and d_z respectively. Let control volume has dimensions then rate of heat conduction is given by [5] [6] [7]

$$Q_x = -kA\frac{\partial T}{\partial x} = -k\,dy\,dz\,\frac{\partial T}{\partial x}$$

$$Q_y = -kA\frac{\partial T}{\partial y} = -k\,dx\,dz\,\frac{\partial T}{\partial y}$$

$$Q_z = -kA\frac{\partial T}{\partial z} = -k\,dy\,dy\,\frac{\partial T}{\partial z}$$

By using by Taylor series expansion, ignoring the higher orders.

$$Q_{x+dx} = Q_x + \left(\frac{\partial Q_x}{\partial x}\right)dx$$

$$Q_{y+dy} = Q_y + \left(\frac{\partial Q_y}{\partial y}\right)dy$$

$$Q_{z+dz} = Q_z + \left(\frac{\partial Q_z}{\partial z}\right)dz$$

Above equations do not involve only heat convection terms as the air is flowing around there is heat loss by convection from the system i.e. tool chips and work piece. Therefore convection rate directed from the control volume to the surrounding air is given as follows.

$$Q_{z.convection} = hA(T - T_{amb})$$

Heat generation in the control volume is equal to the volumetric heat generation rate times the volume of control volume.

$$E_{generated} = Q\,dx\,dy\,dz$$

$$E_{stored} = \rho C_p \frac{\partial T}{\partial t}dx\,dy\,dz$$

So from all of the equations heat balance equation for work piece can be written as

$$E_{in} - E_{\ out} + E_{\ generated} = E_{stored}$$

$$Q_x + Q_y + Q_z - Q_{x+dx} - Q_{y+dy} - Q_{z+dz} - Q_{z.convection} + Q\,dx\,dy\,dz = \rho C_p \frac{\partial T}{\partial t}dx\,dy\,dz$$

If both the sides are divided by$k\,dx\,dy\,dz$, assuming that heat conduction and convection coefficients are constant with time as well as space, then simplified equation for heat balance of work piece can be written as follows [8].

$$\left(\frac{\partial^2 T}{\partial x^2}\right)+\left(\frac{\partial^2 T}{\partial y^2}\right)+\left(\frac{\partial^2 T}{\partial z^2}\right)+\frac{Q}{k}-\frac{hA(T-T_{amb})}{kdz}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

Where $\alpha=\frac{k}{\rho C_p}$

III. DIMENSIONAL ANALYSIS OF THE WORK

For the experimentation following assumptions and modelling equations are used to find out the convective heat transfer coefficients. Here three machining conditions are used i.e. dry machining; wet machining and vortex tube jet assisted machining.

Parameters	Unit	Fundamental dimensions
h	W/m^2k	$MT^{-3}\theta^{-1}$
ρ	kg/m^3	ML^3
v	m/s	LT^{-1}
μ	$kg/m\,sec$	$ML^{-1}T^{-1}$
Cp	$J/kg\ k$	$L^2T^{-2}\theta^{-1}$
K	W/mk	$MLT^{-3}\theta^{-1}$

Let

$$h=f(\rho,v,d,\mu,c_p,k)$$

Therefore

$$f_1=(\rho,v,d,\mu,c_p,k,h)$$

Number of variables (n) =7

Number of fundamental dimensions required (m) =4 (M, L, T, Θ)

According to Buckingham's π theorem,

Number of dimensionless groups =

n-m= 7-4= 3

So we can write that.

$$f_2=(\pi_1,\pi_2,\pi_3)$$

Selecting the recurring set of fundamental dimensions i.e. $(d,v,\mu,k,)$

$$f_1=(d^a v^b \mu^c k^d c_p,k,h)$$

$$(1)\ \pi_1=(d^a v^b \mu^c k^d,h)$$

Let,

$$M^0L^0T^0\theta^0=L^a*(LT^{-1})^b(ML^{-1}T^{-1})^c*(MLT^{-3}\theta^{-1})^d*(MT^{-3}\theta^{-1})$$

$$M=0=c+d+1$$
$$L=0=(a+b-c+d)$$
$$T=0=-b-c-3d-3$$
$$\Theta=0=-d-1$$

On solving above equations following values are obtained.

