# Influence of Cutting Factors on the Cutting Tool Temperature and Surface Roughness of Steel C45 during Turning Process

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**Abstract –** *This study presents the cutting factors that lead to the temperature rise of the cutting tool and its relation to the surface roughness during turning process. Three main factors were studied which are rotational speed, depth of cut and feed rate. The temperatures were measured and recorded directly on a Matlab program using a special interface at rotational speed values of 900, 1200 and 1500 rpm and a depth of cut of 1, 1.5 and 2 mm and feed rate values of 0.1, 0.15 and 0.2 mm respectively. The tests were conducted in the case of dry operation as well as in the case of using coolant to determine the effect of using coolant on both the temperature and the surface roughness and also the ratio of these effects. The results showed that the depth of cut and rotational speed were the most important factors affecting the temperature and the surface roughness. A minimum temperature of 59°C in the cutting tool was reached at a rotational speed of 900 rpm, depth of cut of 1 mm and feed rate of 0.1 mm/rev. However a maximum temperate of 110°C in the cutting tool was reached at a rotational speed of 1500 rpm, depth of cut of 2 mm and feed rate of 0.2 mm/rev. Similarly, low surface roughness of 0.72 µm was obtained at a rotational speed of 1500 rpm, depth of cut of 2 mm and feed rate of 0.15 mm/rev. However, high surface roughness of 2.78 µm was obtained at a rotational speed of 900 rpm, depth of cut of 1.5 mm and feed rate of 0.1 mm/rev.*

***Key Words***: cutting factors, cutting tool temperature, surface roughness, C45, dry operation, coolant.

## 1.INTRODUCTION

Generally, during the machining process a huge amount of heat is generated as well as in different process where deformation of material occurs. The generated temperature at the surface of cutting tool (insert) that in contact with the workpiece is termed as a cutting tool temperature. Hence, heat is a factor which strongly influences the tool performance during this process. The consumed power in metal cutting process is then converted into heat. Several experimental investigations have been performed to predict and measure the temperatures involved during this process using numerical, analytical and experimental techniques. Prediction and measurement of machining forces, temperatures tool wear, residual stresses and many other characteristics were performed with substantial care and many good agreements were found between numerical analytical solutions and experimental data, [1].

N.A. Abukhshim et al [2] explained that the cutting temperature is a key factor directly affecting cutting tools and wear, workpieces surface and precision machining accuracy according to the relative movement between the cutting tool and workpieces. The heat generated amount varies with the kind of operated material and the cutting factors, particularly the cutting speed. These cutting factors such as speed, depth of cut and feed rate were studied using 3-D temperature field of tool during machining and compared with experimental work on C45 workpiece using carbide cutting tool inserts. Cutting speed, surface quality and cutting forces depend mainly on the temperature that high temperatures can cause high mechanical stresses which lead to early tool wear and reduce tool life. Therefore, considerable attention was paid to determine the tool temperatures. The experiments were carried out for dry and orthogonal machining condition. It showed that an increase of tool temperature depended on depth of cut and especially cutting speed in high range of cutting conditions [3]. However, S.R. Das [4] presented an optimal method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieve minimum tool wear and low workpiece surface temperature. The experimental layout was designed based on the Taguchi's L9 Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results confirmed that the depth of cut and cutting speed were the most important parameter influencing the tool wear. The minimum tool wear was found at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev. Similarly, low work piece surface temperature was obtained at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev. Thereafter, optimal ranges of tool wear and workpiece surface temperature values were predicted.

Ali et al. [5], focused on experimental work by measuring the tool-chip interface temperature (TCTI), the tool temperature (TT) and the average surface roughness (Ra), during the turning of AISI 4140 tungsten carbide inserts using an IR pyrometer technique K type thermocouple and a portable surface roughness measurement device, respectively. The Taguchi method L18 (21 × 37) was used for the determination of the optimal control factors. The depth of cut, the cutting speed and the feed rate were taken as control factors. The (ANOVA) was applied to determine the effects of the control factors on the tool-chip interface temperature, the tool temperature and the surface roughness. The coefficients of correlation for TCTI, TT and Ra were found as 92.8, 68.1 and 82.6 respectively.

