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Effect of Coolant Temperature on Machining Characteristics of High Carbon Steel

T. S. Ogedengbe[1*], S. Abdulkareem[2], J. O. Aweda[2].

[1]Elizade University, Ilara-Mokin, Ondo State, Nigeria
[2]University of Ilorin, University road, Ilorin, Kwara State, Nigeria

Abstract- This paper reports on the effect of coolant temperature on machining of high carbon steels. The development of a cooling system to reduce the temperature of water soluble coolant to 7.9°C from ambient temperature was employed in this work to improve the machining performance. The experiments were performed using cooled and ambient temperatures by employing Taguchi L_{18} orthogonal array to design the experimental runs. The cutting speed, feed rate and depth of cut were the machining parameters used; while the tool-work piece interface temperature was monitored using a digital thermometer with k-type thermocouple wire. The selected control factors are material removal rate and surface roughness. The experimental results were analyzed using Minitab 16. The main effects and percentage contributions of various parameters affecting surface roughness and material removal rate were discussed, and the optimal cutting conditions were determined. It was observed that surface finish improved by 65% with the use of the developed cooled system. The reduction in coolant temperature played a vital role in improving surface finish during machining high carbon steels.

Key Words: Coolant, High carbon steel, Machining parameters, Surface roughness, Taguchi method, Material removal rate.

I. Introduction

The rapid development in the medical, automobile and aviation industries are evidently driving the practical investigation in use of prosthetics and light metals such as titanium, aluminium and manganese as alternatives. Researchers and machinists especially from aerospace, medical and automobile industries have shown much interest in High Speed Machining (HSM) processes due to their capabilities in fabricating parts with high surface reliability [1, 2]. In HSM techniques, the use of Computer Numerical Controlled

(CNC) machines has emerged as a popular process for fabrication of parts with high surface reliability owing to its efficient and economical processing nature [3, 4]. Machining carbon steels is one of the major turning operations carried out in manufacturing industries [5, 6]. This is because they possess a wide variety of applications in car manufacturing industry, construction of pipelines, railway parts electrical devices and other major industries [7]. High carbon steel contains 0.55 % to 0.95 % carbon with manganese content ranging from 0.3% - 0.9% (e.g. AISI 1086, AISI 1090 and AISI 1050). They are normally used for components that require high hardness such as cutting tools and blades [8].

Surface Finish is an important quality characteristic for machined parts [9]. It is influenced by factors such as cutting speed, feed rate, work piece hardness, stability of the machine tool and the work piece set up. [10-12]. Improper selection of cutting conditions during machining could result in surfaces with high roughness therefore; a proper estimation of surface roughness has been the focus study of a number of researchers in the past three decades. [13-15]. Yusuf *et*-al, [16] performed an experimental investigation on effects of parameters viz, feed rate, depth of cut and cutting speed and they reported that cutting speed is the most significant factor followed by depth of cut and feed rate. Further, they explained that pattern of cut did not significantly affect the surface roughness or tool life. Nwoke et al [17] carried out an experimental evaluation on how this three parameters affect chatter vibration frequency in CNC turning of 4340 alloy steel material. Recently, Suker *et-al* [18] investigated the effect of cutting conditions in turning process on surface roughness for different materials and claimed that cutting speed was the most influencing process parameter. Cutting fluids are often used in machining with a sole aim of lubricating and cooling so as to reduce friction and wear which occurs on the surface between the tool point and the machined object, machined titanium alloy and adopted the use of water soluble servo cut coolant to improve surface roughness [19-21]. They studied the tool wear rate during machining with and without coolant and claimed that machining with coolant gave a better surface finish and tool life improved by about 30% when using coolant. Okokpujie and Okonkwo [22] study the effects of cutting parameters on surface roughness during end milling of Al 6061 under minimum quantity lubrication (MQL) which also claimed that cutting speed is the most influencing process parameter. Onuoha *et-al* [23] used vegetable-based oils while turning carbon steel and got optimal surface reliability using groundnut oil based cutting fluid. Shetty *et-al.* [24] analyzed surface roughness during turning of Ti-6Al-4V under Near Dry Machining and concluded that the influence of lubrication was the highest physical factor influencing surface roughness with about 95.1% significance when turning Ti6Al4V by using PCBN tool under dry and near dry environment.

