

Effectiveness of Coconut Oil based Nanofluids in Machining of Steel

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Abstract – *The present work illustrates formulation of coconut oil based nanofluids with nano boric acid (nBA) dispersions. These nanofluids are utilized in machining as cutting fluid to test their viability. Experiments are performed in turning AISI 1040 steel under dry, conventional cutting fluid(CCF) and nanofluid. Cutting forces, cutting temperatures, tool wear and surface roughness are measured under varying cutting conditions. It is seen from the results that vegetable based nanofluids has greatly improved the machining performance while comparing with other lubricating conditions. Simulation work is done in order to carry out a comparative analysis between experimental and simulation results. The reduction in cutting forces and cutting temperatures were found to be far better than the conventional cutting fluid. Thus the coconut oil based nanofluid is found to be effective in the utilization of machining both as lubricant and coolant.*

Keywords – Nano Boric acid, Coconut oil, AISI 1040 Steel, Machining, Nanofluids

INTRODUCTION

In this competitive world, production of accurate and quality components is of major prominence. Machining is one of the most important and fundamental processes in manufacturing industry. In machining, there is enormous amount of heat generation due to shearing action and friction at chip-tool interface and tool-workpiece interface [1]. As most of the heat is carried away by chips, still the heat gets accumulated at the tool-workpiece interface which leads to surface damage of the workpiece and catastrophic failure of the tool. In order to overcome this aspect, cutting fluids are used for cooling and lubricating purposes [2]. Generally used cutting fluids are petroleum based which causes environmental pollution and health issues to the operators. Apart from the above mentioned disadvantages, disposal of used oil is an added expense to the manufacturing process [3]. With the advent of Environmental Protection Agency (EPA), cutting fluid disposal has gained prominence. Many researchers

looked for an alternative to the petroleum based cutting without compromising on the machining performance.

Many works were reported on alternatives like solid lubricants, cryogenic cooling, coated tools and Minimum quantity lubrication (MQL) techniques. MQL is a promising technique that involves minimum amount of cutting fluid which generates a mist. The mist generation leads to formation of thin film at the tool-workpiece interface and also acts as a coolant.

The affects of petroleum based cutting fluids led to the invention of vegetable based cutting fluids. With the advent of nanotechnology, nano sized particle inclusions in vegetable oil as cutting fluids gained great importance in the field of manufacturing and research. In addition to this, vegetable oil based fluids offer a solution for environment friendly lubrication and cooling.

Srikanth et al [4] brought a prominent change in the process of manufacturing by

analyzing the performance of vegetable based nano fluids. The nano fluids resulted in enhanced performance of cutting fluids due to their better thermo-physical properties. This made the manufacturing process more efficient. Mahadi et al [5] investigated the performance of boric acid dispersed in kernel oil in machining AISI 431 using MQL. It has been observed that the boric acid aided lubricant outperformed the conventional lubricant. There was an improvement of about 7.21% in surface finish by utilization of vegetable oil based boric acid lubricant compared to conventional lubricant. Deepak et al [6] investigated the coconut oil dispersed with boric acid and graphite powder under MQL mode in machining En8 alloy steel. The MQL method in presence of solid lubricants provided better results compared to the conventional cutting fluid under MQL mode.

This study attempts to illustrate the effectiveness of coconut oil based nano boric acid (nBA) cutting fluid in machining of AISI 1040 steel. Coconut oil is edible oil which contains the fatty acids of triglyceride esters. In vegetable oils, the ester linkage bonds the polar –CO-O- group with triglyceride structure. The oil is stable at high temperature due to the strong intermolecular interactions. This makes the coconut oil suitable as a cutting fluid in machining at high temperatures. Simulation is done for evaluating the efficacy of the nano cutting fluids. Very few simulation studies were reported in MQL nano cutting fluid condition. Modelling and Simulation is conveyed at abiding cutting conditions and analyzed in accordance with the experimental results.

