# STUDY ON THERMAL ASPECTS IN MACHINING

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***Abstract*: In many industrial applications, the hardness of the material plays a very important role on service life of the product. In the conventional machining process, a long procedure is followed to produce hard components, consisting initial rough machining process, followed by hardening to achieve the required hardness and subsequently applying a finishing operation to get the exact dimensions for the finished product. It involves more processing time and may lead to high cost of production. This problem can be overcome by machining hardened material to get the finished product. In hard machining process, the material can be brought to the final finish and heat treated condition by eliminating the processes like rough machining and finish grinding. The present work aims to study the comparative performance of vegetable oil based cutting fluids under air-mist application using different commercially available coated tools during the machining of hardened steel. This work also includes prediction of temperature distribution on cutting tool using Computational Fluid Dynamics (CFD) simulation of metal cutting process under air-mist application. In the present study, machining of cylindrical bars of AISI 4340 alloy steel with varying hardness (35 HRC and 45 HRC) was carried out.**

***Keywords*: HRC, CFD, Machining, HSS, MQL, MRR**

## I. INTRODUCTION

The consumer will always look for sophistication, satisfaction and reliability at low cost in using various products. To satisfy various demands of the consumer and to improve the marketing across the entire world with regard to the quality products, the industrial sector is now focusing on the materials. In many industrial applications, the hardness of the material plays a very important role on the service life of the product. In the conventional machining process, a long procedure is followed which involves some initial rough machining process, followed by hardening to achieve the required hardness and subsequently applying a finishing operation to get the exact dimensions for the finished product. It needs more processing time and may lead to cost escalation. This problem can be overcome by machining hardened components to get the finished product. In hard machining process, the material can be brought to the final finish and heat treated condition by eliminating the processes like rough machining and finish grinding [1]. Hard machining process is suitable to produce complex geometries with good surface quality at low process cost and at low process time.

It is well known that the resultant energy which is dissipated during metal cutting operation by a cutting tool on a work piece, is converted into heat. Various other reasons for this heat generation in the work piece include strain occurring in the microstructures of the work piece material, contact conductance of tool and work piece and friction [6].

The tempt. Cutting zone will be raised. There are some factors which cause thermal deviations during hard turning process. Some of those factors are:

1. Factors like the material strength-hardness & wear-resistance of the cutting-tool will be adversely affected by the excessive temperature [7].

2. Control of dimensional accuracy will be very difficult if there is excessive increase in temperature. The increase in heat will result in dimensional changes of the part being machined [8]. Inherent structural properties of the material of the machined surface can also be adversely affected because of the heat induced thermal damage [9]. 4. Excessive heat and temperature distribution can also result in poor dimensional control of the work piece which finally affects the product quality. At the same time, the tool geometry with reference to rake angle is changed ultimately leading to reduction in tool life [10].

While doing so, the flow zone is subjected to highest temperature and causes tool failure. Hence it can be interpreted that the life of the tool and its performance will be affected by the tool – chip contact length [14].

Sometimes, high cutting temperatures are generated due to undesirable residual stresses.

## II. Literature Review

As per the Gilbert, the core objective functions to optimize the hard turning process are maximum rate of production and minimum cost of production. The cost as well as the rate of production of a product and its quality are influenced by various machining parameters or cutting conditions like the tool rake angles (back rake and side rake angles), flank and end clearance angles, and nose radius play a major role with regard to production cost. The amount of resistance the workpiece material develops to chip free flow. In order to decrease production costs and achieve high productivity, cutting parameters must be kept at the optimal level. This ensures excellent quality and dimensional precision [129].

These parameters include As a result, maintaining favorable cutting conditions when milling is essential to optimizing a machining process. The pace at which material is removed and so productivity may be raised by raising certain process parameters. The cutting edge geometry all affect surface roughness, according to Ozel et al. [92]. Small edge radius can enhance surface roughness, which in turn reduces the workpiece's hardness value. Statistical analysis by Davim and Figuerira [131] found that feed rate and cutting time contributed 29.6 percent and 32 percent to the surface roughness of cold work tool steel, respectively. Using a mathematical model, Palani kumar and Davim [132] projected tool wear during machining glass fiber reinforced plastic composites and determined that cutting speed is more influential than feed-rate & depth-of-cut. Low feed rates, shorter machining times, and fast cutting speeds, according to Aslantas et al. [117], reduce surface roughness.