Okonkwo *et al* [25] carried out

Comparative study of dry and MQL conditions where the MQL mixture used is 10% boric acid and base oil SAE 40, which proved that MQL can reduce the surface roughness by 20% when compared with the dry machining. Machining with coolant will help to reduce wear, corrosion and creep of the materials [28-30].

Although, enormous work available on machining have reported the use of flooded cooling at room temperature, rare work is reported which addresses the use of flooded cooling at reduced temperature (2-9°C) during machining. Therefore in this work, an approach of cooled assisted CNC lathe turning of HCS has been attempted to improve surface roughness and increase MRR.

II. Materials And Methods

The lathe machining was performed using an Ajax-EV 310 model as shown in Figure 1 which has a computer interface unit from GE-Fanuc series D721-10. The program for the cutting process was encoded into the CNC machine via the D721-10.

Fig. 1: Ajax-EV 310 CNC machine used for the experiment

The tool material utilized for this work is PVD (Physical Vapour Deposition) coated specified with code SNMG120408-MR3 TS2000. It is made of tungsten carbide hard micrograin abrasives. The schematic drawing and the photograph of the PVD coated carbide insert are as shown in Figure 2a and b respectively.

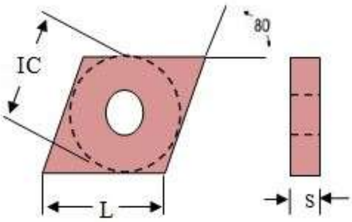

Fig. 2 (a): Schematic drawing for Insert

Fig 2 (b) PVD Coated Carbide Insert

Where IC is inscribed circle, L is length of cutting edge and S is thickness of insert.

AISI 1050 steel was selected and acquired from Owode metal market in Ilorin, Kwara state, Nigeria for use as work piece material. The steel bar stock was 30 mm diameter, 200 mm in length and these bars were machined under dry, wet and cooled conditions. The work pieces were centered and cleaned by removing a 0.5 mm depth of cut from the outside surface, before the actual machining tests. The chemical composition of AISI 1050 steel used in this study is presented in Table 1.

Table 1: Chemical Composition of AISI 1050

Element	Fe	Si	Cr	S	P	Mn	C	Ni
% C	98.07	0.510	0.054	0.045	0.032	0.65	0.54	0.024
Element	Sb	Nb	W	V	Mo	Pb	Cu	Ti
% C	0.0008	0.0013	0.0032	0.0007	0.022	0.0016	0.060	0.0009

The average temperature at the cutting zone was measured using a digital thermometer with k-type thermocouple wire which was placed at a distance of 5mm from the cutting edge of the tool. The setup of the digital thermometer probe is shown in Figure 3. The temperature varied through the tool, chip and work piece. Maximum temperature was developed at the tool rake some distance away from the cutting edge and not at the cutting edge.