MATERIALS AND METHOD

In the current study, the nanofluids are formulated with nBA particles dispersed in coconut oil which is the base fluid. The nano

particles are dispersed with constant nano particles inclusions (NPI) of 0.25% by weight. The nanofluids prepared are analyzed for stability using zeta potential analysis using nano partica SZ100 series nanoparticle analyzer (Horiba scientific make). Considering it to be stable and homogeneous, the size of the particle is considered to be less than 100 nm which is the initial size. These formulated nanofluids are utilized in machining under MQL mode at various cutting conditions. The simulation work is carried out under constant conditions and the results are validated. The input parameters regarding the nanofluids for simulation are obtained from the literature.

Machining

To retrieve the effectuality in machining by nanofluids, the machining is done at abiding conditions considering speed – 60m/min, feed – 0.14mm/rev, depth of cut – 0.5mm under dry, conventional cutting fluid and 0.25% NPI nanofluid conditions under MQL flow rate of 10ml/min. The experiments are performed using a Precision lathe machine on AISI 1040 steel, the composition and thermo-mechanical properties of which are mentioned in Table 1. (diameter: 35 mm, length: 300mm, heat treated, 30±2 HRC). The coated tungsten carbide cutting tool inserts (CNMG120408 NC6110) and the tool holder (PCLNR 20202K12) is selected in accordance with the cutting conditions. At 5 mm from the tool tip, the tool holder has a provision of thermocouple to measure the nodal temperatures.

Dynamometer (Make – Kistler, Model - 5070) is employed in measuring the cutting forces online continuously during machining. The tool flank wear is measured using tool-makers microscope after each single experiment which is approximately 5 min. Surface roughness measurement of machined surface is done using Talysurf.

Finite Element Simulation

The tool (dimensions: 1.0 x 1.0 x 1.0 LBH) and workpiece are modeled in ABACUS

framework as shown in Fig 1. and machining simulation is carried out under constant cutting conditions. Here, John-cook material model is considered as it shows less discrepancy between the predicted and the experimentally found chip morphology and cutting forces. Tangential contact is considered between tool and workpiece. Hence coulumb’s law is applied with coefficient of friction 0.6. The ductile damage criterion was considered for the above model. Majority portion of the data is provided with respect to temperature as it is a coupled thermo-mechanical model. The thermo-mechanical properties are obtained from the literature that is to be given as input data [4, 7].The simulations results give us force and temperatures at tool-workpiece interface. The temperature from the simulation is found to be 593K.

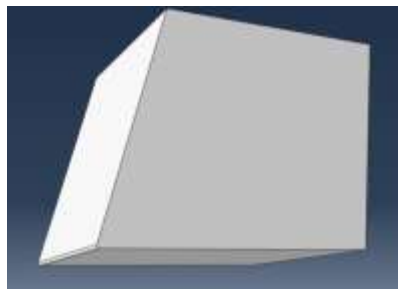
Computational Fluid Dynamics Simulation:

The simulation was performed on the tool considering various cutting fluid conditions

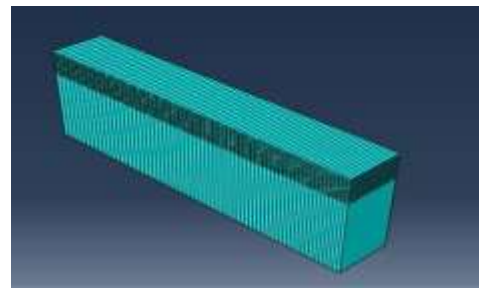
as dry, CCF and coconut oil based nanofluid. The thermal interactions between cutting fluid and tool are simulated in ANSYS CFD module. The resultant temperature in ABACUS framework (598 K) is taken as the heat source at tool tip to observe the interaction of cutting fluid and tool. The simulation parameters required are presented in table 2. The 2-D geometry of the tool is model with a rectangular enclosure where tool is considered as solid domain and the rectangular portion is the liquid domain. Now, very fine mesh is generated for the tool to obtain more accurate results. The left side of the rectangle is given as velocity inlet and the opposite side as pressure outlet (Fig. 2(a)). The flow is considered to be laminar. The boundary conditions are specified properly which are velocity input (MQL flow rate) and pressure outlet (atmospheric pressure). In dry cutting, the air (298 K) is employed as cutting fluid with an inlet velocity of 0.2 m/s. It is input from the material library of ANSYS CFD module.