Adeel et al. [6] concentrated on optimizing the cutting parameters using two performance measures, workpiece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The orthogonal array, signal to noise ratio and (ANOVA) were employed to study the performance characteristics in turning process. The experimental results showed that the workpiece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process to increase machine utilization and decrease production cost in an automated manufacturing environment.

Akhil et al. [7], compared the captured temperature of 3-D work with the experimental technique on C45 alloy steel specimen using carbide clamps. It was used different parameters of cutting factors such as the speed, surface quality, and the depth of cut which affect the temperature rise. The experiments were performed in the case of dry and orthogonal pieces. The results showed a maximum temperature of 141.5°C in the cutting tool during this kind of experiments. However, the generated heat during metal cutting processes affected material properties and the tool wear. Sana [8] analyzed the 3-D transient temperature distributions in a metal cutting process using a finite element FE code of Deform 3-D. It was studied the effects of the rake angle, cutting speed, feed rate for both tool and work piece materials on the temperature and heat flux. The results showed that increasing the cutting speed and feed rate increased the cutting temperature. While, increasing rake angle reduced the cutting tool temperature. It was indicated that, as cutting speed increased from 103.2 to 250 m/min an increase in temperature equal to 21.9% occurred. With a reduction in the rake angle from +5° to -5°, temperature increased by 12.3%. As the feed rate increased from 0.16 mm/rev to 0.25 mm/rev, the temperature increased by 13.82%.

Sushil [9] studied the effect of cutting high temperature on the cutting performance and the quality of the final product was also examined. The experimental work was done using the thermocouple to measure the temperature and the piece of soft steel operator was on a conventional turning machine. The coating was used to study the effect of the coating on the performance of the cutting tool and compared it with non-coated tool. It was found that the coating of the tool increases the life of a tool as compared to uncoated tool for the same cutting velocity or for the same tool life. However, Ajay et al. [10] explained the description of the thermodynamic procedures and the calibration method that was provided to determine the temperature values at the cutting point. In his experimental work, a thermocouple was used to measure the temperature because it is easy to install, use, inexpensive and bits of tungsten coated carbide were used. The results showed a comprehensive description of the temperature development at the cut-off point and the calibration method.

Muataz et al. [11] Presented and optimized the development of new models of machining parameters mathematically to minimize the cutting tool temperature at the end of a milling process by integrating the genetic algorithm (GA) with the statistical approach. The mathematical models for the cutting tool temperature and surface roughness parameters have been developed, in terms of cutting speed, feed rate, and axial depth of cut by using response methodology method (RSM). Two objectives have been considered, minimum cutting temperature and minimum arithmetic mean roughness (Ra). Due to the complexity of this machining optimization problem, a multi objective genetic algorithm (MOGA) has been applied to resolve the problem, and the results have been analyzed.

Finally, it was found that these studies were not conducted by studying the influence of cutting tool temperature in the cases of dry and with cooling operation. So, this paper will focus on this comparison and the extent of contribution of liquid coolant in reducing the cutting temperature and forecasting and their relationship to surface roughness. The current research will consider three variables which are speed of rotation, depth of cut and feed rate as indicators of the cutting temperature and surface roughness in both dry and with coolant operating in metal C45.

## 2. EXPERIMENTAL TESTS

In this work the material of alloy steel C45 has been used in the experimental work. This specimen of C45 alloy steel has a maximum carbon solubility of 0.45% which is categories as medium carbon steel. This kind of steel is normally used for the engineering application due to its high strength and toughness. A cylindrical specimen of steel C45 of 250 mm long and 30 mm diameter is installed on CNC lathe machine (spinner TC42) as shown clearly in

Figure 1. This steel C45 specimen has the chemical composition and mechanical properties as stated by Prashant [12-13] are shown in Table 1 and Table 2.