$$a=1,b=0,c=0,d=-1$$
$$\pi_1=(d^1v^0\mu^0k^{-1},h)$$
$$\pi_1=(d^1k^{-1},h)=hd/k$$
$$\pi_1=\frac{hd}{k}=Nusselt\ Number$$

(2) Second dimensionless group

$$\pi_2=(d^a v^b \mu^c k^d,c_p)$$

Let,

$$M^0L^0T^0=L^a*(LT^{-1})^b(ML^{-1}T^{-1})^c*(MLT^{-3}\theta^{-1})^d*(L^2T^{-2}\theta^{-1})$$

$$M=0=c+d$$
$$L=0=(a+b-c+d+2)$$
$$T=0=-b-c-3d-2$$
$$\Theta=0=-d-1$$

On solving above equations following values are obtained.

$$a=0,b=0,c=1,d=-1$$
$$\pi_2=(d^0v^0\mu^1k^{-1}c_p)$$
$$\pi_2=\mu\frac{c_p}{k}$$
$$\pi_2=\mu\frac{c_p}{k}=Prandtle\ \ Number$$

(3) Calculating third dimensionless group

$$\pi_3=(d^a v^b \mu^c k^d,\rho)$$

Let,

$$M^0L^0T^0\theta^0=L^a*(LT^{-1})^b(ML^{-1}T^{-1})^c*(MLT^{-3}\theta^{-1})^d*(ML^3)$$

$$M=0=c+d+1$$
$$L=0=(a+b-c+d-3)$$
$$T=0=-b-c-3d$$
$$\Theta=0=-d$$

On solving above equations following values are obtained.

$$a=1,b=1,c=-1,d=0$$
$$\pi_2=(d^1v^1\mu^{-1}k^0\rho)$$
$$\pi_3=\frac{\rho vd}{\mu}$$

$$\pi_3=\frac{\rho vd}{\mu}=Reynolds\ \ Number$$

In this experimental investigation our aim is to find out the cooling rate i.e. convective heat transfer coefficients.

IV. EXPERIMENTAL INVESTIGATION

Following diagram shows experimental setup for the project purpose.

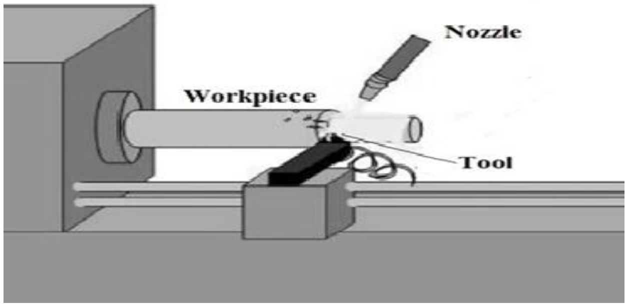


Fig. 2 Experimental setup

All geared TRUMAC lathe machine is used for conducting the experiments. Following materials were used for the investigations. Aluminium 60882 and AISI 1018 are mostly used for the industrial manufacturing purposes [10]. Following tables shows the chemical composition of the specimens used for the machining.

Chemical Analysis									
Al 6082 (Ø =24mm)	Al	Mn	Zn	Fe	Mg	Sn	Si	Cu	Ti
(%)	Bal	0.73	0.01	0.19	0.4	0.01	1.24	0.1	0

Table 1 Chemical composition of Al6082

AISI 1018 (Ø =24mm)	C	Mn	Si	S	P
(%)	0.18	0.89	0.33	0.031	0

Table 2 Chemical composition of Al6082

Coated Carbide insert is used as a tool. All the faces of inserts are used for different machining conditions.