Table 1. Composition and thermo-mechanical properties of AISI 1040 Steel [7]

C %	Mn%	Si%	S%	P%
0.36 – 0.45	0.6 – 1.0	0.2 – 0.3	0.025	0.015
Density (kg/m ³)		7870		
Thermal Conductivity (W/m- ⁰ C)		51.9		
Young's modulus (GPa)		206		
Poisson's ratio		0.29		



(a)



(b)

Fig. 1. Geometric model of (a) Tool and (b) Workpiece with discrete elements

Table 2. Input parameters for CFD simulation [4]

Thermo-physical Properties	Tool Insert	0.25 % NPI Nanofluid
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Specific heat	39.8 J/mol-K	3972.78 J/kg-K
Density	15600 kg/m ³	0.991 kg/m ³
Thermal Conductivity	110 W/m-K	0.57 W/m-K
Dynamic Viscosity		0.84 cP

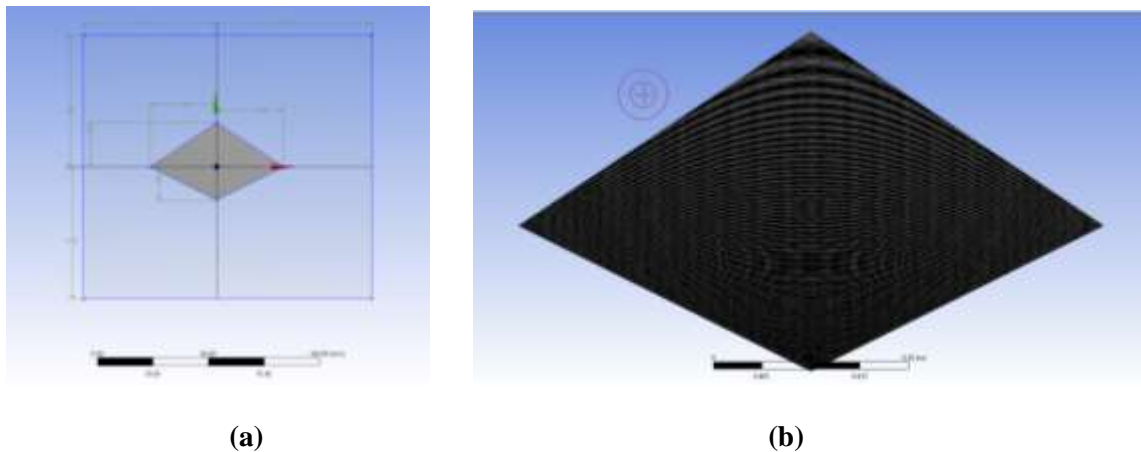


Fig. 2. (a) 2-D geometry of cutting with fluid domain, (b) Cutting tool after Meshing

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RESULTS AND DISCUSSION

The present research work investigates the effectiveness of coconut oil based nanofluids (CC+nBA) as coolant and lubricant compared to dry and CCF. The values of results related to cutting temperatures, forces, tool wear and surface roughness are evaluated in varying cutting fluid conditions of dry, CCF and coconut oil based nanofluid. Later, the simulation results have been validated with available experimental results.

