

Effect of machining variables and coolant application on HSS tool temperature during turning on a CNC lathe

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Abstract - Cutting variables in the operation of a Computerized Numerical Control (CNC) lathe machine can affect parameters such as the work piece, tool temperature, material surface finish, material properties and vibration. A programmable CNC lathe machine was used in this work to examine the effect of different cutting variables on HSS tool temperature. Carbon steel material of C20 carbon equivalent and ferritic stainless steel was machined at different cutting speeds, depth of cut with an HSS tool. A type K thermocouple was fitted at a distance 5 mm from tool nose by a direct surface contact on tool under an applied pressure. A constant feed rate was maintained throughout the experiments. Temperature profiles were obtained for different depth of cut ranging between 0.5 and 2.5 mm and cutting speed range of 500 to 800 rpm and a constant feed rate of 7 mm /minute. Tool Temperatures were observed to increase with cutting speed and depth of cut. Increase in depth of cut from 0.5 to 1.5 mm resulted into a 64% increase in tool temperature while coolant application reduced tool temperature by as much as 63.2% in stainless steel. Tool life can be significantly enhanced by appropriate machining variables selection.

Keywords: CNC lathe machine; temperature; cutting parameters; type K thermocouple

1. Introduction

Computerized Numerical Control (CNC) lathes are rapidly replacing the older production lathes due to their ease of setting, operation, repeatability and accuracy. Unlike the manually controlled lathes, CNC machines are often totally enclosed thus enhancing safety during application. Substantial amount of heat is generated from the shearing action associated with machining process, the heat is transmitted through the shank of the tool. Friction and shearing exist at the tool – chip interface and below the tool edge respectively with conductive heat transfer through work piece, the chip and the tool. The cutting zone temperature is a key factor which directly affects tool wear, work piece surface integrity and machining precision according to the relative motion between the tool and work piece.

Temperature in the cutting zone depends on contact length between tool and chip, cutting forces and friction between tool and work material. Cutting variables such as cutting velocity, feed and depth of cut affect temperature and which by extension also affect the material strength and hardness [1, 2]. Heat generated is unevenly distributed between chip, cutting tool and the blank work-piece. Mode of distribution depends on configuration, size and thermal conductivity. From 10 – 20% of total heat generated goes into the tool while the remaining heat is dissipated through the chip and blank workpiece [3]. Main techniques used to evaluate the cutting temperature during machining are classified into two, contact and non-contact methods. Contact requires direct conduction through a sensor. These methods are; embedded thermocouple, thermally sensitive paint, Physical vapour deposition (PVD) film method and thermo – chemical powders while non - contact radiation methods are; infrared radiation pyrometers, infrared cameras and optical thermocouple techniques. Other methods are use of thermo-sensitive paint, metallography based on microstructural and microhardness variations, use of thermal

cameras [4], of all the various methods, the most widely used for obtaining average chip – tool interface temperature is the thermocouple. Other methods suffer from various disadvantages such as slow response, indirectness and complications in measurement [5].

Choice of any temperature measurement technique depends on the thermal situation, accessibility of sensor to the object location, dynamics of the situation, accuracy needed, instrumentation cost, data collection and analysis [6]. Thermocouples offer the following advantages (a) simplicity, (b) remote signal measurement and low cost [7]. Goyal *et al.* [8] carried out an exhaustive study of most existing experimental techniques of temperature measurement applicable to metal cutting. Their paper discussed in details seven different methods in practice highlighting the advantages and disadvantages of temperature on cutting tool. Abhang *et al.* [9] predicted temperature at chip / tool interface during lathe turning process. Their results show that increase in cutting speed, feed rate, and depth of cut increases the cutting temperature while increasing the nose radius reduces the cutting temperature [10]. Ghodam *et al.* [11] compared cutting tool temperatures of uncoated and CVD coated tungsten carbide tools. A tool - work thermocouple embedded in the work piece was used to convert the measured emf to the work / tool interfacial temperatures. As feed rate or depth of cut increases temperature of uncoated tool increases at an higher rate than the coated tool. They concluded that coating of the tool increases the tool life and can be used at higher cutting speeds [11]. Knowledge of tool thermal history during machining serves as valuable information for the prediction of tool wear, surface finish, choice of coolant and application rate, control of cutting characteristics and a valuable data base for development of appropriate predictive software on thermal characteristics and cutting variables [12]. An appreciable temperature rise beyond certain standards could be indicative of faulty tool or work-piece setting. This can negatively affect part quality, dimensional accuracy and introduction of residual stresses.