Roughness and feed rate appear to have a non-linear connection, according to their findings. A variety of AISI 4140 steel work pieces, each with a distinct hardness degree, were hard turned by Derakhshan and Akbari [61]. Analyzed process parameters revealed that the best S.R was achieved at the cutting-speed of 473/min for a 50 HRC work piece. In hard turning, S.R is strongly controlled by feeding-rate, cut-out-speed & cutting depth, according to Suhail Adeel et al [134].

While crater position and extension are influenced by feed rate, the model also showed that this is a significant effect. According to Chavoshi and Tajdari [136], CBN inserts on AISI 4140 steel resulted in surface roughness changes depending on spindle speed and material hardness fluctuation. Surface polish was improved when the hardness value was between 50 and 55 HRC, however spindle speed was shown to have no influence.

Young and Liou [154] measured the temperature at the back side of chip and at the tool-chipping-interface temperature and developed the relationship bet$^{n}$ cutting-tool flank wear and cutting temperature. They also described a relationship bet$^{n}$ tool-wear & temp. and force-on the tool. Kato and Fujii [155] developed some more techniques for measuring the temperatures like metallographic examination of used inserts, thermo sensitive paint technique and PVD film method. The distribution of temperature along the rake and flank faces of the ceramic tools was measured by Yourong et al. [156] with the help of infrared camera. In an experimentation process, Kottenstette [157] and Klocke and Einesblatter [104] made an inspection of the cutting temperature at the interface zone by using two – colour pyrometers. The various effects of temperatures which were shown during the formation of curled chips were studied by Wang et al. [158].The influence of cutting temperature on the tool wear was analyzed by Kitagawa T. et al. [159]. Chu and Wall bank [160] described the significance shown by the flank face forces on the work piece temperatures. By using conjugated gradient methodology, Lima et al. [161] predicted cutting temperature and performed numerical methods of solving to get the results using finite volumes approach. A study was done by Brio et al. [162] about the effects of generation of heat flux and tool coatings thickness on the cutting temperature.

When the temperature of a C1630 workpiece was measured using a mixed ceramics type MC 2 ($Al2O3$ + TiC) tool, the researchers found that when all of the process parameters increased, the temperature rose to a maximum of 1043 C. While milling aluminium 6061-based metal matrix composites with a K-20 carbide tool, Sri Ramakrishna and Ravinder Reddy forecasted the temperature along the cutting tool edge, shear zone, and interface areas with thermocouple, maintaining the feed rate constant. The tool–chip contact reached a maximum temperature of 3150C at a cutting speed of 50 m/min.

Shu et al. [166] used the CFD modeling approach to offer a numerical thermal modeling of cutting temperature. A smart tool was employed in this operation that has the cooling arrangement built in. Liang et al. [167] developed a 3D inverse heat conduction approach to forecast the tool–chip contact temperature during machining in dry conditions. For the machining of a Ti6Al4V work piece with a hardness of 340 HV using an HSS tool, Cotterell et al. [168] used an infrared thermal camera to monitor cutting temperature and shear strain. The results showed that as cutting speed rose, so did the shear strain. Friction in primary and secondary zones was also higher as cutting speed and feed rate were increased. Sushil [169] used a K-type tool work thermocouple to detect the temperature of the tungsten carbide cutting tool while milling EN8 alloy steel with an uncoated and CVD coated tool. When the feed rate was raised from 0.83 mm/rev. to 1.65 mm/rev. with the uncoated tool, the tool rake face experienced a significant temperature increase. Coated tools outperform uncoated ones in terms of tool life at greater cutting speeds when compared. [170] The quantity of heat transmitted during forceful turning was determined by Kundrak et al. using CFD modeling.