Machining

Cutting Forces

The tangential cutting force (F_z) that is measured continuously during machining using kistler dynamometer which uses dynoware software is stated. It is seen that the F_z in case of dry cutting is high compared to CCF and nanofluid. F_z in case of dry condition has shown a trend of alternative increase and decrease. There was considerable reduction in cutting forces in

case of coconut oil based nanofluids. This is due to the viscosity of nanofluid. At low viscosities, the nanofluid has high heat dissipation capacity. At high viscosities, it forms consistent film between tool-workpiece interfaces reducing the coefficient of friction. This results in the reduction of forces leading to enhanced machining performance. Thus the CC + nBA nanofluids were more effective in machining compared to dry and CCF considering the above factors (Figure 3(a)). The application of CCF and nanofluids (CC+nBA) has reduced the cutting forces by 8.5% and 14.5% compared to dry cutting condition, respectively.

Cutting Temperatures

Variation of cutting temperatures with cutting conditions is shown in Fig. 3(b). It can be seen that nanofluids are more effective compared to dry and CCF in reducing the cutting temperatures. Due to low viscosity of nanofluids, there is consistent film formation which results in low coefficient friction leading to lower heat generation. The low viscosity also leads to easier heat removal as the nanofluid flows away from the cutting zone carrying away the generated heat. The solid nano particles due to their high thermal conductivity and nanofluids' heat transfer coefficient result in low cutting temperatures. Thus coconut oil based nanofluids show higher performance in machining compared to dry and CCF.

Thus, the implementation of coconut oil based nanofluids in machining is beneficial due to their low temperatures.

Tool Wear

Tool flank wear under varying lubricant conditions is shown in Figure 3(c).

It is found that tool wear is high in case of dry machining compared to CCF and nanofluid. The coconut oil based nanofluid has reduced the tool wear because of its better lubricating property. It will reduce the friction coefficient between tool and workpiece leading to reduction in tool wear. It can be noticed that tool wear is found to be the highest in dry condition followed by CCF and least in case of nanofluid. Thus nanofluids are effective in machining owing to its better performance.

Surface Roughness

Surface roughness (Ra) is represented under various lubricating conditions as shown in Fig. 3(d). It is seen that the surface roughness is high in case of dry cutting condition. The surface finish is found to be improved when coconut oil based nBA nanofluid is used. The consistent film formation led to the decrease in frictional coefficient further leading to decrease in cutting forces and temperatures. Due to proper lubrication of nanofluid, there is reduction in surface roughness of the workpiece. Thus the surface quality of the workpiece improved due to the application of nanofluid in machining. It will reduce surface roughness by 24.74% and 12.19% compared to dry machining, and CCF respectively. Thus nanofluids lead to enhanced machining performance and good surface quality of the products.

FEM Simulation

Here, the tool and workpiece interaction geometry is modeled in ABACUS framework. The cutting forces and cutting temperatures are observed from the simulation which is compared to the experimental results. The cutting forces and cutting temperatures are shown in the figures 4 (a) and 4 (b). It can be observed that maximum cutting forces and cutting

temperatures are found to be 510 N and 598 K respectively under dry condition.

Discrepancy in simulation and experimentation is studied under dry cutting condition in terms of cutting force and temperature in order to validate the model (figure 5).

It is seen from the bar chart that the variation in experimental and simulation results

is quite small. So the considered model is accurate and can be used to model under various cutting conditions. The error in simulation results of forces and temperatures is found to be approximately 6% and 5% respectively compared to experimental results.

