COMPARISON OF TECHNIQUES OF MEASUREMENT OF CUTTING TEMPERATURE IN TURNING OPERATION UNDER DIFFERENT MACHINING CONDITIONS

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ABSTRACT

The power consumed in metal cutting is largely converted into heat and this heat in turn results in wear of tool and deteriorates the surface of material. Several attempts have been made to predict the temperatures involved in the process as a function of many parameters, as well as many experimental methods to measure temperature directly. Some simple analysis can be used to show the effects of cutting parameters, such as cutting speed and feed rate. This paper presents a review of the different methods used to measure cutting temperature. Some experimental results using different methods are presented. A simulation was done to find the cutting temperature in turning of AISI 316 and result obtained was verified with experimental data.

Keywords: Dry machining, Infrared technique, MQL, Thermocouple technique, Turning

I. INTRODUCTION

In manufacturing industries, there is increase demands of increase in productivity and reduction in costs, high speed machining proves to be an excellent solution. Increasing the metal removal rate means that more material can be cut in a shorter time and this has been achieved by increasing the cutting speed, the feed rate and the depth of cut. To do this in an economical way depends on many areas related with metal cutting, namely the machine tool, the cutting tool, the cutting fluid and the materials. The increase in power to remove more material in a shorter time increases the heat generation near the cutting edge of the tool, and the power consumed in metal cutting is largely converted into heat. This heat is dissipated by the four systems processing the material: the cutting tool, the workpiece, the chip formed and the cutting fluid. Dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining. Surface damage by oxidation, rapid corrosion and burning etc. Thermal flaking and fracturing of cutting tool due to thermal shocks. These factors make it necessary to measure the cutting temperature precisely. The exact and precise idea about cutting temperature is helpful in assessment of machinability. Conventional cutting fluid could not remove heat efficiently as it fails to penetrate the chip tool interface. Various advancements were made into the fields of cutting tool selection. Addition of Extreme Pressure Additives (EPA) had better performance as compared to the conventional one but it also fails to ensure the penetration of coolants at chip tool interface. High pressure lubrication oil managed to have both lubricating and cooling properties, but strict environment laws limit its uses. With main consideration on cost and stringent environment laws, dry machining and MQL proved economical. MQL refers to the use of minimum quantity lubrication, generally a flow rate of 50-500 ml/hr which is almost quarter of conventional fluids used in flood cooling conditions. Barrow D Silva et al [1], Herchang et al [2] and Komanduri et al [3] extensively reviewed the common techniques used for temperature measurement. These techniques can be classified as tool-work thermocouple, embedded thermocouple, radiation pyrometers, metallographic techniques and method of using powders of constant melting points. Stephenson [4] and Alvelidand Lezanksi et al [5] reviewed the technique of use of powders of constant melting points for the measurement of cutting temperature on grey cast iron and aluminium using WC tools. The major limitations of these processes are that it only gives a mean temperature along the tool-chip interface and local temperature cannot be measured. Muller et al [6] developed a fibre optic pyrometer which is two color based to measure the temperature on surface of unknown emissivity. Darwish et al and young [9] facilitated the use of Infrared Camera for the measurement of tool-chip interface temperature [7] an insulated wire is inserted into the workpiece through a hole of small diameter. With the melting of material, machining of the wire is also done and this forms a thermocouple between the wire and the tool. Boothroyd [8] proposed a method to calculate the mean temperature in the body of the chip from the measurement of the tool force and through knowledge and data of cutting parameter and thermal properties respectively. NIOSH [10] estimates reveal that almost 1.2 million workers are possibly exposed to the effects of MWF.it also recommended that respiratory protection should be used for MWF concentrations of 0.5 mg/m or more. Aerosol exposures of MWF's can cause diseases such as chronic bronchitis and asthma. Dhar et al. [11] utilized MQL technique in turning of AISI 4340 steel with carbide tool. Process parameters, velocity- 110m/min, feed rate- 0.16 mm/rev, depth of cut – 1.5 mm were set. Cutting fluid at the rate of 60 ml/hr was supplied and mixed with compressed air before being applied on cutting zone. MQL proved to be beneficial under same cutting conditions. There is a huge reduction in tool wear and surface roughness as compared to dry and wet machining.

