International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

Measurement of Cutting Temperature in CNC Turning Center

[1]Anil Kumar, [2]Dr. Pankaj Khatak

[1]Research Scholar, Department of Mechanical Engineering, Guru Jambheshwar University of Science and Technology, Hisar-125001, Haryana, India. aniljangra370@gmail.com

[2]Associate Professor, Department of Mechanical Engineering, Guru Jambheshwar University of Science and Technology, Hisar-125001, Haryana, India. pankajkhatak@gmail.com

Abstract - Turning is the widely used process for producing cylindrical segments by a well-ordered subtraction of material from a part using a cutting tool. The heat produced and consequently the increase in the temperature effects tool life and thermal properties of work piece. The monitoring of cutting temperature will help in estimation of tool life and machining performance. The present work deals with the experimental measurement of cutting temperature using K-type thermocouple. A round bar of Mild steel AISI 1018 was turned with coated carbide insert on CNC turning center. The cutting temperatures results were compiled for three cooling conditions (without coolant, Minimum quantity lubrication with LUBECUT 1800 EA and Al_2O_3 nanofluid) with the variation of process parameters, spindle speed (800-1200 rpm), feed rate (80-100 mm/min) and depth of cut (0.5-1.5 mm). It is realized that cooling achieved with Al_2O_3 nanofluid was highest as compare to other cooling environments under similar test conditions.

Keywords: Cutting temperature, Minimum quantity lubrication (MQL) technique, CNC turning center, Al_2O_3 nanofluid.

Nomenclature

s	Spindle speed (rpm)
f	Feed rate (mm/min)
d	Depth of cut (mm)
Al_2O_3	Aluminium oxide
T_{wc}	Temperature without coolant (°C)
T_c	Temperature with coolant (°C)
$T_{Al_2O_3}$	Temperature with Al_2O_3 nanofluid (°C)
MQL	Minimum quantity lubrication

I. Introduction

CNC turning center is used for manufacturing of highly precise cylindrical parts. A significant amount of heat is generated at the time of metal cutting, due to energy deformation in cutting zone and friction between the tool and workpiece. Tool life may be reduced and thermal properties of workpiece are affected with the increase in temperature. An understanding of temperatures in this area provides vision to improve the properties of tool materials and coatings [1]. The metallurgical state of machined surface is dependent on the temperature of the cutting tool [2]. Cutting temperatures are also influenced by process parameters like spindle speed, feed rate, depth of cut, rake angle, and other properties of material [1]. Cutting temperature is a scalar field variable, it differs through the system and can't be individually defined by values at limited points. Therefore, different types of measurement techniques were developed that were based on various principles.

W.Grzesik [3] investigated the average Chip-tool boundary temperature and found that the heats transferred into the chip-tool are influenced by the thermal properties of the work piece material and coating. D. O'Sullivan and M. Cotterell, Abukhshim et al. [4, 5] showed that increase in tool wear lead to increase in cutting tool forces and machined surface temperature. Srikant et al. [6] experimentally examined the effect of nanoboric acid inclusion in SAE-40 and coconut oil in AISI 1040 steel turning. They concluded that the inclusion of nanoparticles in cutting fluids enhanced heat transfer rate which results, decrease in cutting temperature. L. B. Abhang and M. Hameedullah [7] realised that the chip-tool interf.ace temperature was mainly influenced by spindle speed as compared to others. During ste.el turning they concluded that a good arrangement between process parameters may create lowest cutting temperature. Amrita et al. [8] experimentally studied the performance of dry, flood flow and MQL lubrication of soluble oil with nanographite and without nanographite in AISI 1040 steel turning. The result

 DOI : 10.18231/2454-9150.2018.0942

shows that MQL with nanographite-soluble oil enhanced cooling than without nanographite, and flood cooling. Sougata Roy and Amitava Ghosh [9] evaluated that, MQL shows better cooling as compared with dry and flood cooling.10% - 30% decrease of cutting temperature was observed with MQL as compared to flood cooling. Khalil et al. [10] recognized the valuable effects of Nano lubricant with SDBS, there were effectual cooling, preservation of tool hardness and favourable chip–tool and work–tool interactions. Pavan kumar et al. [11] analysed that 0.5% weight proportionate graphite crystalline Nano particles leads minimum cutting temperature and surface roughness. Shuncai Li et al. [12] investigated the temperature and vibration of different tool wear state in turning. They found that the temperature of middle wear tool state was a little higher than tool of initial wear state and temperature of severe wear tool state was higher than tool of middle wear state. The vibration of the severe wear tool was the strongest and vibration of middle wear tool was weakest. Thus the monitoring of cutting temperature will help in estimation of tool life and machining performance.