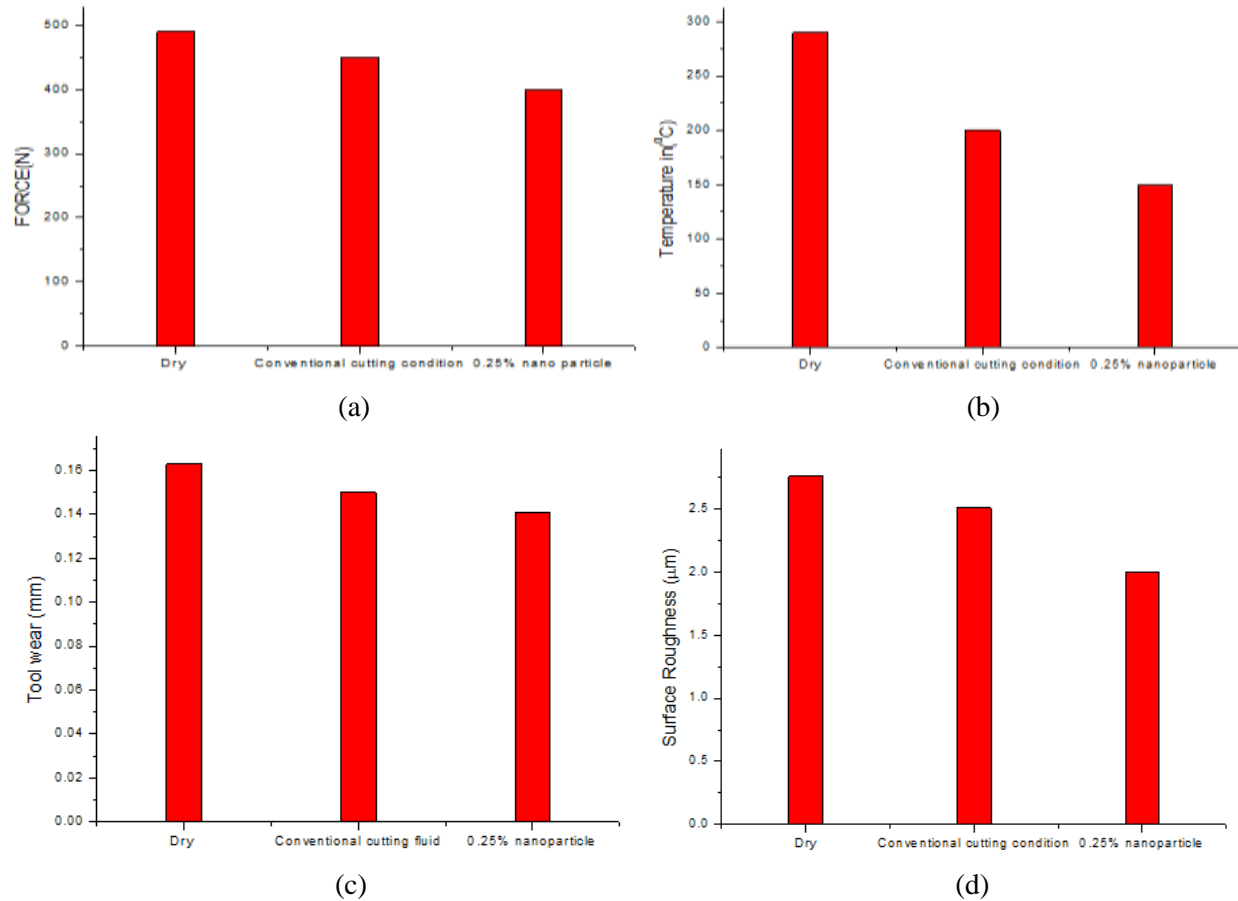


Fig .3. Comparison of (a) Cutting forces, (b) Cutting temperatures, (c) Tool Wear and (d) Surface roughness under different lubrication conditions