**Fig – 1:** CNC Lathe machine (Spinner TC42) with view of cutting zone.

**Table -1:** C45 chemical; composition (in volume fraction %), Prasanth [12-13].

| C | Cr | Mo | Si | Mn | Ph |
|---|---|---|---|---|---|
| 0.45 % | 1.2 % | 0.14 % | 0.25 % | 0.67 % | 0.008 % |

**Table -2:** C45 Physical and Mechanical Properties, Prasanth [12-13].

| quantity | Value | Unit |
|---|---|---|
| Thermal Conductivity | 25 | w/m.K |
| Specific Heat | 460 | J/kg.K |
| Melting Temperature | 1450-1510 | °C |
| Density | 7700 | Kg/m$^3$ |
| Young's Modulus | 2000 | MPa |
| Tensile Strength | 650-880 | MPa |
| Elongation | 8-25 | % |
| Fatigue Strength | 275 | MPa |
| Yield Strength | 350-550 | MPa |

A thermocouple of temperature range between 0°C and 900°C which is k-type is used to measure the cutting tool temperature. This kind of thermocouple has been selected because it is easy to calibrate and has a fast time response and also has a high frequency range during the tests. In addition to that it is inexpensive. This thermocouple is inserted in a prepared slot where it is attached to the carbide tip installed in the cutting tool and connected directly to a MATLAB program to record the variable temperature for further analysis. Figure 2 shows the tool holder of PSBNR2525M12- type with a square insert. The shown insert in figure 2 used in this experiment is SNMG120408-type has 12 mm length, 4 mm thickness and 8 mm corner radius. It has inclination angle of -6° and orthogonal rake angle -6° with a nose radius of 0.8 mm. It has been used in both in both cases of dry operation and with coolant operation. The used coolant in this experiment is synthetic fluid as refrigerant. It contains no petroleum or mineral oils and consists of chemical lubricants and rust inhibitors dissolved in water, [14]. This fluid is designed for high cooling capacity, lubricity, corrosion prevention and easy maintenance. The flow rate during the experiment was 25 liters/min under pressure of 30 MPa.

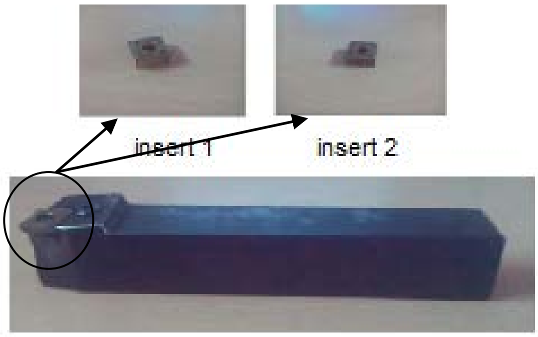

**Fig - 2** View of tool holder (PSBNR2525M12- type) with square insert (SNMG120408-type), [15].

**Fig – 3:** Surface roughness measurement device.

The cutting conditions were selected at speed ranging from 900 to 1500 rpm, feeding rate from 0.1 to 0.2 mm/rev, and depth of cutting from 1 to 2 mm. These values have been determined in order to give the required finishing quality in applications of steel C45. The tungsten carbide inserts of SNMG120408-type were used based on recommendations by the cutting tool manufacturer. Tests were conducted in dry condition and with coolant condition. A total of 54 samples of steel C45, were prepared and all samples were unmetered, of which 27 were in dry case run and 27 with a coolant case run at the same cutting conditions and the same operating time. The roughness at each experiment in case of dry and with coolant operation was also measured through a mobile roughness measurement device as shown in Figure 3.

## 3. RESULTS AND DISCUSSIONS

Table 3 shows the values of the cut off factors identified after the previous studies and the limits of the three cutting values of the C45 metal which achieve its important applications and require a roughness of the surface. Therefore, these factors were selected according to the following table.

**Table-3**: Experimental training dataset, [15].

| NO | Cutting parameters | | |
|---|---|---|---|
| | N (rpm) | S (mm/rev) | a (mm) |
| 1 | 900 | 0.1 | 1 |
| 2 | 1200 | 0.1 | 1 |
| 3 | 1500 | 0.1 | 1 |
| 4 | 900 | 0.15 | 1 |
| 5 | 1200 | 0.15 | 1 |
| 6 | 1500 | 0.15 | 1 |
| 7 | 900 | 0.2 | 1 |
| 8 | 1200 | 0.2 | 1 |
| 9 | 1500 | 0.2 | 1 |
| 10 | 900 | 0.1 | 1.5 |
| 11 | 1200 | 0.1 | 1.5 |
| 12 | 1500 | 0.1 | 1.5 |
| 13 | 900 | 0.15 | 1.5 |
| 14 | 1200 | 0.15 | 1.5 |
| 15 | 1500 | 0.15 | 1.5 |
| 16 | 900 | 0.2 | 1.5 |
| 17 | 1200 | 0.2 | 1.5 |
| 18 | 1500 | 0.2 | 1.5 |
| 19 | 900 | 0.1 | 2 |
| 20 | 1200 | 0.1 | 2 |
| 21 | 1500 | 0.1 | 2 |
| 22 | 900 | 0.15 | 2 |
| 23 | 1200 | 0.15 | 2 |
| 24 | 1500 | 0.15 | 2 |
| 25 | 900 | 0.2 | 2 |
| 26 | 1200 | 0.2 | 2 |
| 27 | 1500 | 0.2 | 2 |