In present work turning of AISI 316 stainless steel is done under dry condition and MQL condition. The Effect of feed rate, cutting velocity, and depth of cut is observed on temperature for both dry and MQL technique. The different parameters are chosen according to Taguchi L9. The temperature obtained through these experiments is measured using thermocouple and infrared measurement techniques and is then compared to the result obtained from the simulation of turning operation in similar conditions.

II. EXPERIMENTAL DETAILS

2.1. Material

The work material chosen was AISI 316 stainless steel of length 50mm and diameter 40mm. The composition of material is shown in table 1

Table 1 Composition of AISI 316

Element	% Fe	% Cr	% C	% P	% Mn	% Mo	% Ni	% S	% Si
Wt. %	62	18	0.08	0.045	2	3	14	0.03	1

2.2 Cutting conditions

The experiments were conducted in HMT lathe having maximum spindle power of 11kw and the spindle speed from 400 rpm to 1000 rpm under dry and MQL conditions. WIDIA cemented carbide tools CCMT 09T304-TN2000 were used for turning. The experiment set up is shown in Fig. 1. A fresh cutting edge was used for conducting each experiment. In order to remove irregularities and to avoid oxidation, material of 0.5mm depth was removed. The Minimum Quantity Lubrication (MQL) delivery system used in this study is a commercially available MQL fluid delivery system from UNIST Coolubricator as shown in Fig. 3.the air compressor used to maintain the pressure for MQL is in Fig 2. The cutting fluid was prepared by mixing of 5%vol. of ‘Servo Cut S’ oil.

Figure 1 NN22 LATHE

The principle of the temperature measurement by a thermocouple is that when two different metals are connected together, and if these parts called hot and cold junctions are maintained at two different temperatures, an electromotive force (emf) is produced across these two junctions. The emf generated is a function of the materials used for the thermocouple as well as the temperatures of the junctions. K type thermocouple is shown in figure 3.2. Infrared camera is a device which forms an image with the use of infrared radiations. It is similar to the common camera which makes images using visible lights. Infrared camera is shown in figure 3.3

Figure 2 K type thermocouple

Figure 3 Infrared camera

2.3 Design of experiment

In engineering analysis and optimization Taguchi is widely used for robust parameter design to find factor settings that minimize response variation, while adjusting the process on target. Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In this way the number of experiment are reduced using orthogonal array and thereby reducing the effect of uncontrollable factors [19]. According to Taguchi Design of Experiment 3- Level Design with 3 independent factors L9 was carried out.

Speed, Feed and Depth of cut are the independent factors. Effect of these parameters was seen on the temperature variation in dry and MQL condition. Values of the independent parameters were set according to 3-levels and the range was selected as shown in table 2.

Table 2 Value of Independent Parameters

	Low	Medium	High
Speed (m/min)	30	60	90
Feed (mm/rev)	0.04	0.1	0.16
Depth of cut (mm)	0.4	0.8	1.2

III. RESULTS AND DISCUSSION

Table 3 OBSERVATIONS

Exp. No.	Speed	Feed	Depth of cut	Dry Thermo couple	MQL Thermo couple	Dry Infrared	MQL Infrared	Dry Simulation	MQL Simulation
1	30	0.04	0.4	110.5	38.2	184.3	121.3	116.5	45.3
2	30	0.1	0.8	175.5	49.9	229.5	169.2	185.6	57.5
3	30	0.16	1.2	256.5	65.5	279.3	198.7	276.6	71.2
4	60	0.04	0.8	169.4	59.3	257.3	164.8	175.1	65.8
5	60	0.1	1.2	213.2	63.1	260.8	187	226.1	68.3

6	60	0.16	0.4	157.5	50.7	210	143.3	175.6	55.8
7	90	0.04	1.2	188.7	62.9	263	217.2	209.3	67.7
8	90	0.1	0.4	153.3	50.1	220.8	151.2	166.4	54.4
9	90	0.16	0.8	213.3	63.6	251.2	176.5	222.2	68.1

A simulation was carried out in similar conditions in both MQL and dry machining as shown in figure 4 that shows the operation being carried out at 90m/s speed, 0.16mm/rev feed and with depth of cut of 0.8mm and figure 5 shows the operation being carried out at 90m/s speed, 0.1mm/rev feed and with depth of cut of 0.4mm The figure clearly represents the temperature distribution and as most of the heat is carried by chips, the temperature is highest for them.