## III. Experimental Work

The machining experiments using vegetable-oil based cutting fluids were performed under min. quantities fluid application under air-mist mode. To supply the cutting fluid in the form of air-mist i.e. mixture of cutting fluid with air, at the cutting zone, a new experimental set up was fabricated which is shown in Fig. 3.1. It consisting of a storage-tanking of 10 litres capacity and has pipe lines for which pressure control valves are fitted. Pressure gauges are arranged to measure the pressure across the pipe lines. An air compressor of maximum pressure capacity of 30 bar, is coupled to the cutting fluid tank. The outlet of the tank is connected to a pipe line having a nozzle of 6 mm diameter through which as a high velocity jet.

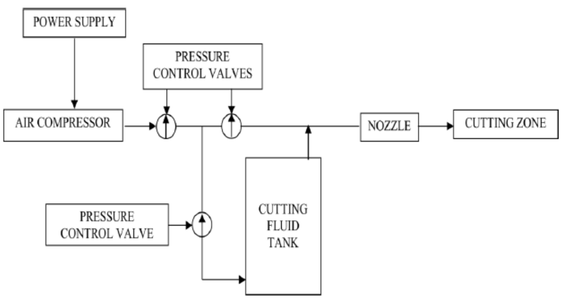



Fig. 1 Schematic representation of minimum cutting fluid application in air-mist mode

Minimizing the amount of cutting fluid used is achieved by using compressed air and vegetable oil-based water-soluble oils to spray the cutting fluid on the cutting surface. The cutting fluid is sprayed or misted at the cutting area in a very tiny amount. Figure 3.2 depicts the experimental setup for supplying cutting fluid in the form of air mist. A very tiny amount of cutting fluid may be delivered as an air-mist directly to the cutting area using this setup.

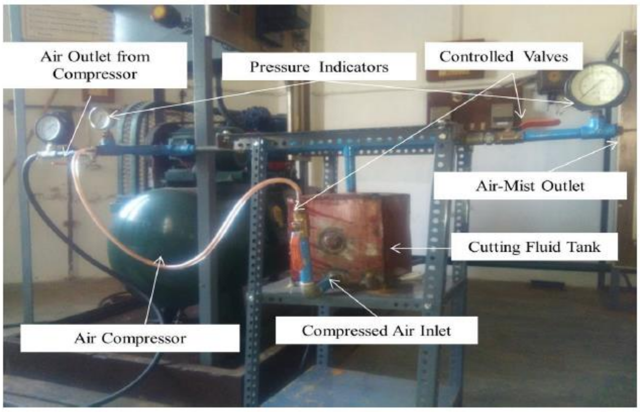
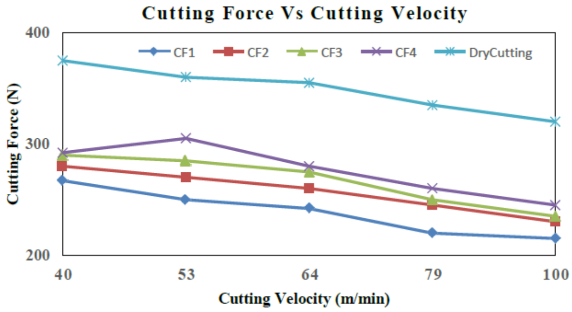



Fig. 2 Experimental setting-up for min. fluid usage under air-mist mode

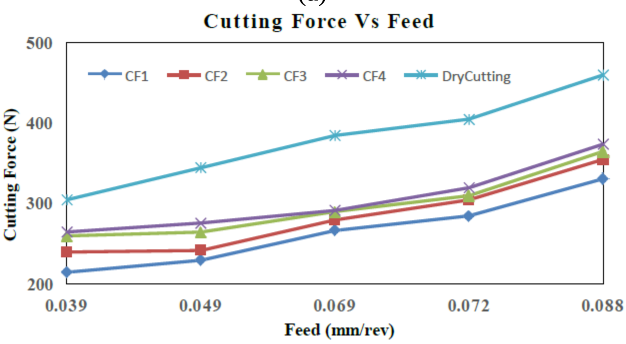
The air pressure (P) and cutting fluid quantity (Q) may both be adjusted separately using this set-up. In addition, the cutting fluid can be applied to the cutting zone at the interface between the tool chip and the cutting edge, or at the interface between the tool work and the cutting edge itself. An air-mist cutting fluid may be delivered at a maximum pressure of 30 bar and flow rates ranging from 2 ml/min to 30 ml/min using the experimental setup. Control valves allow the compressor's exit pressure to be used to modulate the air-mist pressure. Based on the amount of fluid in the tank, cutting fluid will be delivered accordingly. At the bottom of the cutting fluid tank, there is a supply of compressed air. As the cutting fluid level rises, so does the amount of cutting fluid carried by air. To provide a consistent supply of cutting fluid, the tank's cutting fluid level must be kept at a certain height. A vegetable oil-based water-soluble cutting fluid was used in the setup, which caused the air to be atomized at the interface between the tool and the workpiece or between the tool and the chip. Special fittings were used to ensure that a mist nozzle was placed where it would not interfere with the machine's tool, the work piece, or the chip during the cutting operation.