Cutting fluids application during machining are meant to lubricate and cool the tool / work – piece interface region [13]. They are broadly classified as water miscible and straight oils. The straight oils are used primarily for lubrication of tool / work interface. Soluble oils act as both coolant and lubricant for the sliding surfaces during machining. Other researchers that had looked at influence of cutting fluid on temperatures are Shaw *et al.* [14], Smart and Trent [15]. At cutting speeds in excess of 200 m/min, cutting fluids have no significant effect on cutting zone temperature Viera *et al.* [16], studied the cooling ability of different cutting fluids on AISI 1020 steels and deduced that chip – tool interface temperature increased with increasing cutting speed during machining while semi-synthetic cutting fluids was the most effective among the coolants. Researchers had found that high pressure coolant application to chip – tool interface reduces cutting temperature, tool life and surface finishes are improved [17, 22].

In this work the effect of machining variables on tool temperature during dry and wet machining of mild and stainless steel on a CNC lathe was experimentally examined using type K thermocouple sandwiched under pressure between cutting tool and a gasket material. The temperature values on both materials were compared and the results are hereby reported. For every machining variable 5(five) different values were tested and corresponding temperature values taken.

2. Experimental Methods

2.1 Materials and Machine Specification

Temperature history measurement was carried out on Tungsten high speed steel (HSS) tool. The AISI T-1 grade was used with chemical composition shown in Table 1.

Table 1: Chemical Composition of AISI T – 1 HSS Tool in wt % (Source: ASTM/A600 standards)

C	Si	Mn	Cr	V	W	Fe
0.65–0.75	0.20-0.40	0.20-0.40	3.75-4.50	0.90-1.30	17.25-18.75	77.05-73.90

Final specification of work piece material was diameter 50 mm against a length of 70 mm.

Compositional analysis of the work-pieces was carried out by a specialized laboratory. Atomic Absorption Spectrometer was used for the analysis. Material used for machining was mild steel and stainless steel with the composition given in Table 2.

Table 2: Composition of Machined Mild Steel Material (wt %)

C	Si	S	P	Mn	Ni	Cr	Cu	AL	Ca	Fe
0.10	0.32	0.08	0.01	1.16	0.23	0.03	0.22	0.03	0.03	97.85

The stainless steel used belongs to the Ferritic steel category with less than 0.08% C, 12 – 19% Cr, 0 – 5% Ni, less than 5% Mo and traces of Ti. Temperature was monitored at tool tip at a distance 5 mm from nose tip. A horizontal CNC lathe machine was used. The specifications are: - Make: AJAX Machine; Model number: AJEV 310; Maximum distance between centers is 1500 mm, Tail stock diameter: 95 mm; speed range is 10 – 2500 rpm.

2.2 Temperature measurement

A type K thermocouple (Ni – Cr / Ni - AL) connected to a temperature data logger was used in taking the temperature measurement. The thermocouple hot junction was positioned at a distance 5 mm from tool nose on rake surface. A heat resistant insulating material of the rubberized asbestos cloth type of 4 mm thickness was placed on the thermocouple as an interface with a clamping steel bar. This method is nondestructive as no part of the HSS tool is drilled or welded towards thermocouple probe insertion. The assembly was carefully clamped on the tool post cautiously maintaining the relative distance of thermocouple to tool tip. Figure 1(a) is a schematic of the arrangement of thermocouple and tool while figure 1(b) is the set – up of tool on tool post and work-piece mounted on 3 – Jaw CNC lathe chuck. Pressure resulting from tool clamp caused an effective contact between tool and workpiece.