II. EXPERIMENTATION

The experiments were carried on using CNC turning center (Model: STALLION 100SU) manufactured by M/s Hindustan Machine Tools (HMT) Ltd. Kerala, installed in CNC Laboratory of Mechanical Engineering Department, Guru Jambheshwar University of Science & Technology, Hisar, Haryana, India.

2.1 Tool and work piece material

Surface Coated (TiN-TiCN-Al_2O_3-TiN) carbide insert, manufactured by Kennametal was used as a cutting tool.

Cylindrical bar of Mild steel AISI 1018 (Table 3.1) with initial diameter 25 mm and length 100 mm was taken as a work piece material. AISI 1018 mild steel has good toughness, strength and ductility.

Table-3.1: Chemical composition of mild steel AISI 1018. [13]

Carbon	Manganese	Silicon	Sulphur	Phosphorus	Iron
0.17%	0.53%	0.22%	0.017%	0.018%	Balance

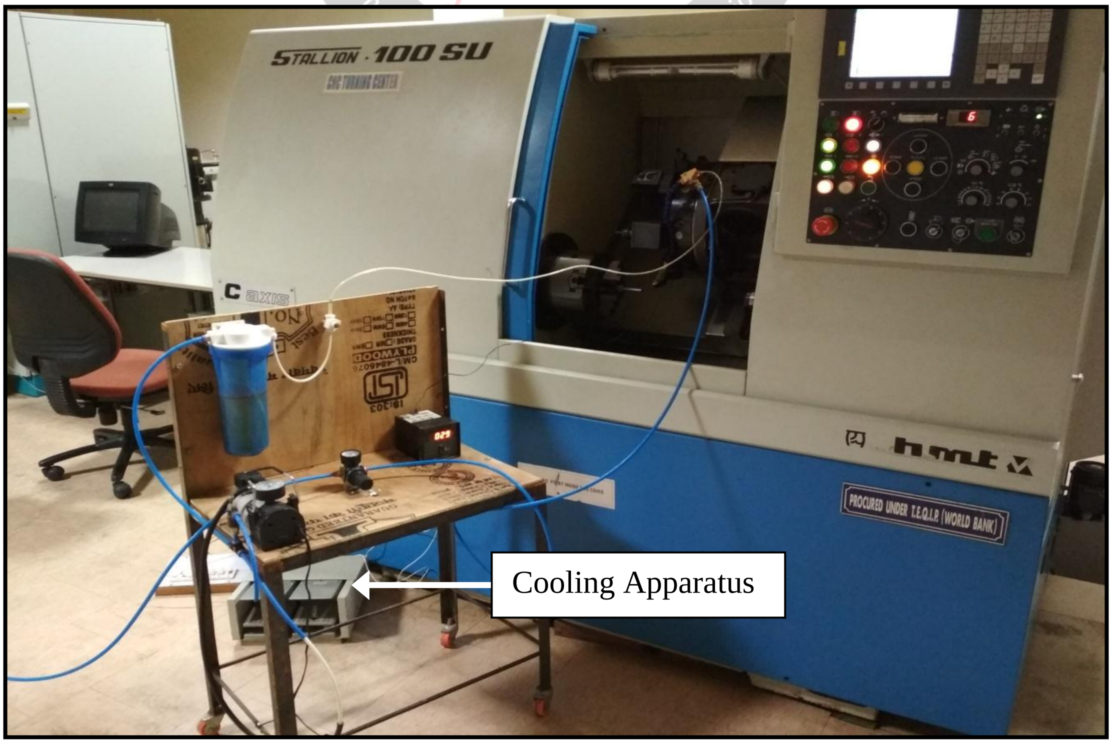
2.2 Coolant

A well-known commercially available semi synthetic coolant, LUBECUT 1800 EA was used as a cutting fluid. The cutting fluid was prepared by mixing of 100 ml of LUBECUT 1800 EA in 1000 ml of water to prepare 10% concentration cutting fluid [14].