Where

N: is rotational speed, rpm.

S: is feed rate, mm/rev.

a : is depth of cut, mm.

A total of 54 samples of steel C45, were prepared and a total of 150 reading per each sample were taken as one reading every 5 seconds. The number of samples in the dry case operation is 27 and in the case of coolant case operation is also 27 at the same cutting conditions and time. All collected reading is then fed to a MATALB program. All samples were tested and the roughness of each sample was measured where five roughness values were taken on the surface of each sample. The average roughness of each sample was calculated and the mean temperature was also calculated for each sample for both cases. These values are collected and figured as follows;

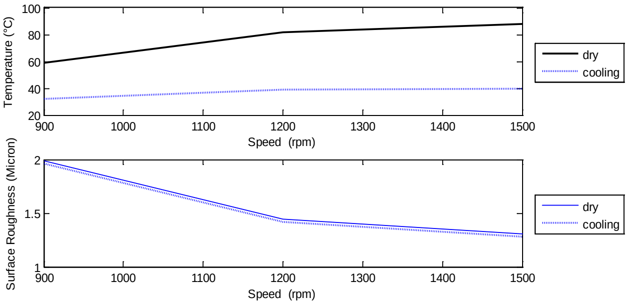

**Fig - 4:** Temperature and surface roughness against speed for dry and coolant at S=0.1 mm/rev and a=1 mm.

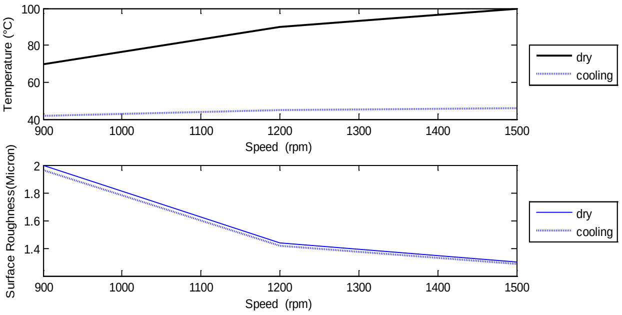

**Fig - 5:** Temperature and surface roughness against speed for dry and coolant at S=0.15 mm/rev and a=1.5 mm.

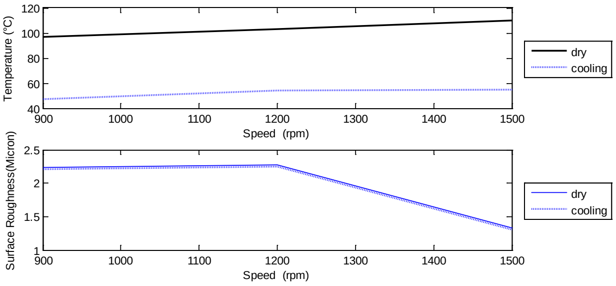

**Fig - 6:** Temperature and surface roughness against speed for dry and coolant at S=0.2 mm/rev and a=2 mm.

Figure 4 shows the relationship between temperature and surface roughness against speed for dry and coolant condition at feed rate 0.1 mm/rev and depth of cut 1 mm. It indicates that the temperature increases from 59°C to 82°C at increasing speed from 900 to 1200 rpm. However the temperature increases from 82°C to 88°C at increasing speed from 1200 to 1500 rpm in dry operation case.