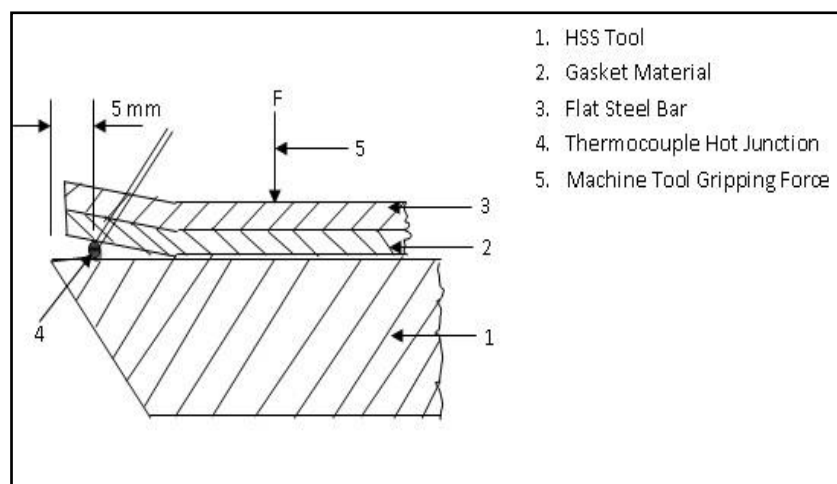


Figure 1(a) Sectional view showing positioning of thermocouple hot junction.

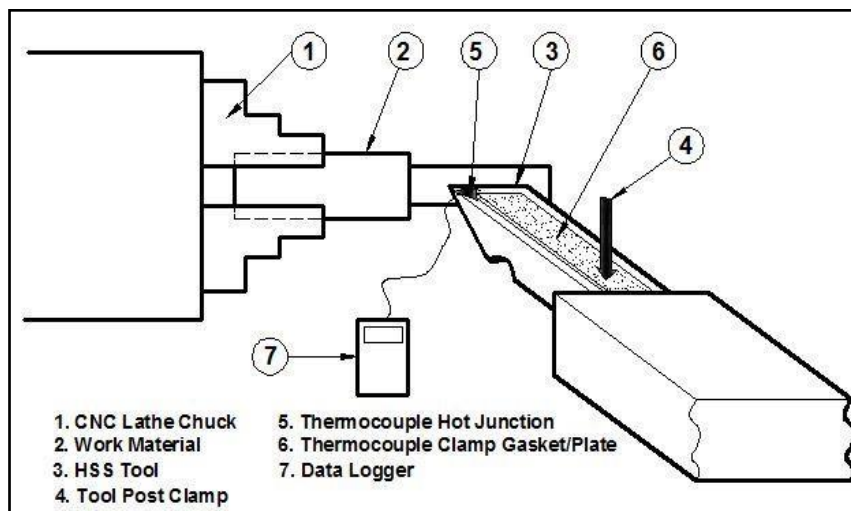


Figure 1(b) Mounting of the Work-piece and tool with thermocouple

Temperature of tool was recorded at short intervals of 2 seconds under the following machining conditions. Table 3 shows the selected machining characteristics for both dry and wet cut.

Table 3: Selected Machining Variables

	Dry		Wet	
	Cutting Speed (rpm)	Depth of Cut (mm)	Cutting Speed (rpm)	Depth of Cut (mm)
1	500	0.5, 1.0, 1.5, 2.0, 2.5	500	0.5, 1.0, 1.5
2	650	0.5, 1.0, 1.5, 2.0, 2.5	650	0.5, 1.0, 1.5
3	800	0.5, 1.0, 1.5, 2.0, 2.5	800	0.5, 1.0, 1.5

A constant feed rate of 7 mm/min was used while machining duration was limited to 600 seconds. After every experiment, ample time was allowed for the tool to cool to initial state of atmospheric temperature before commencement of the next cut.

Data entry in the data logger were opened and converted into graphical plots of temperature versus time for the various machining variables.

2.3 CNC Lathe Machine Set – Up

Work-piece was mounted on the three jaw chuck and automatically clamped. Machine was programmed using G and M – Codes to set the depth of cut. Reference points were chosen for X and Z axis then subsequently add the depth of cut to the indicated X axis value. Process termination is done with respect to the Z – axis.

3. Results and Discussion

3.1 Tool Thermal History under Varying Depths of Cut

Figure 2 shows temperature variation with time at cutting speed of 500 rpm and depths of cut ranging from 0.5 to 2.5 mm for mild steel. In all cases temperature increased gradually with machining time

and also with increasing depth of cut. At a typical machining time of 570 seconds and depths of cut of 1.0 and 2.5 mm, temperature values of 46 and 77°C was observed respectively. Increasing depth of cut by 150% at 500 rpm resulted into a 67.4% increase in temperature.