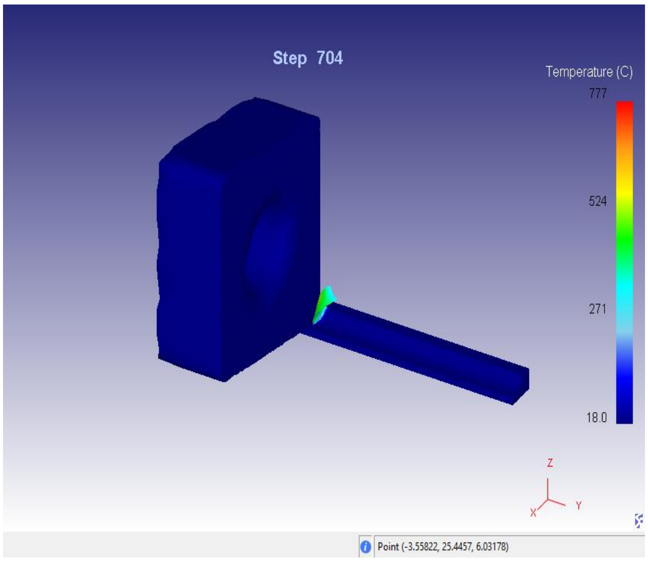


Figure 4 Simulation at 90m/s speed, 0.16mm/rev feed and 0.8mm depth of cut

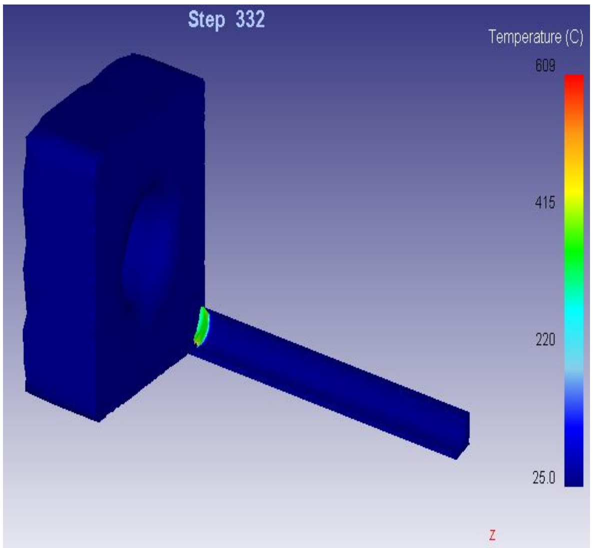
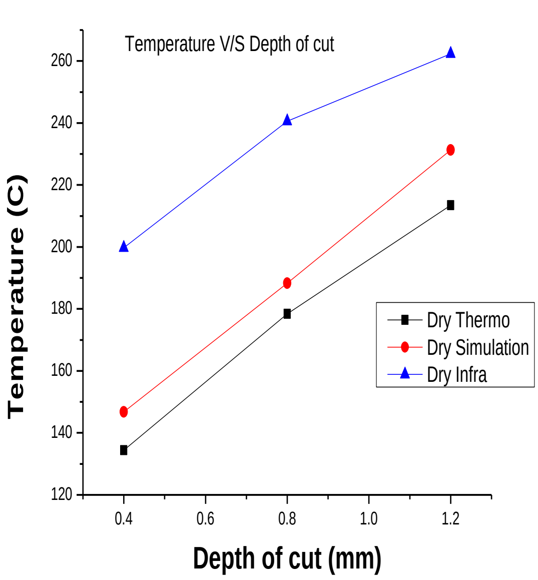
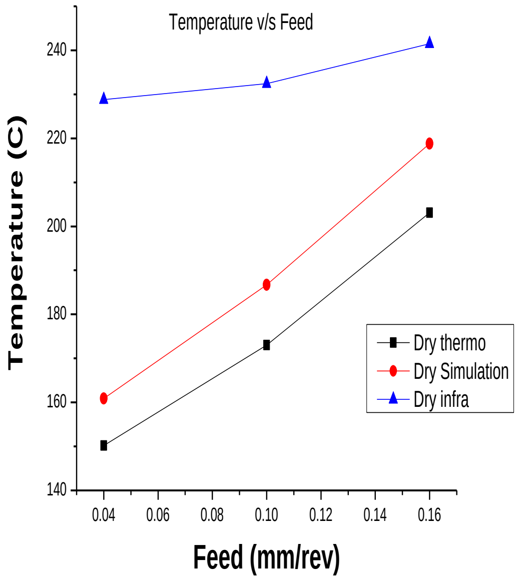