Al_2O_3 nanofluid (0.5 wt.%) was prepared by magnetic steering of Al_2O_3 nanoparticles in base fluid (Water and LUBECUT 1800 EA) with mixing time of 5 hours at 700 rpm.

2.3 Experimental Setup

An experimental setup was designed and established for conducting the experiments under three cooling conditions namely, without coolant, Minimum quantity lubrication (MQL) with LUBECUT 1800 EA and Al_2O_3 nanofluid with the variation of process parameters; spindle speed (800-1200 rpm), feed rate (80-120 mm/min) and depth of cut (0.5-1.5 mm). The pictorial view and schematic flow diagram of setup is shown in Fig.2.1.



 DOI : 10.18231/2454-9150.2018.0942

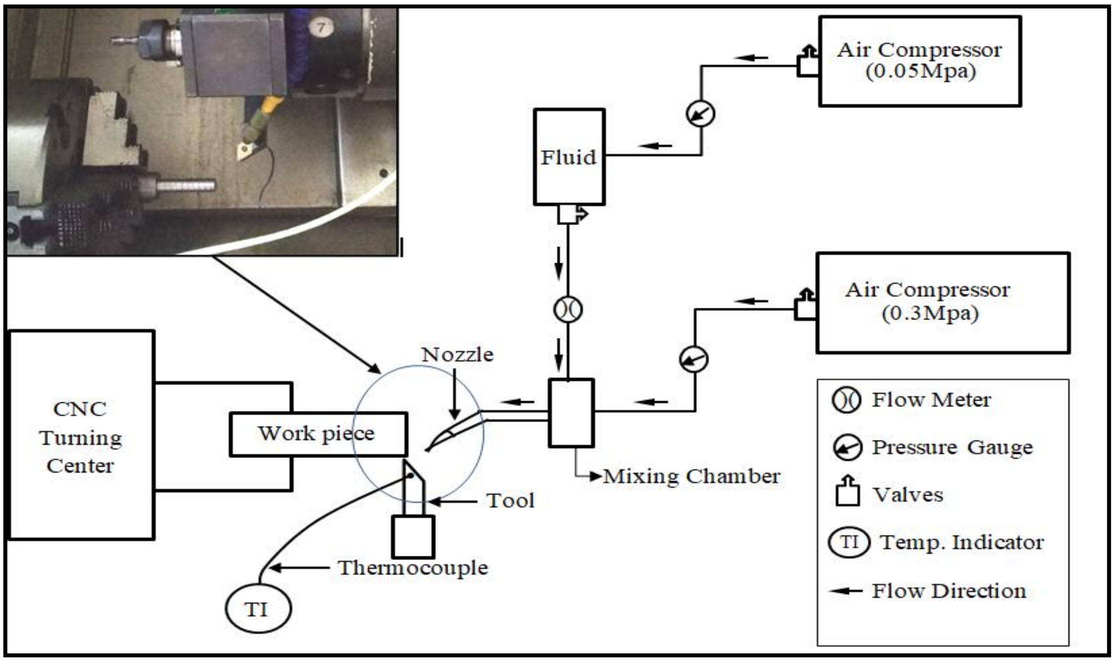


Fig.2.1 Experimental Setup and Schematic diagram of Minimum quantity lubrication

2.4 Experimental Conditions

According to the competency of machine tool, literature reviews and test experiments the operating range of input parameters were selected and are depicted in Table 2.1

Table 2.1 Parameters selected for experiments

Sr. No.	Parameter	Selected Parameter
1	Machine tool	CNC turning center (STALLION 100SU)
2	Work piece	Mild steel AISI 1018
3	Cutting tool	Coated carbide inserts
4	Spindle speed	800-1200 rpm
5	Feed rate	80-120 mm/min
6	Depth of cut	0.5-1.5 mm
7	MQL supply	Air: 3 bars, Lubricant: 120 ml/hr.
8	Environment	Without coolant, MQL with LUCBCUT 1800 EA and with AL_2O_3 Nanofluid
9	Measurement of cutting temperature	K-type thermocouple

2.5 Experimental Procedure

The experiments were carried with three machining conditions.