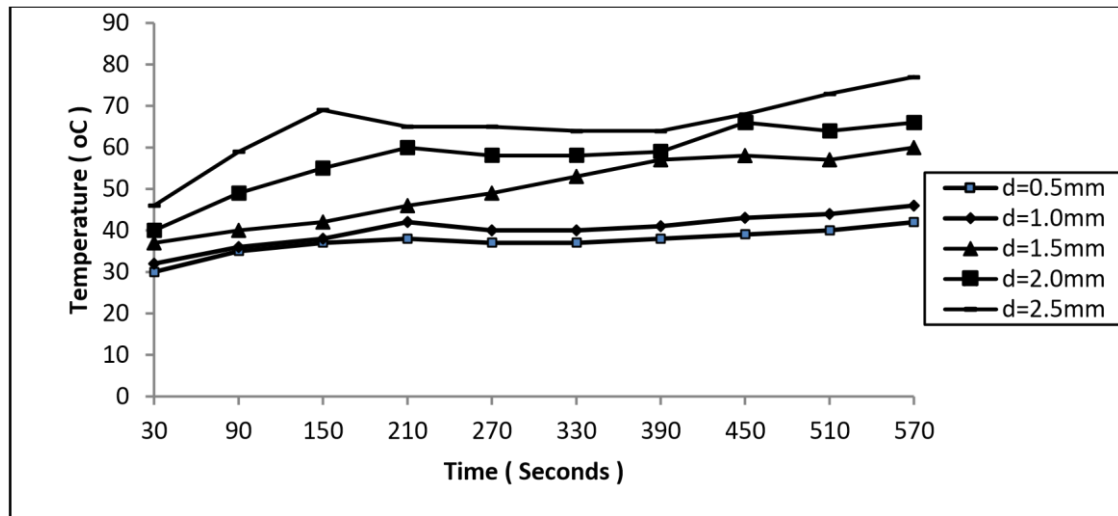


Figure 2: Variation of tool temperature with time at speed 500rpm for mild steel

Figure 3 shows temperature variation with time at cutting speed of 650 rpm and depths of cut ranging between 0.5 and 2.5 mm for mild steel. In all cases temperature increased gradually with machining time and also with increasing depth of cut. At a typical machining time of 570 seconds and depths of cut of 0.5 and 1.5 mm, temperature values of 42°C and 73°C was observed respectively. Increasing depth of cut by 150% at 650 rpm resulted into a 52.5% increase in temperature.

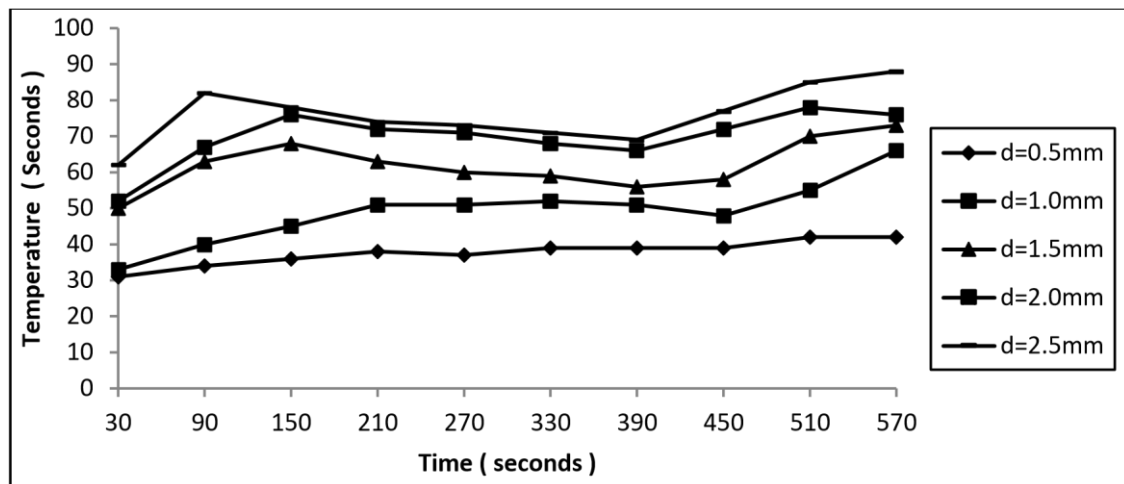


Figure 3: Variation of tool temperature with time at speed 650rpm for dry machining of mild steel