Figure 5 shows also the relationship between temperature and surface roughness against speed for dry and coolant condition at feed rate 0.15 mm/rev and depth of cut 1.5 mm. It indicates that the temperature increases from 70°C to 90°C at increasing speed from 900 to 1200 rpm. However the temperature increases from 90°C to 100°C at increasing speed from 1200 to 1500 rpm. And the same relation is shown in Figure 6 but at feed rate 0.2 mm/rev and depth of cut 2 mm. It shows that the temperature increases from 97°C to 103°C at increasing speed from 900 to 1200 rpm and the temperature increases from 103°C to 110°C at increasing speed from 1200 to 1500 rpm. These group of figures confirmed that the feed rate value, depth of cut and rotational speed have been shown a significant effect on the temperature rise. This was evident in the average temperature curve where the highest mean temperature is at the highest speed.

However, in case of the presence of coolant, there is a significant decrease in the average temperature because of the presence of coolant effect and can be determined through the comparison of results with the case of dry operation. While, in roughness curves, the average surface roughness is reduced by increasing the rotational speed, the feed rate, and reducing the depth of cut and decrease surface roughness with the presence of coolant.

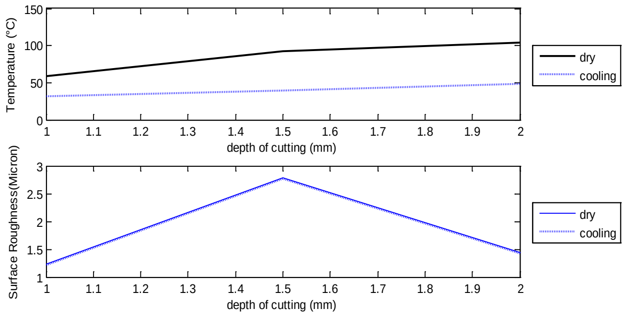

**Fig - 7:** Temperature and surface roughness against depth of cut for dry and coolant at N=900 rpm and S=0.1 mm/rev.

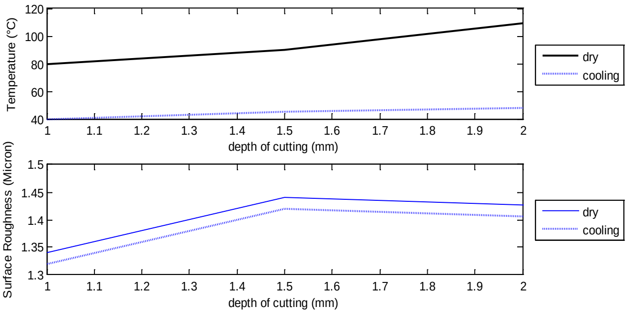

**Fig - 8:** Temperature and surface roughness against depth of cut for dry and coolant at N=1200 rpm and S=0.15 mm/rev.

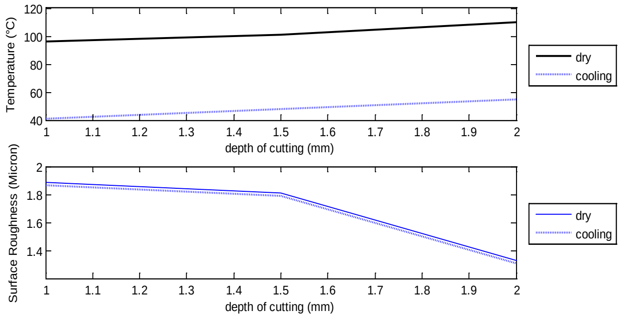

**Fig - 9:** Temperature and surface roughness against depth of cut for dry and coolant at N=1500 rpm and S=0.2 mm/rev.

Figure 7 shows the relationship between temperature and surface roughness against depth of cut for dry and coolant condition at feed rate of 0.1 mm/rev and speed 900 rpm. It shows that the temperature increases from 59°C to 93°C at increasing depth of cut from 1 to 1.5 mm. However the temperature increases from 93°C to 104°C at increasing depth of cut from 1.5 to 2 mm in dry operation case.

Figure 8 shows the relationship between temperature and surface roughness against depth of cut for dry and coolant condition at feed rate of 0.15 mm/rev and speed 1200 rpm. It indicates that the temperature increases from 80°C to 90°C at increasing depth of cut from 1 to 1.5 mm. However the temperature increases from 90°C to 109°C at increasing the depth of cut from 1.5 to 2 mm. While Figure 9 shows also the relationship between temperature and surface roughness against depth of cut for dry and coolant condition at feed rate of 0.2 mm/rev and speed 1500 rpm. It indicates that the temperature increases from 96°C to 101°C at increasing the depth of cut from 1 to 1.5 mm. However the temperature increases from 101° C to 110° C at increasing the depth of cut from 1.5 to 2 mm.