- Machining without coolant
- Machining with coolant LUBECUT 1800 EA, under (MQL) technique
- Machining with Al_2O_3 nanofluid under MQL technique

The steps for conducting experiments without coolant are describes as follows:-

1. Power on CNC turning center and its hydraulic system.
2. Clamp the mild steel AISI1020 workpiece in the chuck.
3. Select the turning tool from 8-station tool turret.
4. Perform the offset setting of CNC turning center.
5. Prepare and load the turning part programme.
6. Simulate the part programme to detect collision and near misses.
7. Attach the cooling apparatus with CNC turning center as shown in Fig.2.1.
8. Execute the part programme and record the temperature.
9. Record the temperature at every 30 seconds intervals till the steady state is reached.
10. Repeat the steps from 1-9 using different parameters.

Steps for conducting experiments under MQL technique cooling machining condition are describes as follows:-

1. Power on CNC turning center and its hydraulic system.
2. Clamp the mild steel AISI1020 workpiece in the chuck.
3. Select the turning tool from 8-station tool turret.
4. Perform the offset setting of CNC turning center.
5. Prepare and load the turning part programme.
6. Simulate the part programme to detect collision and near misses.
7. Ensure that all the electrical and fluid connections of the cooling apparatus and CNC machining center (Fig2.1) are connected.
8. Attach the cooling apparatus with CNC turning center as shown in Fig.2.1.
9. Execute the part programme, and simultaneously start the cooling apparatus.

 DOI : 10.18231/2454-9150.2018.0942

ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

10. The mist spray from nozzle is made to flow in such a way that it covers the entire cutting zone. The MQL supply was maintained at air pressure of 3 bars and fluid flow of 120 ml/hr.
11. Record the temperature at every 30 seconds intervals till the steady state is reached.
12. Repeat the steps from 1-11 using different parameters.

III. RESULTS AND DISCUSSION

In this study, machining process parameters for CNC turning center, taking cutting temperatures performance criteria under without coolant, with coolant, LUBECUT 1800 and with Al_2O_3 nanofluid using minimum quantity lubrication (MQL) technique will be analysed. The values of cutting temperature were experimentally recoded against process parameters specifically; spindle speed (800-1200 rpm.), feed rate (80-120 mm/min.), and depth of cut (0.5-1.5 mm) and are depicted in Table 3.1. The mean values of cutting temperatures for a given process parameter were calculated by changing the other two process parameters and are plotted with the help of MINITAB and Microsoft excel.

Table 3.1 Cutting temperature with different cutting conditions

Run	s	f	d	T_{wc} (°C)	T_c (°C)	$T_{Al_2O_3}$ (°C)
1	800	80	0.5	69.3	28.4	27.9
2	800	100	1	124.8	48.3	38.4
3	800	120	1.5	175.4	74.8	48.0
4	1000	80	1	130.2	61.7	47.2
5	1000	100	1.5	184.6	87.2	65.5
6	1000	120	0.5	70.7	36.1	26.0
7	1200	80	1.5	192.1	92.4	71.7
8	1200	100	0.5	78.4	40.5	29.6
9	1200	120	1	134.9	75.0	47.8

3.1 Cutting Temperature without Coolant (T_{wc})

The mean of temperatures under machining without coolant against the variations of Spindle speed, feed rate, and depth of cut are plotted in Fig 3.1

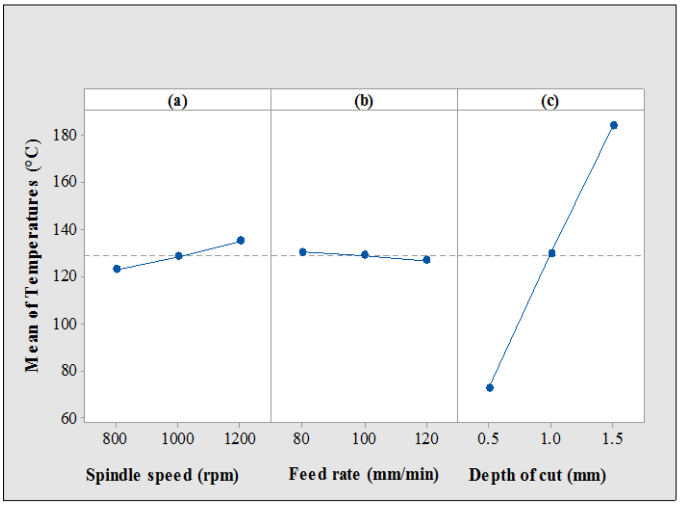


Fig.3.1: Cutting Temperature (Mean) against process parameters

Fig.3.1 (a) displays the influence of spindle speed on the mean temperatures. With increase in spindle speed, cutting temperature of the cutting zone increases. This increase of cutting temperature may be attributed to the friction increases between the tool and workpiece.