Figure 5 Simulation at 90m/s speed, 0.1mm/rev feed and 0.4mm depth of cut

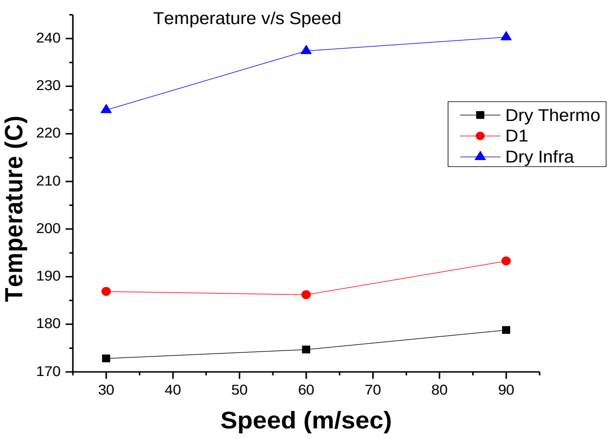
3.1 Effect Plot Discussion

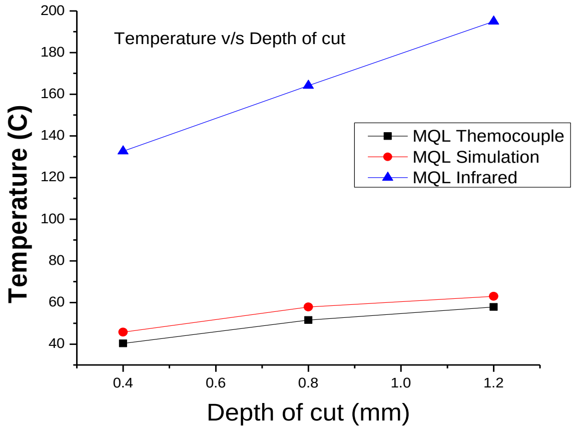




a) Temperature v/s Depth of cut in Dry b) Temperature v/s Feed in Dry

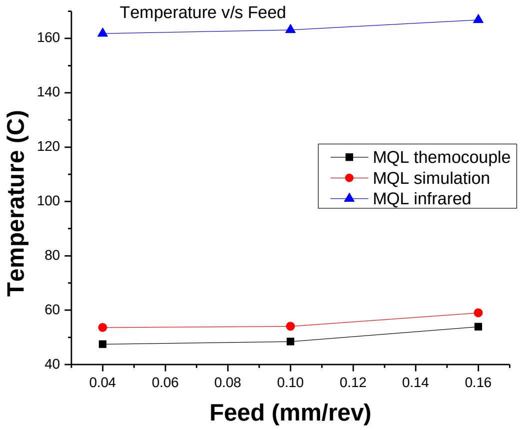
Temperature in dry condition was measured using two experimental techniques and was compared with the simulated one. Plot 1 shows the variation of temperature with depth of cut. Value of temperature increases with increase in depth of cut. Similarly plot 2 and plot 3 show the rise in temperature with feed and cutting speed respectively.