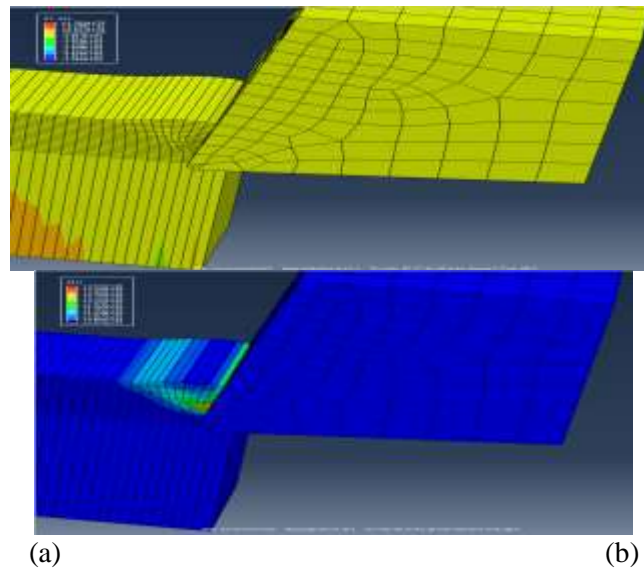


Fig.4. (a) Force and (b)Temperature development with time

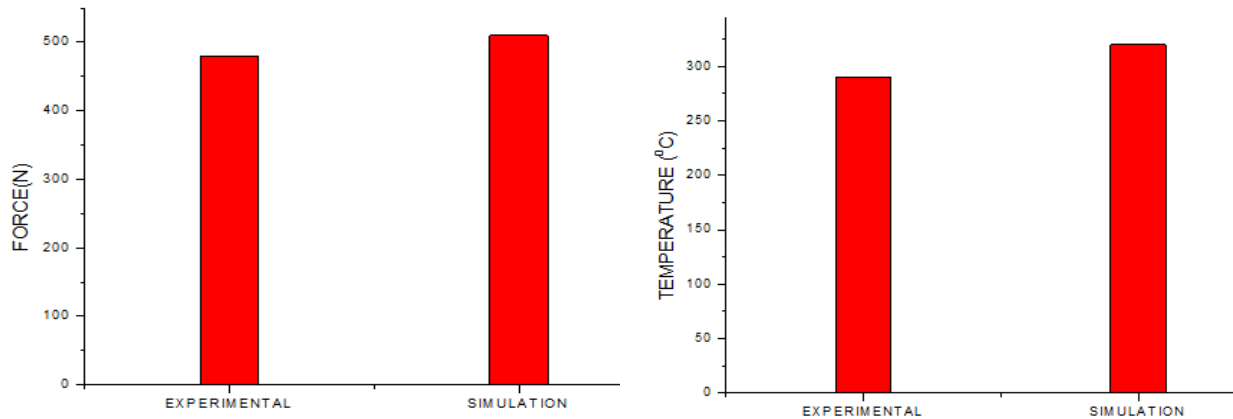


Fig.5. Comparison of experimental and simulation values of forces and temperatures

CFD Simulation

Here, the maximum temperature obtained from FEM simulation is employed as heat source .i.e. 598 K. The temperature distribution over the cutting tool under various lubricant conditions is shown in the figure 6. It is observed that the under various lubricant conditions the minimum temperatures are obtained over the tool after the application of

cutting fluid under MQL mode. These are found to be 405 K, 365 K and 323 K in case of dry, CCF and coconut oil base nanofluid respectively. It can be seen that nanofluids have shown better performance compared to dry and CCF. That is temperature is decreased by greater extent in case of nanofluids compared to dry and CCF.

These results are validated with the experimental results and they are in good

agreement with each other. Thus the model used

is found to be accurate.