Figure 4 shows temperature variation with time at cutting speed of 800 rpm and depths of cut ranging between 0.5 and 2.5 mm for mild steel. In all cases, temperature increases gradually with machining time and also with increasing depth of cut. At a typical machining time of 570 seconds and depths of cut of 1.0 and 2.5 mm, temperature values of 66 and 115°C was observed respectively. Increasing depth of cut by 150% at 800 rpm resulted into a 74.2% increase in temperature. Akhil *et al.* [2] obtained 61.2 and 90.4°C at depth of cut of 1.0 and 2.0 mm respectively with cutting speed 685 rpm and 12 mm/min feed rate).

Figure 5 shows observed maximum temperature under different depths of cut and machining speeds. Temperature consistently increased with depth of cut and machining speed, attaining the values 75, 86 and 111°C at machining speeds of 500, 650 and 800 rpm respectively. For a typical depth of cut of 2.50 mm and 540 seconds of machining time increase of speed by 60% resulted into a 48% increase in temperature.

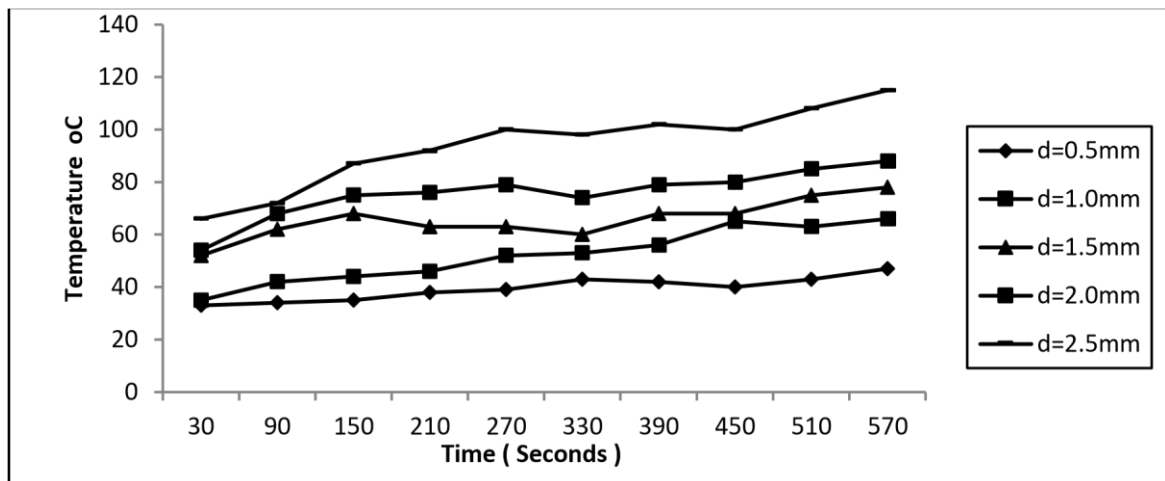


Figure 4: Variation of tool temperature with time at speed 800 rpm in dry machining of mild steel