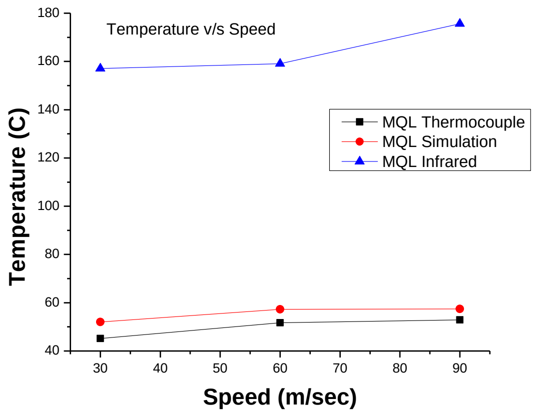


c) Temperature v/s Speed in Dry

d) Temperature v/s Depth of cut in MQL



e) Temperature v/s Feed in MQL



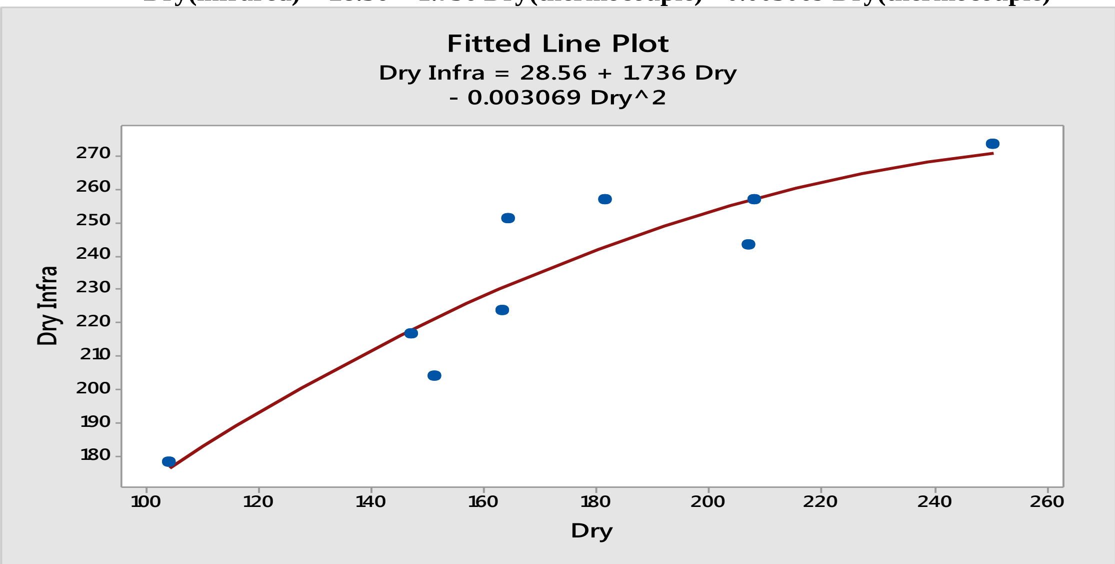
f) Temperature v/s Speed in MQL

Figure 6: Temperature v/s Process Parameters plots

Temperature was further measured in the MQL conditions and temperature using thermocouple and infrared technique and was compared with the simulated one. Plot 4, Plot5, Plot 6 show the variation of cutting temperature with the depth of cut, feed and speed respectively.

Since the pattern between the temperatures measured from the two techniques are similar, a relationship between the two is established using regression analysis and is plotted in plot 7.

$$\textbf{Dry(infrared)} = 28.56 + 1.736\ \textbf{Dry(thermocouple)} - 0.003069\ \textbf{Dry(thermocouple)}^2$$



Plot 7 Relation between temperature measured from thermocouple and infrared technique in dry condition.

IV. CONCLUSION

The following conclusions can be deduced from the study

- The temperature measured from the infrared camera is higher in value as compared to that of the thermocouple.

- Temperature measured through thermocouple and infrared technique in MQL conditions give lower value as compared to that of dry conditions.
- Magnitude of temperature measured using both techniques increases with the increase of feed, depth of cut, and speed.
- Simulation done is also valid as the temperature in all cases is within ±10% of the temperature measured by thermocouple technique.

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