The mean of cutting temperatures against feed rate is plotted in Fig.3.1 (b). With increase in feed rate, cutting temperature decreases. Growth in feed rate from 80 to 120 mm/min, results in temperature decreases from 130.53 to 127.00 °C.

Fig.3.1 (c) indicates the variation of the cutting temperature in cutting region with depth of cut. For the depth of cut 0.5 mm, the recorded temperature was72.80°C, with a rise in depth of cut 1.5 mm, the value of temperature raises to184.03 °C, which represents rise in temperature of 60%. The rise in temperature with the increase in depth of cut may be due to effective increase in sectional area of chips.

3.2 Cutting Temperature with Coolant (T_c)

The mean of temperatures under machining with coolant against the variations of spindle speed , feed rate, depth of cut are plotted in Fig 3.2

 DOI : 10.18231/2454-9150.2018.0942

ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

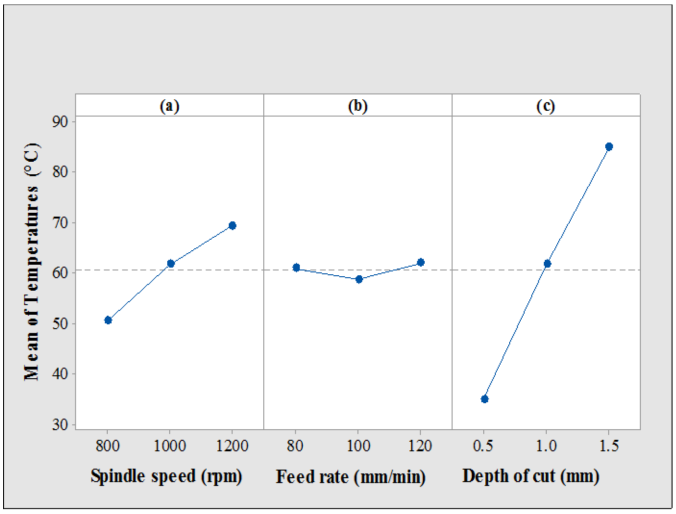


Fig.3.2: Cutting Temperature (Mean) against process parameters

Fig.3.2 (a) displays the influence of spindle speed on the mean temperatures in machining with coolant condition. With the rise in spindle speed, friction may increases; which induce the rise of temperature in cutting zone.

The variation of temperatures in cutting region with respect to feed rate for turning with coolant is shown in Fig.3.2 (b). With the increase in feed rate, cutting temperature decrease and after onward it increases. As shown in Fig.3.2 (b), for feed rate 80 to 100mm/min cutting temperature decreases from 60.83 °C to 58.67 °C and for feed rate 100 to 120mm/min temperature increases from 58.67 to 61.97 °C.

The change of the cutting temperature noted in cutting zone against depth of cut is shown in Fig 3.2 (c). At depth of cut 0.5 mm, the noted temperature was 35.00 °C, and with growth in depth of cut to 1.5 mm, the value of temperature rises to 84.80°C, which represents a growth in temperature of 58 %.

3.3 Cutting Temperature with Al_2O_3 Nanofluid ($T_{Al_2O_3}$)

The mean of temperatures under machining with coolant against the variations of spindle speed , feed rate, depth of cut are plotted in Fig 3.3

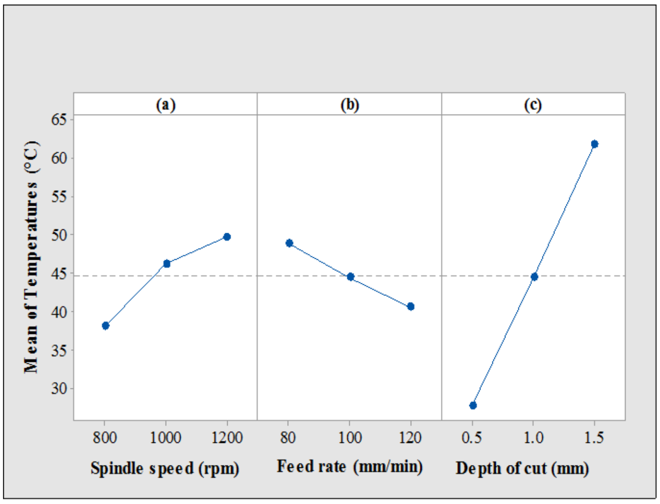


Fig.3.3: Cutting Temperature (Mean) against process parameters

Fig.3.3 (a) shows the influence of spindle speed on cutting temperature in machining with Al_2O_3 nanofluid as coolant. With increase in spindle speed cutting temperature also increases. This increase in temperature may be the effect of friction increases between tool and workpiece.