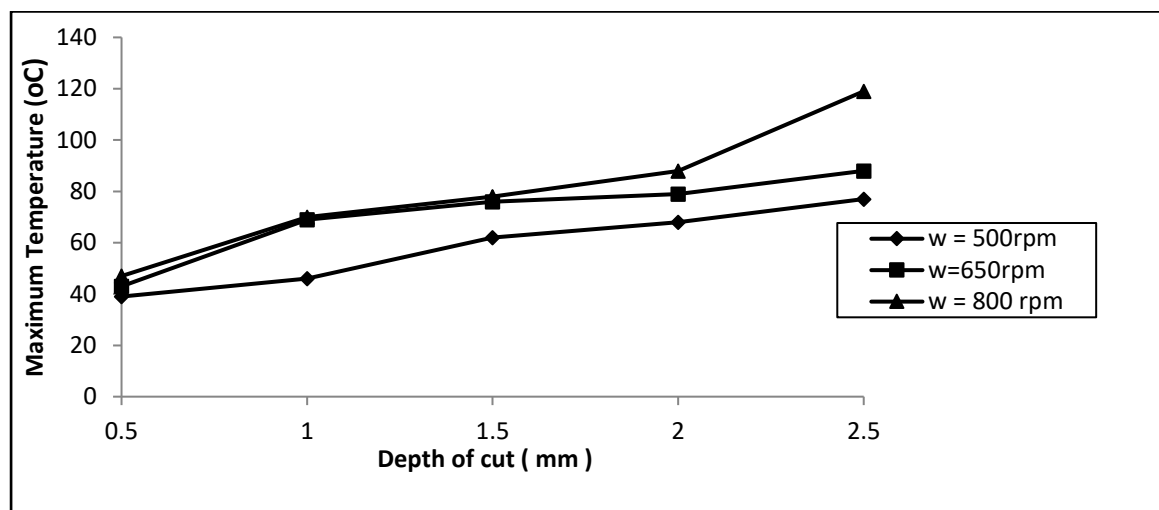


Figure 5: Variation of tool maximum temperature with depth of cut in dry machining of mild steel

3.2 Effect of Material Type on Tool Temperature History

Figure 6 shows temperature variation with time at cutting speed of 650 rpm and depths of cut ranging between 0.5 and 1.5 mm for stainless steel work material. At all depth of cut temperature increases gradually with machining time and also with increasing depth of cut. At a typical machining time of 570 seconds and depths of cut of 0.5 and 1.5 mm, temperature values of 82 and 118°C was observed for stainless steel while mild steel indicated 42 and 73°C respectively. This is explained in terms of the higher tensile strength of stainless steel (680 MN/m²) as compared with mild steel (370 MN/m²). Higher deformation energy is required to shear the work piece along the shear plane in stainless steel as compared with mild steel thus resulting in higher temperature history. Increasing depth of cut by 150% at 650 rpm resulted into a 43.90% increase in temperature in the machining of stainless steel material.

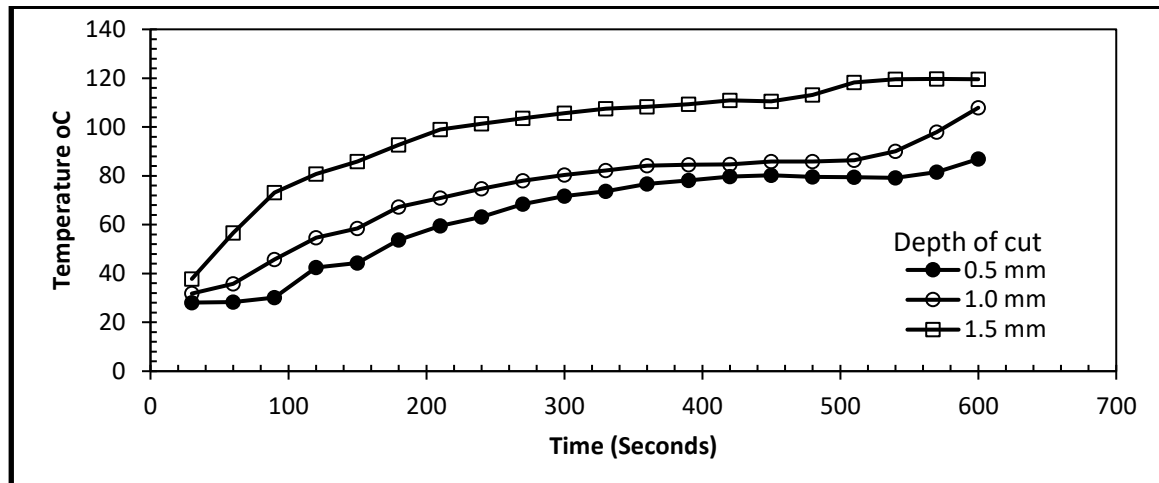


Figure 6: Tool temperature variation with time at 650 rpm using stainless steel materials