Figures 7, 8 and 9 show generally that the value of the depth of cut and the rotational speed and the feed rate at the highest value of the depth of cut as clear in Figure 7. However, a highest value of the tool temperature is shown in Figure (8) and this is because change value of rotational speed to the highest value. The relation of feed rate with both temperature and surface roughness when the N=1200 rpm, S=0.15 mm/rev, in dry operation and operation with the presence of coolant and values depth of cut were 1,1.5 and 2mm. While the temperature was higher at the highest depth of cut and the highest rotational speed as shown clearly in Figure 9. The relation of feed with both temperature and surface roughness when the N=900 rpm and S=0.1 mm/rev, in dry operation and operation in the presence of coolant and values depth of cut of 1, 1.5 and 2 mm respectively.

Theses Figure (7,8 and 9), in case of the presence of coolant, there is a significant decrease in the average temperature because of the presence of coolant effect and it affects the change in temperature according to the change of the three cut factors as in dry operation and can be determined through the comparison of results with the case of dry operation. However, in roughness curves, the average surface roughness is reduced by increasing the rotational speed, the feed rate, and reducing the depth of cut and decrease surface roughness with the presence of coolant.

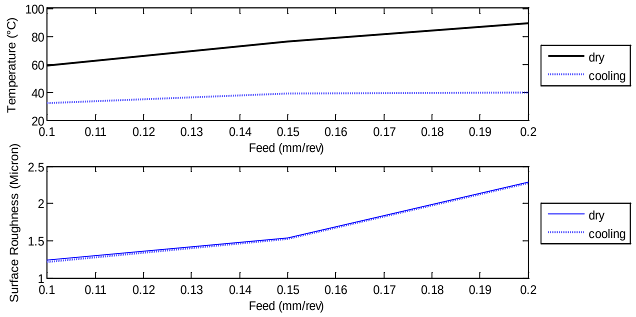

**Fig - 10:** Temperature and surface roughness against depth of cut for dry and coolant at N=900 rpm and a=1 mm.

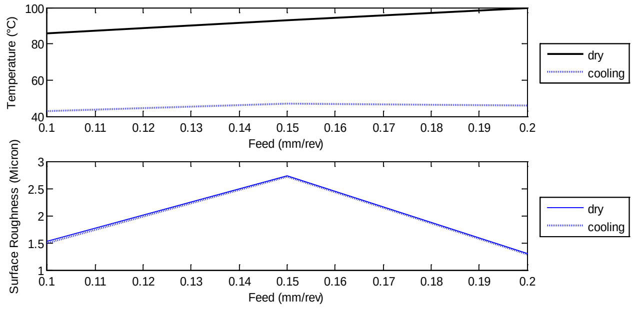

**Fig - 11:** Temperature and surface roughness against depth of cut for dry and coolant at N=1200 rpm and a=1.5 mm.

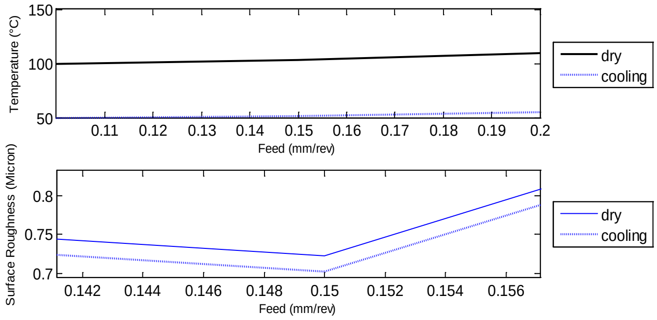

**Fig - 12:** Temperature and surface roughness against depth of cut for dry and coolant at N=1500 rpm and a=2 mm.

Figure 10 shows the relationship between temperature and surface roughness against feed rate for dry and coolant condition at depth of cut of 1 mm and speed 900 rpm. It indicates that the temperature increases from 59°C to 76°C at increasing the feed rate from 0.1 to 0.15 mm/rev. However the temperature increases from 76°C to 89°C at increasing the feed rate from 0.15 to 0.2 mm/rev in dry operation case too.