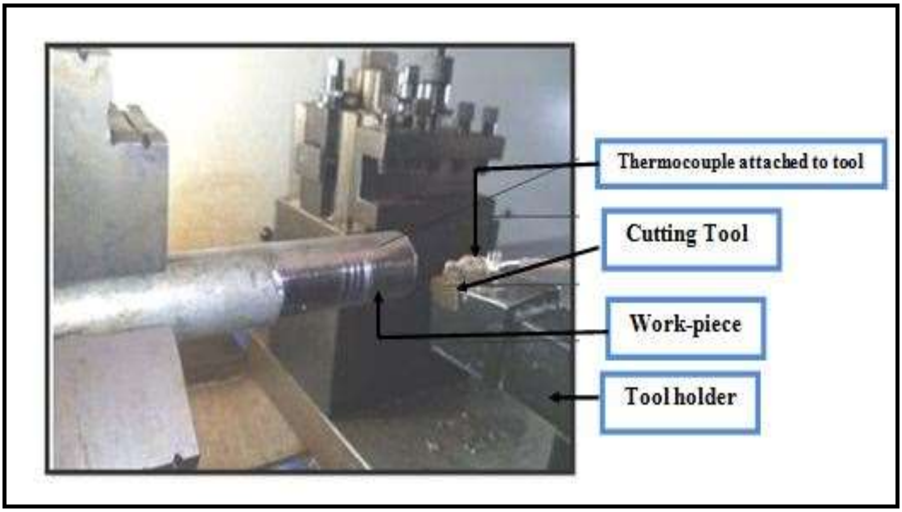

Fig. 3: Experimental setup of tool and work piece

A cooling system as shown in Figure 4 was developed to reduce the temperature of the coolant in the sump of the CNC lathe machine to between 7.9^{o}C. This was done to improve the surface roughness of the work piece. The cooling system evaporator was seated in the sump located at the base of the CNC machine. A schematic of the cooling system set-up is shown in Figure 5.

Aeroil N5, a soluble oil with heat capacity of 4200J/kgK and density of 1000kg/m^3 was used as coolant in the sump of the machine.