3.3 Effect of Coolant Application on Tool Temperature History

Figure 7 shows cutting tool maximum temperatures at various spindle speeds under dry and wet cutting conditions. Peak temperatures of 120°C and 37.4°C were observed under dry and wet machining conditions for stainless steel at 750 rpm. Coolant application reduced peak temperature by as much as 68.83%. Table 4 shows a comparison of HSS tool temperatures in the machining of mild and stainless steel at machining time of 570 seconds

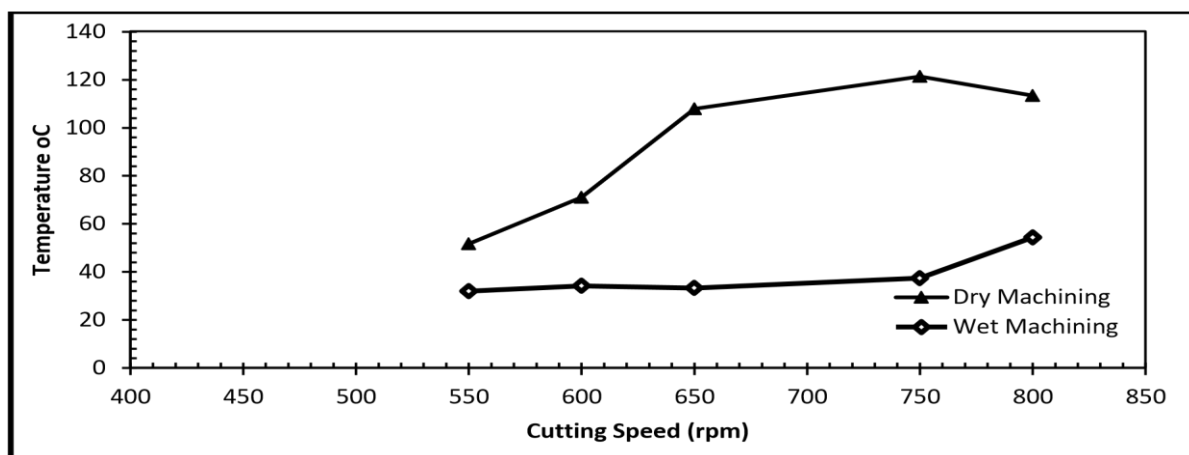


Figure 7: Variation of tool temperature with cutting speed in dry and wet machining of stainless steel

Table 4: Comparison of HSS Tool Temperatures in Machining of Mild and Stainless Steels

Machining Variables	Machining Speed (rpm)					
			500	650	500	650
			Mild Steel		Stainless Steel	
(a) Peak temperature at given depth of cut	0.5 mm	°C	40.0	42.0	39.7	81.6
	1.0 mm	°C	46.0	66.0	51.0	97.9
	1.5 mm	°C	58.0	73.0	54.3	119.7
(b) Percent temperature increase at 0.5 to 1.5 mm depth of cut increase.		%	40	42.5	26.9	31.8
(c) Temperature with coolant application	1.0 mm	°C	-	-	32	36.0
(d) Percent temperature reduction due to cooling		%	-	-	37.3	63.2

4. Conclusions

This investigation has shown the influence of cutting variables and work – material type on HSS tool tip temperature. Tool tip temperature was measured using type K thermocouple with the hot junction pressed on the tool by a modest clamping force with an insulating material interface. Tool temperature generally increased with increasing depth of cut and speed while a change of material affected the thermal history. Specific conclusions from this investigation are as listed:

- HSS tool tip temperature increased by as much as 49.35% by increasing speed by 60%.(500 to 800 rpm)
- Peak temperature attained during machining increased with depth of cut. In mild steel maximum temperature value of 115°C was attained at 2.5 mm depth of cut.
- Temperature gradually increased with time in all cases. Temperature increased from 37.8°C to a maximum of 119.7°C over a time period of 570 seconds in stainless steel machining.
- Work material mechanical strength affected temperature history with stainless steel material of higher mechanical strength than mild steel causing higher tool temperature.
- A temperature reduction from 97.9 to 36°C translating to 63.23% reduction obtains during coolant application in stainless steel machining.
- HSS tool deformation became significant during machining of stainless steel at depths of cut in excess of 1.5 mm. (A stronger cutting tool than HSS is recommended for machining stainless steel beyond 1.5 mm depth of cut.)

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