The same relationship between temperature and surface roughness against feed rate for dry and coolant condition is shown in Figure 11 at depth of cut of 1.5 mm and speed 1200 rpm. It shows that the temperature increases from 86°C to 93°C at increasing the feed rate from 0.1 to 0.15 mm/rev. However the temperature increases from 93°C to 100°C at increasing the feed rate from 0.15 to 0.2 mm/rev in the same case of dry operation. Figure 12 shows the relationship between temperature and surface roughness against feed rate for dry and coolant condition also at depth of cut of 2 mm and speed 1500 rpm. It indicates that the temperature increases from 100°C to 103°C at increasing the feed rate from 0.1 to 0.15 mm/rev. However the temperature increases from 103°C to 110°C at increasing the feed rate from 0.15 to 0.2 mm/rev.

It is realized that in Figures 10, 11 and 12, increasing the feed rate and reducing the speed of the rotation lead to a relative decrease in the average roughness. But when the feed rate and speed of rotation increase to the highest value, this may result in a significant reduction in the roughness compared to the previous conditions.

After examining the operating condition in this paper, the following table shows the highest temperature reached for alloy steel C45 as well as the lowest temperature as clear in Table 4. These temperature values are in both cases of dry and coolant conditions.

**Table – 4:** The highest and lowest temperatures.

| | Cutting parameters | | | Dry Condition | Coolant condition |
|---|---|---|---|---|---|
| | N (rpm) | S (mm/rev) | a (mm) | T (°C ) | T (°C ) |
| Minimum | 900 | 0.1 | 1 | 59 | 32 |
| Maximum | 1500 | 0.2 | 2 | 110 | 57 |

However, Table 5 shows the highest and lowest surface roughness reached for the alloy steel C45. These surface roughness values are in both cases of dry and coolant conditions to be a minimum of 0.722 μm in dry condition and 0.702 μm in coolant condition. While it reaches to a maximum value of 2.787 μm in dry condition and a maximum value of 2.767 μm in coolant condition.

**Table – 5:** The highest and lowest surface roughness.

| | Cutting parameters | | | Dry Condition | Coolant condition |
|---|---|---|---|---|---|
| | N (rpm) | S (mm/rev) | a (mm) | Ra (μm ) | Ra (μm ) |
| Minimum | 1500 | 0.15 | 2 | 0.7223 | 0.7023 |
| Maximum | 900 | 0.1 | 1.5 | 2.7870 | 2.7670 |

## 6. CONCLUSIONS

The main conclusion from this work can be summarized as follows;

- Generally, the depth of cut and rotational speed were the most important factors affecting the cutting tool temperature and the surface roughness in dry operation as well as in coolant operation on CNC machine during turning processes.
- A minimum temperature of 59°C in the cutting tool in case of dry operation and 32°C in case of coolant operation were reached at a rotational speed of 900 rpm, depth of cut of 1 mm and feed rate of 0.1 mm/rev.
- However, a maximum temperate of 110°C in the cutting tool in case of dry operation and 57°C in case of coolant operation were reached at a rotational speed of 1500 rpm, depth of cut of 2 mm and feed rate of 0.2 mm/rev.
- Low surface roughness of 0.72 μm in dry operation and 0.70 μm in coolant operation were obtained at a rotational speed of 1500 rpm, depth of cut of 2 mm and feed rate of 0.15 mm/rev.
- However, high surface roughness of 2.78 μm in dry operation and 2.787 μm in coolant operation were obtained at a rotational speed of 900 rpm, depth of cut of 1.5 mm and feed rate of 0.1 mm/rev.
- Increasing the depth of cut and the speed of rotation together has a higher effect on the cutting tool temperature than increasing the feed rate.
- Feed rate value has a slight effect on cutting tool temperature compared to speed of rotation and depth of cut.
- Finally, the speed of rotation is the largest factor affecting the cutting tool temperature followed by the depth of cut and then feed rate.
- However, increasing the speed of rotation and reducing the depth of cut leads to a decrease in surface roughness.

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