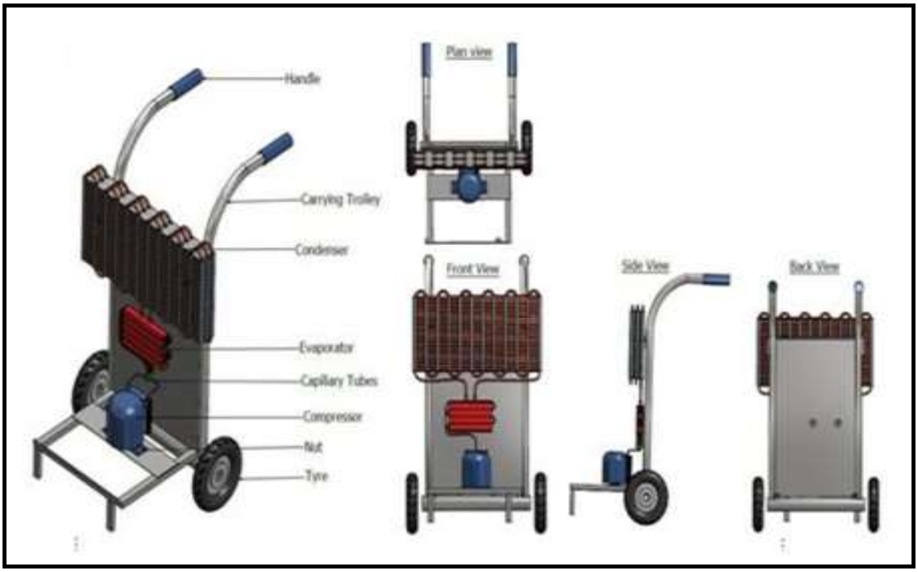

Fig. 4: The Developed Cooling System

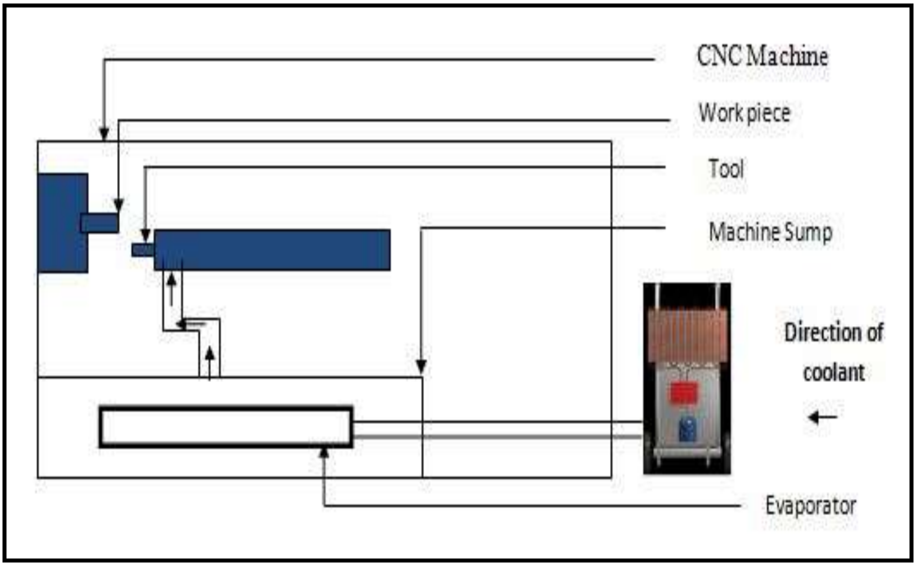

Fig. 5: Schematic for cooling system set-up

In this study, Taguchi method was used to design the experimental runs to determine the optimal control factors for maximizing the MRR and minimizing the SR in lathe machining. Three control factors and their levels with the machining conditions are shown in Table 2. The control factors were decided based on preliminary experiments, literature and machine constraints. The use of Taguchi to design the experiment generated the orthogonal array as shown in Table 3, which was used to determine the experimental steps by developing a design matrix for the experiment. The quality of the response variables were evaluated using signal-to-noise ratio (S/N).

Table 2: Machining Parameters

Factor	Level		
	1	2	3
Speed (m/min)	1178	1374	1570
Feed rate (mm/rev)	50	60	70
Depth of cut (mm)	0.1	0.2	0.3

Table 3: Experimental design matrix

EXPERIMENTAL RUN	**CUTTING SPEED _m/min_**	**FEED RATE _mm/min_**	**DEPTH OF CUT _Mm_**
1	1178	50	0.1
2	1178	60	0.2
3	1178	70	0.3
4	1374	50	0.1
5	1374	60	0.2
6	1374	70	0.3
7	1570	50	0.2
8	1570	60	0.3
9	1570	70	0.1
10	1178	50	0.3
11	1178	60	0.1
12	1178	70	0.2
13	1374	50	0.2
14	1374	60	0.3
15	1374	70	0.1
16	1570	50	0.3
17	1570	60	0.1
18	1570	70	0.2

The performance of AISI 1050 during CNC lathe turning was examined using surface roughness and MRR after the machining process. The experimental investigations were carried out by turning the work piece 18 times separately for dry, wet and cooled conditions as shown in Table 3. The experiment was carried out under wet condition with the coolant used at ambient temperature of 29.5^{o}C, while the temperature during cooled experimental run was at 7.9^{o}C. The surface roughness was measured using a 2011 model of TR 210 a profilometer with a precision of

0.005-16 µm. The material removal rate according to Das *et-al*, [28] was calculated using equation 1:

$$MRR = \frac{\text{Volume Removed}}{\text{Cutting Time}} = \frac{\pi l(D-d)}{\frac{4L}{FN}} \text{ mm}^3\text{/min} \qquad (1)$$

Where L, F and N are length of piece, Speed and Feed respectively

The experimental results from Table 4 were analyzed using signal-to-noise (S/N) ratio. Smaller-is-better S/N ratio was chosen for Surface roughness (SR), and larger-is-better S/N ratio was chosen for material removal rate (MRR), since smaller SR and higher MRR indicates better performance of the process.