## IV. Experimental Result & Discussion

Cutting forces for a TiAlN-coated tool vary with cutting velocity and feed when using various vegetable oil-based cutting fluids in an air-mist application, as shown in Fig. 3. Temperature rises with an increase in cutting speed. The material's strength was reduced as the temperature rose at the shear plane, reducing cutting forces [294]. Coconut oil-based cutting fluid had a lesser cutting force than other vegetable oils, according to the research. With high friction between tool and chip contact, cutting force is substantially higher in dry turning than it is in other circumstances. Because of the small capillaries that occur in these surfaces, cutting fluid may be absorbed by the capillaries and used to build a thin layer that reduces friction. Air-mist application fragments the cutting fluid into small globules, which then penetrate the tool-chip contact and reduce friction.




(a)




(b)

Fig. 3 Variability in the cut-out forcing with (a) cutting velocity and (b) feed using TiAlN coated tool under air-mist application under different vegetable oil based cutting fluids

The experimental output also indicated that force of cutting is less in the case of vegetable-oil dependent cut-fluids when compared via mineral-oil dependent cut-out fluid. The higher viscosity index of the vegetable oils forms a thicker lubrication film which provides better separation of the surfaces [295]. The fatty acids present in the vegetable oils forms strong protection layer between

the sliding surfaces. In all vegetable oils the length of triglycerides is of similar length with different levels of unsaturation.
Design of experiments, analysis of variance (ANOVA), and average responses were used to investigate the impact of cutting parameters and minimum cutting fluid application parameters on the machining of AISI 4340 steel. Cutting speed, feed rate, and depth of cut were all chosen in conjunction with carbide and coated carbide tools based on previous research assessments [314-319]. On the other hand, Table 1 shows the input operating parameters and levels. Seven operational parameters were measured at two different levels, totaling seven. The influence of the specified parameters was studied using Taguchi's L8 orthogonal array. Experiments with two replications were carried out in eight separate experiments. Table 2 displays the operational parameters and their values for eight trials (L8).

Table 1 Different operating parameters and their levels used for 35 HRC steel

| S. No. | Operating parameter | Levels of parameters | |
|---|---|---|---|
| | | Level-1 | Level-2 |
| 1 | Direction of the fluid impingement | Tool-Chip Interface (TC) | Tool-work interface (TW) |
| 2 | Exit pressure of the Nozzle (P) (bar) | 5 ($P_1$) | 10 ($P_2$) |
| 3 | Quantity of Cutting Fluid (Q) (ml/min) | 10 ($Q_1$) | 20 ($Q_2$) |
| 4 | Concentration (C) (%) | 10 ($C_1$) | 20 ($C_2$) |
| 5 | Cutting velocity (V) (m/min) | 40 ($V_1$) | 64 ($V_2$) |
| 6 | Cutting feed (F) (mm/rev) | 0.039 ($F_1$) | 0.069 ($F_2$) |
| 7 | Depth of cut (D) (mm) | 0.5 ($D_1$) | 1 ($D_2$) |