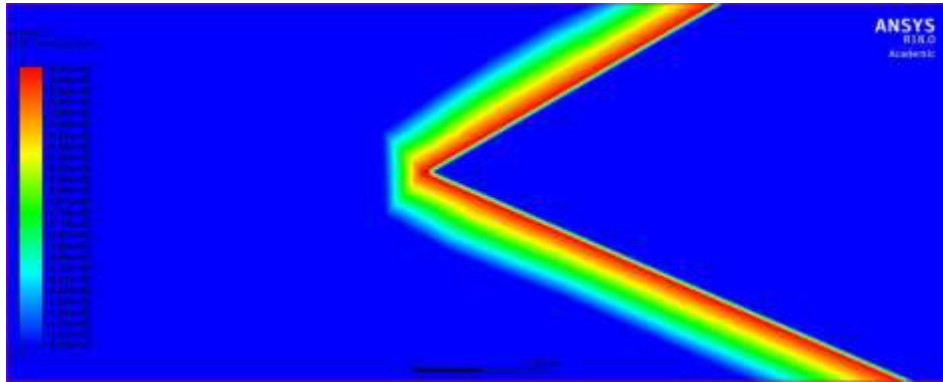


Fig.6(a) Distribution of cutting temperature over the tool in dry machining

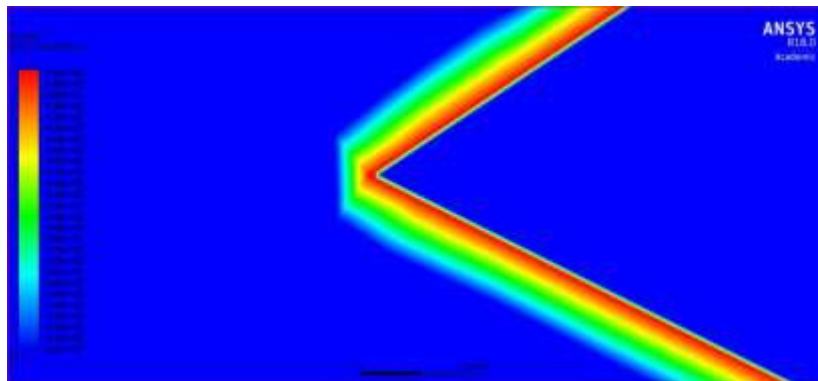


Fig 6(b) Distribution of cutting temperature over the tool under nanofluid condition (0.25% NPI)

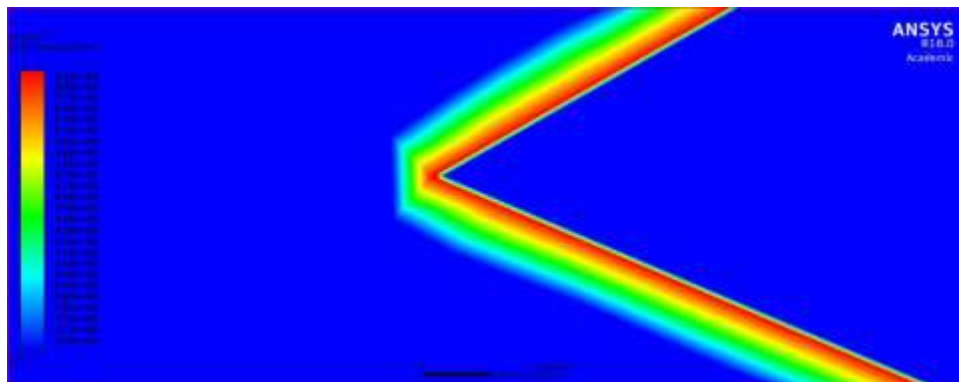


Fig. 6(c) Distribution of cutting temperature over the tool under conventional fluid condition

CONCLUSIONS

- Compared to dry and CCF condition, there is higher reduction in cutting forces and temperatures in case of nano fluids.
- Cutting forces and temperatures were found to decrease by 14% and 16% by use of nanofluids when compared to dry cutting. Thus the nanofluids help in the enhancement of machining performance and improve the surface quality, and tool life
- From simulation under constant cutting conditions The temperature of the tool is decreased by greater extent in case of nanofluids as compared to dry and CCF The temperatures observed in case of dry, conventional and nano cutting fluid conditions were 405K, 365K and 323K respectively.

In terms of economy, nanofluids are costlier as a separate system is to be maintained while supplying the nanofluid so that they don't agglomerate and also the cost of nano particles is higher. It may be recalled from the literature [10] that nanofluids give better surface finish at higher speeds. Therefore, only the requirement of good surface finish can justify the cost of using nanofluids. As it is vegetable based and also MQL is used the disposal is not required which do not affect the environment.

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