The variation of temperatures in cutting region according to the feed rate under the machining with Al_2O_3 nanofluid is shown in Fig 3.3 (b). With increase in feed rate, cutting temperature continuously decreases due to good thermal conductivity of nanofluid. As shown in Fig.3.3 at feed rate 80 to 100mm/min cutting temperature decreases from 48.93to 44.50°C and then at 120 mm/min it's drop to 40.60 °C.

The change of cutting temperature in machining with Al_2O_3 nanofluid cooling against depth of cut is presented in Fig.3.3 (c). With increase in depth of cut temperature increase continuously.

3.4 Cooling Effects in Different Machining Conditions

The cutting temperature is plotted against the three process parameters, spindle speed (Fig. 3.4), feed rate (Fig. 3.5), and depth of cut (Fig. 3.6) for the three machining conditions (without coolant, with coolant, with Al_2O_3 nanofluid).

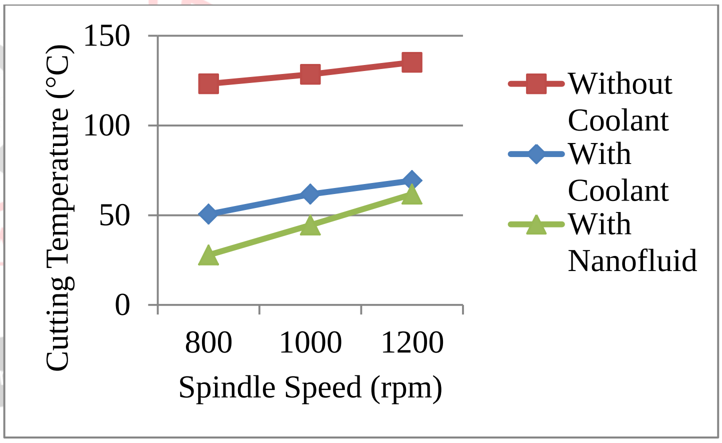


Fig.3.4 Spindle Speed vs. Cutting Temperature

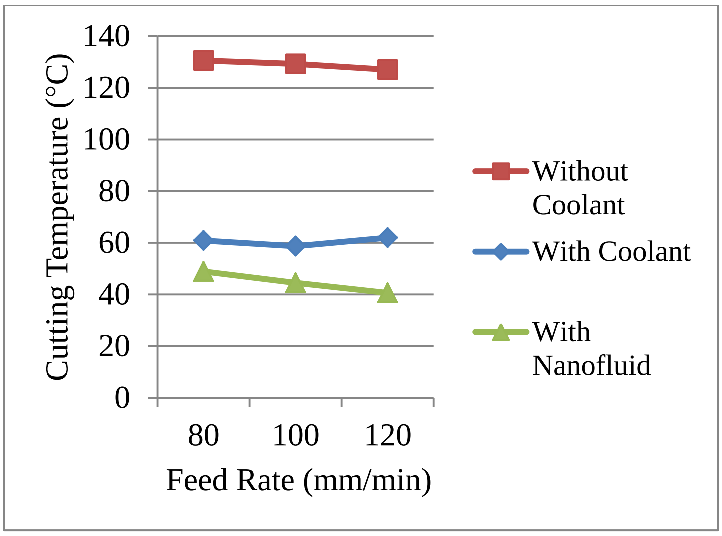


Fig.3.5 Feed rate vs Cutting Temperature

DOI : 10.18231/2454-9150.2018.0942

ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

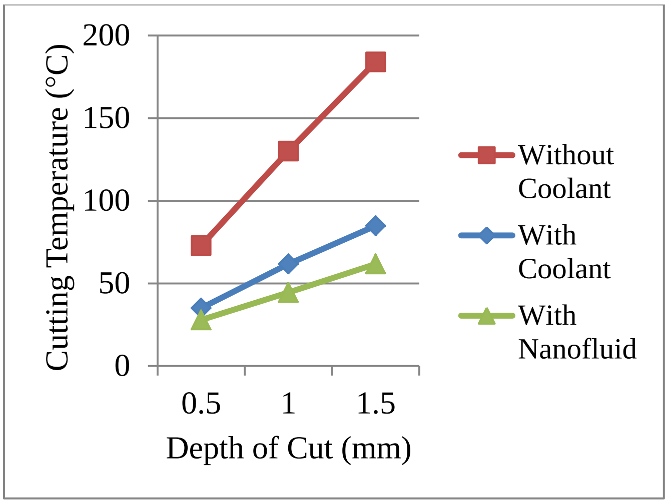


Fig.3.6 Depth of cut vs cutting temperature

It can be observed from Fig. 3.4 that the cutting temperature at a particular spindle speed is highest without coolant and lowest for Al_2O_3 nanofluid. Fig.3.5 shows that cutting temperatures are highest without coolant and decreases significantly with nanofluid for all the values of feed rates. The quantum rise in cutting temperature, without coolant as compared to nanofluid is less at low value (0.5 mm) than at high value (1.5 mm) of depth of cut.

3.5 Mathematical Model for Cutting Temperature

The mathematical relations (3.1, 3.2, and 3.3) between performance parameter (cutting temperature) and process parameters (spindle speed, feed rate, and depth of cut) were established with the regression analysis technique on experimental data (Table 3.1) using Minitab software. The following relations obtained from regression analysis are used to calculate the predicted values of cutting temperatures at different parametric conditions, within the range of experiments performed.