Table 2 Standard L8 Orthogonal Array used for Experiments (Operating parameters and their levels for eight experiments)

| Trials | Operating Parameters and their Levels | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | TC | $P_1$ | $Q_1$ | $C_1$ | $V_1$ | $F_1$ | $D_1$ |
| 2 | TC | $P_1$ | $Q_1$ | $C_2$ | $V_2$ | $F_2$ | $D_2$ |
| 3 | TC | $P_2$ | $Q_2$ | $C_1$ | $V_1$ | $F_2$ | $D_2$ |
| 4 | TC | $P_2$ | $Q_2$ | $C_2$ | $V_2$ | $F_1$ | $D_1$ |
| 5 | TW | $P_1$ | $Q_2$ | $C_1$ | $V_1$ | $F_1$ | $D_2$ |
| 6 | TW | $P_1$ | $Q_2$ | $C_2$ | $V_2$ | $F_2$ | $D_1$ |
| 7 | TW | $P_2$ | $Q_1$ | $C_1$ | $V_1$ | $F_2$ | $D_1$ |
| 8 | TW | $P_2$ | $Q_1$ | $C_2$ | $V_2$ | $F_1$ | $D_2$ |

The surface roughness, cutting temperature, cutting force and tool wear were considered as output parameters. The flank wear for each experiment was measured after machining of 90 sec. These results showed that the minimum cutting fluid application parameters were significantly influencing the performance of the tool. The nozzle exit pressure is the significant parameter in minimum fluid application mode. The complete experimental results and the percentage of contribution of each input parameter on output parameters based on ANOVA are discussed as hereunder.

Table 3 Experimental Results based on Taguchi's L8 Orthogonal Array

| Expt. No. | Cutting Force (N) | | Surface Roughness (µm) | |
|---|---|---|---|---|
| | Trial1 | Trial 2 | Trial1 | Trial2 |
| 1 | 425 | 420 | 0.49 | 0.49 |
| 2 | 385 | 385 | 0.68 | 0.68 |
| 3 | 395 | 390 | 0.86 | 0.86 |
| 4 | 320 | 325 | 0.55 | 0.55 |
| 5 | 390 | 385 | 0.62 | 0.62 |
| 6 | 395 | 390 | 0.36 | 0.36 |
| 7 | 350 | 345 | 0.45 | 0.45 |
| 8 | 360 | 355 | 0.43 | 0.42 |
| Expt. No. | Cutting Temperature ($^0$C) | | Flank Wear (mm) | |
| | Trial1 | Trial 2 | Trial1 | Trial2 |
| 1 | 520 | 518 | 0.22 | 0.21 |
| 2 | 700 | 695 | 0.34 | 0.35 |
| 3 | 545 | 548 | 0.26 | 0.22 |
| 4 | 515 | 512 | 0.22 | 0.25 |
| 5 | 650 | 645 | 0.33 | 0.31 |
| 6 | 570 | 575 | 0.28 | 0.29 |
| 7 | 525 | 530 | 0.31 | 0.33 |
| 8 | 470 | 475 | 0.19 | 0.23 |

The experiments were conducted in two replications (conducted two times) at the same operating conditions as given in Table 3. In this work, the experiments were conducted two times at the same operation conditions as trail 1 and trail 2. In each trail, the performance parameter repeatedly measured for three times and average of three measurements was taken as final measured value. The experimental results for the eight run experiments with two replications are shown in Table 3.

## V. CONCLUSION AND FINDINGS

Based on the tuning experiments conducted on AISI 4340 hardened steel of hardness levels of 35HRC and 45HRC with different commercially available coated carbide tools using vegetable oil based cutting fluids under air-mist mode application, the following conclusions were drawn. Conclusions also include the Computational Fluid Dynamics simulation of hard turning process under air-mist mode cutting fluid application:

❖ The performance of coated carbide tools improved considerably under vegetable oil based cutting fluid under minimum cutting fluid application when compared to mineral oil based cutting fluids during machining of AISI 4340 steel

❖ The coconut oil based cutting fluid performed better during turning in terms of minimum cutting temperature, minimum cutting force, minimum surface roughness and minimum wear than the canola oil, castor oil and mineral oil based cutting fluids during machining of 35 HRC AISI 4340 steel under mist application using TiAlN coated tool. The experimental results also indicated that the canola oil is performing better than the castor oil.

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