III. Results and Discussion

Table 4: Machining Results for Dry, wet and cooled conditions

RUN	SPEED *(m/min)*	FEED *(mm/min)*	DOC *(mm)*	**MRR** ***(mm3/min)***	**SR** ***µm***	**Tmax** ***oC***	**SR** ***µm***	**Tmax** ***oC***	**SR** ***µm***	**Tmax** ***oC***
					Dry		**Wet**		**Cooled**	
1	1178	50	0.1	184,577.21	4.054	373.0	1.832	144.3	0.562	58.2
2	1178	60	0.2	189,875.06	4.193	394.1	2.068	162.1	0.335	63.4
3	1178	70	0.3	192,338.44	3.676	350.2	1.631	125.0	0.558	55.3
4	1374	50	0.1	225,287.85	4.352	410.2	2.334	176.2	0.321	64.5
5	1374	60	0.2	245,395.87	4.369	410.8	2.345	175.8	0.395	63.7
6	1374	70	0.3	265,676.58	4.419	411.2	2.338	176.0	0.410	64.2
7	1570	50	0.2	490,763.90	4.761	534.3	2.999	221.6	0.121	69.6
8	1570	60	0.3	521,155.48	4.665	504.3	2.802	212.3	0.132	70.5
9	1570	70	0.1	544,397.88	4.455	410.4	2.354	174.8	0.356	65.4
10	1178	50	0.3	190,956.03	3.852	363.2	1.704	131.0	0.612	56.0
11	1178	60	0.1	187,492.65	4.500	441.2	2.510	180.7	0.396	64.2
12	1178	70	0.2	190,186.45	4.332	401.0	2.186	166.6	0.331	63.1
13	1374	50	0.2	227,880.67	4.792	521.1	2.880	220.5	0.156	71.5
14	1374	60	0.3	248,762.76	3.984	367.2	1.762	135.0	0.594	55.4
15	1374	70	0.1	255,501.09	3.997	438.1	2.501	180.6	0.312	65.7
16	1570	50	0.3	502,023.45	4.201	547.1	3.020	233.1	0.110	72.5
17	1570	60	0.1	484,912.32	4.462	411.8	2.349	175.2	0.411	63.6
18	1570	70	0.2	578,456.23	4.342	458.2	2.78	188.5	0.342	68.4

From Table 5, results show that cutting speed was the most influencing factor, followed closely by depth of cut. The feed rate had a lower effect on the SR compared to other factors. The optimum control factor combination for minimum SR during dry machining is obtained as S_3, F_2 and D_2 (i.e 1570m/min, 60mm/rev and 0.2mm). Table 6 shows that the same ranking trend was noticed during wet machining at 29.5^{o}C as cutting speed was also the most important factor affecting the surface roughness, followed by the depth of cut. The feed rate had the lowest effect on SR. The optimum control factors for wet machining at 29.5^{o}C are S_3, F_1, D_2 (i.e 1570m/min, 50mm/rev and 0.2mm). However as shown in Table 7, when machining with coolant application at temperature of 7.9^{o}C, cutting speed is the most influencing factor followed by Feed rate. The depth of cut had a lower effect on the SR compared to other factors. The optimum control factors combination for cooled at 7.9^{o}C are S_1, F_3, D_1 (i.e 1178m/min, 70mm/rev and 0.1mm).

Table 5: S/N ratio response table for SR and MRR (Dry)

Factors	Levels				
	Level 1	Level 2	Level 3	Delta	Rank
Surface Roughness (SR)					
Cutting Speed (S)	-12.24	-12.69	-13.02*	0.78	1
Feed Rate (F)	-12.71	-12.78*	-12.45	0.33	3
Depth of Cut (D)	-12.67	-12.99*	-12.30	0.69	2
Material Removal Rate (MRR)					
Cutting Speed (S)	112.0	113.3	114.5	2.5	3
Feed Rate (F)	111.8	113.4	114.7	2.9	2
Depth of Cut (D)	108.1	114.1	117.6	9.5	1

*Optimum level for factors for each response.

Table 6: S/N ratio response table for SR and MRR (Wet at 29.5^{o}C)

Factors	Levels				
	Level 1	Level 2	Level 3	Delta	Rank
Surface Roughness (SR)					
Cutting Speed	-5.872	-7.369	-8.637*	2.765	1
Feed Rate	-7.596*	-7.166	-7.116	0.480	3
Depth of Cut	-7.238	-8.019*	-6.621	1.398	2
Material Removal Rate (MRR)					
Cutting Speed	112.0	113.3	114.5	2.5	3
Feed Rate	111.8	113.4	114.7	2.9	2
Depth of Cut	108.1	114.1	117.6	9.5	1