$$T_{wc}\ (°C) = -3.38 + 0.02992\, s - 0.0883\, f + 111.23\, d \quad (3.1)$$

$$T_c(°C) = -39.1 + 0.04700\, s + 0.0283\, f + 49.80\, d \quad (3.2)$$

$$T_{Al_2O_3}\ (°C) = 2.6 + 0.02900\, s - 0.2083\, f + 33.90\, d \quad (3.3)$$

3.5.1 Mathematical Equation Validation

The validation of the mathematical equations (3.1, 3.2, and 3.3) is established by matching the predicted values of temperatures, with the experimental values under similar test conditions. Tables 3.2, 3.3, and 3.4 compared the predicted values of temperature from the regression equations and its corresponding values from the experiments. The error percentage is within permissible limits [15]; hence regression equations can be utilized for prediction of cutting temperature values for any combination of process parameters within the rages of experiments.

Table 3.2 Tests without coolant

Run	s	f	d	T_{wc} (°C) (Predicted)	T_{wc} (°C) (Measured)	Error (%)
1	800	90	0.6	79.3	74.6	5.92
2	1000	85	1.2	152.5	164.2	7.67
3	1200	110	0.8	111.8	118.0	5.54

Table 3.3 Tests with coolant

Run	s	f	d	T_c (°C) (Predicted)	T_c (°C) (Measured)	Error (%)
1	800	90	0.6	30.9	33.2	7.4
2	1000	85	1.2	70.0	73.1	4.4
3	1200	110	0.8	60.25	56.4	6.3

Table 3.4 Tests with Al_2O_3 nanofluid cooling

Run	s	f	d	$T_{Al_2O_3}$ (°C) (Predicted)	$T_{Al_2O_3}$ (°C) (Measured)	Error (%)
1	800	90	0.6	27.6	26.2	5.0
2	1000	85	1.2	54.57	58.1	6.6
3	1200	110	0.8	41.61	44.8	7.8

IV. CONCLUSIONS

An experimental setup was designed to measure the average cutting tool temperature with k-type thermocouple during machining operation on CNC turning center (Stallion 100 SU) with work piece material mild steel AISI1018 and coated carbide as cutting tool. The cutting temperature results were compiled for three cooling conditions (without coolant, MQL with LUBECUT 1800 EA and Al_2O_3 nanofluid) with the variation of process parameters, spindle speed (800-1200 rpm), feed rate (80-100 mm/min) and depth of cut (mm). The following conclusions may be drawn on the basis of results and discussions.