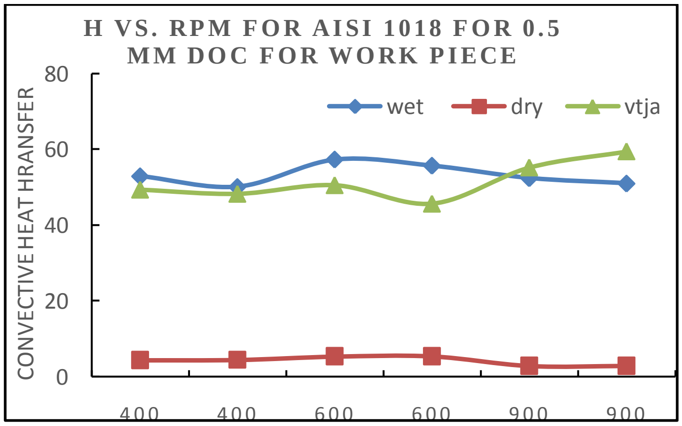
According to the requirement three sets of machine RPM were fixed 400 rpm, 600 rpm and 900 rpm. Depth of cut of 0.5 mm and 1 mm are used. Feed is maintained automatic for turning purpose. Dry, wet and VTJA condition of turning are used. In dry machining no coolant is used while in case of wet machining synthetic coolant is used. In VTJA compressed air coming from vortex tube is used as a coolant. Different specimens are used for different machining conditions. Following images shows the different machining conditions.

With the help of Infrared Thermometer temperature of tool as well as work piece are measured simultaneously during turning process. These temperatures are measured according to the equal marking on the 10 cm long specimen and at 9-10 points' temperature of tool and work piece are recorded.

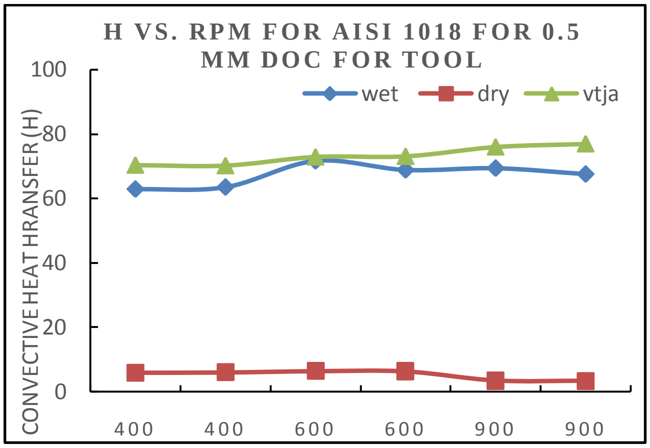
V. RESULTS AND DISCUSSIONS

Following are the different results plotted for convective heat transfer of the work piece at 0.5 mm and 1 mm depth of cut. Readings are recorded for two sets of RPM.

A. Graph of heat transfer for AISI 1018 at 0.5mm Depth of cut for work piece & tool



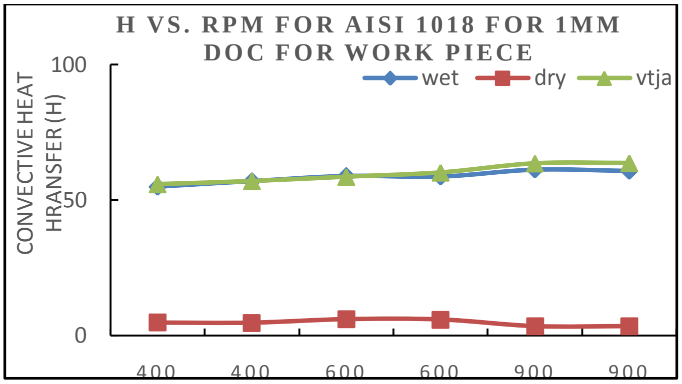
Graph 1. Rpm Vs. Heat Transfer Coefficient



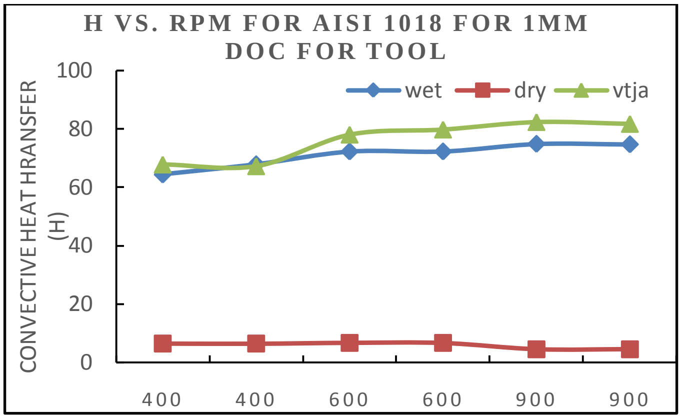
Graph 2. Rpm vs. Heat Transfer Coefficient