Table 7: S/N ratio response table for SR and MRR (Wet at 7.9^{o}C)

Factors	Levels				
	1	2	3	Delta	Rank
Surface Roughness (SR)	1	2	3		
Cutting Speed (S)	6.914*	9.410	13.520	6.605	1
Feed Rate (F)	12.132	9.242	8.470*	3.662	2
Depth of Cut (D)	8.289*	11.829	9.727	3.540	3
Material Removal Rate (MRR)					
Cutting Speed (S)	112.0	113.3	114.5	2.5	3
Feed Rate (F)	111.8	113.4	114.7	2.9	2
Depth of Cut (D)	108.1	114.1	117.6	9.5	1

Similarly, from Tables 5, 6 and 7, depth of cut is the most influencing factor affecting MRR followed by feed rate. Cutting speed had a lower effect on the MRR compared with the other factors. The optimum control factor combination for maximum MRR is S_3, F_3 and D_3 (i.e 1570m/min, 70mm/rev and 0.3mm). S, F and D represent Speed, Feed rate and Depth of Cut while 1, 2 and 3 represents the various levels. The MRR for various experimental runs is shown in Figure 6.

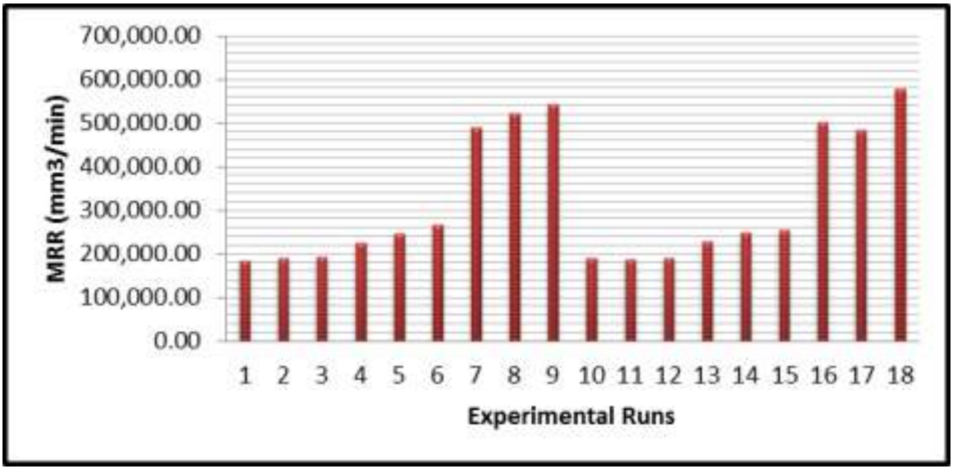

Fig. 6: MRR during Experimental runs

It was found that high values of MRR were recorded with high cutting speeds and feed rate. This result agrees with Shah *et-al* [26]. The highest MRR was obtained at 1570m/min, 70mm/rev and 0.3mm (i.e. Experimental run 18). This agrees with the optimum control factor combination for maximum MRR stated earlier (i.e 1570m/min, 70mm/rev and 0.3mm). Hence, when feed rate and cutting speed are decreased, the MRR also reduces.

The result from Aniza *et*-al [27] shows similar pattern.

As shown in Figure 7, during dry machining, maximum and minimum surface roughness values were 4.792µm and 3.676µm respectively. These improved during wet machining to maximum and minimum values of 3.020µm and 1.631µm respectively.