- The highest decrease in cutting temperature of the order of 51.9% and 62.6% was achieved with LUBECUT 1800 EA and Al_2O_3nanofluid respectively as compared to machining without coolant at 1.5mmdepth of cut, 120 mm/min feed rate, and 1200 rpm spindle speed.
- A maximum error of around 7.8% in cutting temperature was realised with the developed mathematical model for the prediction of cutting temperature.
- The lowest cutting temperature respectively was 69.3, 28.4, and 27.9 °C under without coolant, with LUBECUT 1800 EA coolant and with Al_2O_3

 DOI : 10.18231/2454-9150.2018.0942

ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

nanofluid is obtained with parameters spindle speed 800rpm, feed rate 80 mm/min, depth of cut 0.5mm/min, which may be the optimal machining condition for CNC turning centre.

- Under specified conditions depth of cut is most influenced process parameters to cutting temperature.

REFERENCES

[1] Stephenson, David, and John Agapiou, Metal Cutting Theory and Practice Third Edition, 2016.

[2] Sivasakthivel, P. S., and R. Sudhakaran, Optimization of machining parameters on temperature rise in end milling of Al 6063 using response surface methodology and genetic algorithm, The International Journal of Advanced Manufacturing Technology,) 67 (2013) 2313–2323.

[3] W. Grzesik, Experimental investigation of the cutting temperature when turning with coated indexable inserts, International journal of machine tools & manufacture 39 (1999) 355–369.

[4] D. O'Sullivan, M. Cotterell, Temperature measurement in single point turning, Journal of material processing technology, 118 (2001) 301-308.

[5] N.A. Abukhshim, P.T. Mativenga and M.A. Sheikh, Investigation in heat partition in high speed turning of high strength alloy steel, International journal of machine tool & manufacture, 45 (2005) 1687-1695.

[6] R. R. Srikant, DN Rao, MS Subrahmanyam and P Vamsi Krishna, Applicability of cutting fluids with nanoparticle inclusion as coolants in machining,Proc. IMechE Vol. 223 Part J: J. Engineering Tribology, DOI:10.1243/13506501JET463 (2008).

[7] L. B. Abhang, M. Hameedullah, Chip-tool interface temperature prediction model for turning process, International journal of engineering science and technology, 2(4), 2010, 382-393.

[8] M Amrita, RR Srikant, AV Sitaramaraju, MMS Prasad and P Vamsi Krishna, Experimental investigations on influence of mist cooling using nanofluids on machining parameters in turning AISI 1040 steel, Journal of engineering tribology 227 (2013) 1334–1346.

[9] Sougata Roy and AmitavaGhosh, High-speed turning of AISI 4140 steel by multi-layered TiN top-coated insert with minimum quantity lubrication technology and assessment of near tool-tip temperature using infrared thermography, Journal engineering manufacture 2014, Vol. 228(9) 1058–1067.

[10] A.N.M Khalil, M.A.M Ali, A.I. Azmi, Effect of Al_2O_3 nanolubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant, 2nd International materials, industrial, and manufacturing engineering conference, MIMEC2015, 4-6 February 2015, Bali Indonesia, Procedia Manufacturing 2 (2015)130 – 134.

[11] D. Pavan kumar, S. Srikiran and Ch.V.S. Parameswara Rao, Experimental investigations of graphite nanoparticles and cutting parameters in turning of AISI 1040 steel with MQL, International journal of modern trends in engineering and research, Volume 03, Issue 06, [June– 2016] ISSN (Online):2349–9745.

[12] Shuncai Li, Qiu Yu, Guanlei Yuan and Li Liang, Experimental study of turning temperature and turning vibration for the tool of different wear state, IOP Conf. Series: Materials science and engineering 322 (2018) 042031 doi:10.1088/1757-899X/322/4/042031.

[13] Batra Metallurgical & Spectro Station, FIR No. 93665

[14] Semi-synthetic cutting fluid LUBECUT 1800 EA manufactured by Pratap Tex-Chem Pvt. Ltd. (Pune - 412 111, Maharashtra, India.)

[15] Mehul Gosaia, Sanket N. Bhavsarb, Experimental study on temperature measurement in turning operation of hardened steel (EN36), 3rd International conference on innovations in automation and mechatronics engineering, ICIAME 2016, Procedia Technology 23 (2016) 311 – 318.

DOI : 10.18231/2454-9150.2018.0942