For wet machining of AISI 1018 work piece, from graph 1 it is clear that at 600 rpm and 0.5 mm depth of cut convective heat transfer is maximum and goes on decreasing as the speed increases. But in case of VTJA machining of work piece convective heat transfer is maximum for high speed machining. While for dry machining heat transfer is less as compare to dry and VTJA machining. Graph 2 shows that convective heat transfer during VTJA increases as the speed of machining increases for the carbide tool.

B. Graph of heat transfer for AISI 1018 at 1mm Depth of cut for work piece & tool



Graph 3 Heat Transfer Coefficient Vs RPM

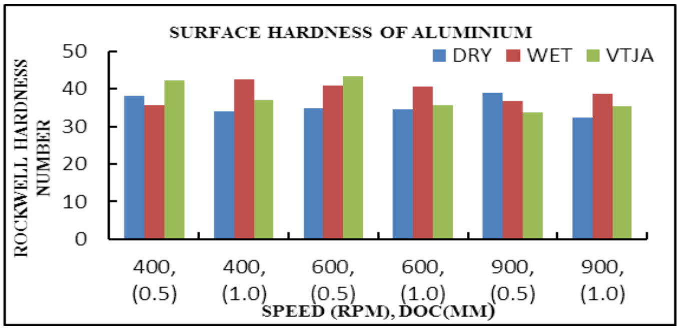


Graph 4 Heat Transfer Coefficient Vs. RPM

Form Graph 3 it can be concluded that heat transfer in case of wet and VTJA machining condition is almost similar for the 400, 600 and 900 rpm.

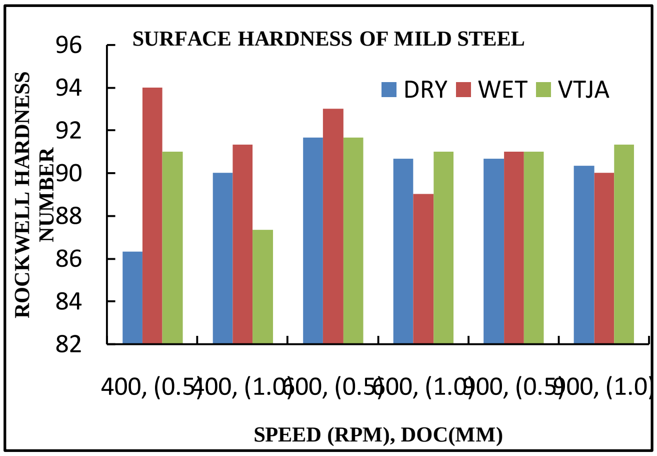
C. Comparison of hardness for different machining conditions

1) Hardness of AL 6082



Graph 5 Hardness during different machining for Al

2. Hardness of AL 6082



Graph 6 Hardness during different machining for AISI 1018

From graph 5 and 6 it can be stated that excepting few readings surface hardness during VTJA machining is more accordance with other wet and dry machining. These readings of hardness were recorded with help of Rockwell hardness testing machine.

V. CONCLUSION

From the above experimental investigation it can be concluded that convective heat transfer of the work pieces of Aluminium as well as mild steel is found to be better during VTJA machining process. While for the carbide tool also convective heat transfer is far better in the case of VTJA machining. Hence it can concluded that due less temperature of compressed air cooling of work pieces occurs quickly in VTJA machining.

Investigating the hardness of the aluminium and mild steel work pieces it is clear that all three i.e. Dry, Wet as well as VTJA machining shows almost similar results. But in case of more speed VTJA could be useful.

VI. ACKNOWLEDGMENT

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