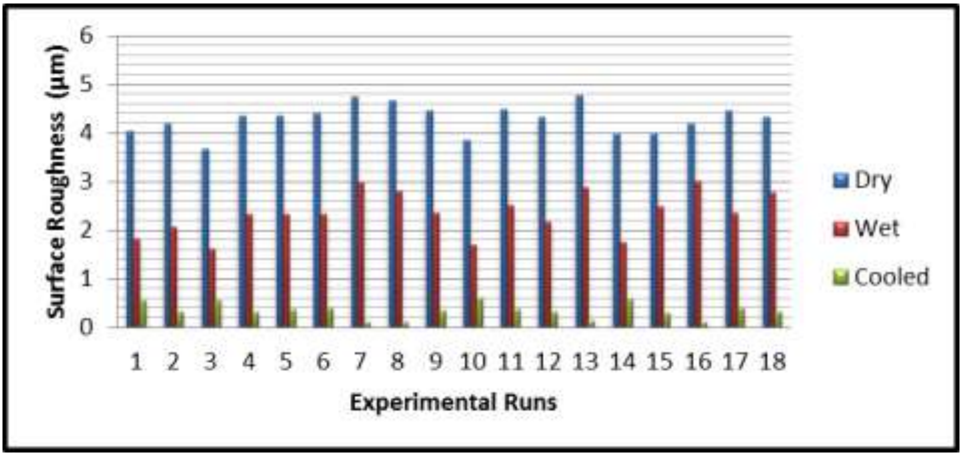

Fig. 7: Surface Roughness during various machining conditions

However, due to a reduction in the temperature of the coolant from room temperature to 7.9^{o}C, the surface integrity of the machined work piece improved with the maximum and minimum surface roughness values further reducing to 0.612µm and 0.110µm respectively. These improvements were as a result of a decrease in heat generation as shown in Figure 8. Similar result was gotten by Shetty *et-al* [24] where they found that lubrication had a high effect on SR. The maximum temperature at tool-work piece interface improved from 534^{o}C during dry machining to 221^{o}C during wet machining (representing a 58.6% improvement) and 70^{o}C during cooled machining (representing a 86.9% improvement) respectiv

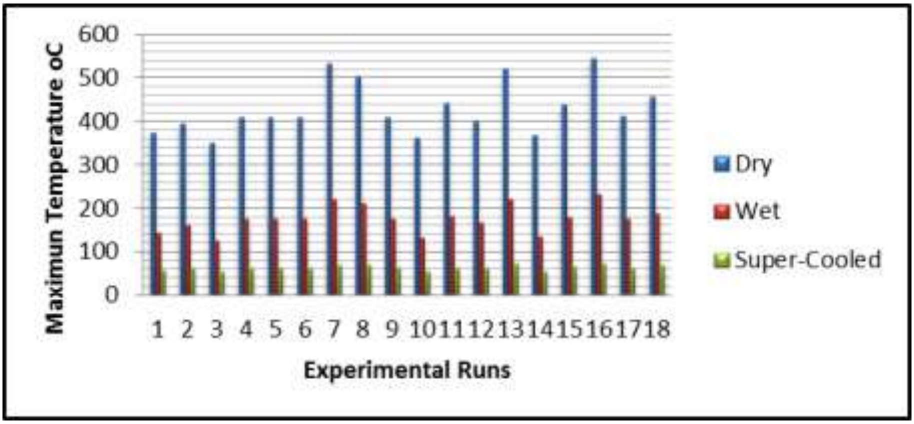

Fig. 8: Maximum Temperature attained during Experimental runs.

IV. Conclusion

Summarily, in this work, an experimental investigation on the effect of machining AISI 1050 steel with a view to improve process performance using a cooled coolant was attempted. The effects of cutting speed, feed rate, depth of cut were analyzed on SR and MRR. Experimental results aided the drawing of the following conclusions;

1. The use of cooled coolant played a vital role in improving the SR in the machining of AISI 1050 steel bar. The maximum surface roughness recorded reduced from 4.792µm during dry machining to 3.020µm during wet machining at room temperature. It further reduced to 0.612µm during cooled machining condition.
2. The application of the coolant ensured the reduction in the temperature at the tool-work-piece inter-phase as there was a 58.6% reduction in temperature during wet machining and 86.9% reduction in temperature during cooled machining.
3. The analysis of the data indicates that cutting speed is the most significant control factor on SR for all the three machining conditions with delta values of 0.78, 2.765 and 6.605 respectively. The depth of cut was also a significant factor affecting SR with delta values 0.69 and 9.5 for dry and wet machining conditions.

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