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Experimental Investigation of Cutting Parameters Effect on Surface Roughness During Wet and Dry Turning of Low Carbon Steel Material

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Abstract— *Surfaces quality is one of the most specified customer requirements for machine parts. The major indication of surfaces quality on machined parts is surface roughness. This research aims to study the cutting parameters (spindle speed, feed rate and depth of cut) and their effect on the surface roughness of low carbon steel workpieces machined under dry and wet turning conditions, using carbide cutting tool with a constant tool nose radius. Results revealed that, surface roughness is highly affected by the cutting parameters and also the cooling conditions.*

Keywords**: Turning, Surface roughness, cutting parameters, wet and dry cutting.**

I. Introduction

Efficiency of the interfaced machine parts is highly related to the surface quality of the contacted surfaces; this quality is generally characterized as the surface roughness [1]. Surface roughness is highly influenced by the cutting parameters in the different machining technologies, which are cutting speed, feed rate and depth of cut. Therefore, when the aim is gaining higher surface roughness, then, the correct choose of the cutting parameters is an essential procedure. Turning is one of the most common cutting technologies, which in a single-point cutting tool is used in removing metal layer by layer [2]. Due to their basic influence on the surface roughness, cutting parameters have been the interest study area for many researchers in the academic and the industrial institutions. Mehmet and Ilhan [3] conducted a study where they used turning of Co28Cr6Mo medical alloy machined on a CNC lathe to investigate the influence of the cutting parameters (rotational speed, feed rate, depth of cut and nose radius) on the surface roughness. They achieved the optimum surface roughness as 0.81 µm when the spindle speed was 318 rpm, the feed rate 0.1 mm/rev, 0.7 mm depth of cut and 0.8 mm was the nose radius. Bheem et al. [4] found that feed rate had the highest influence on the average surface roughness amongst the other two cutting parameters; cutting speed and depth of cut. Also, Suker et al. [1] were on an agreement with that, where they found that, feed rate is the most affecting factor. They stated that, obtaining the optimum surface roughness might be achieved by maintaining low feed rates with high cutting speeds. On the contrary of that, Thamizhmanii et al. [5] proved that, depth of cut has the most significant role in introducing the minimum surface roughness, followed by feed rate and the cutting speed. Das et al. [6] in their study of cutting parameters effect on surface roughness, machining force and flank wear, they stated that surface roughness is mainly affected by feed rate, while cutting speed affects the flank wear the most, feed rate together with the depth of cut are the main factors in affecting cutting forces. The aim of this study, is to investigate the effect of the cutting parameters (spindle speed, feed rate and depth of cut) on the surface roughness of a low carbon steel sample under wet and dry conditions. The cutting process was applied using a constant nose radius of an insert-carbide cutting tool.

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II. EXPERIMENTAL PROCEDURE

This paper investigates the effect of the cutting parameters (spindle speed, feed rate and depth of cut) on the surface roughness of a low carbon steel cylindrical sample (Fig. 1) with 125 mm length and 25 mm in diameter, using a carbide cutting tool.

Figure 1. Low carbon steel sample

Table 1 shows the chemical composition of the used samples material and their percentage.

TABLE 1. THE CHEMICAL COMPOSITION OF THE USED SAMPLE

Component	*C*	*Mn*	*Si*	*K*	*P*	*Ni*	*Al*
Wt. Percentage %	0.25	0.61	0.18	0.01	0.063	0.098	0.01

Turning process was applied with and without the use of the coolant liquid. Three levels were set for the three cutting parameters. Values of these levels are listed in table 2.

TABLE 2. THE THREE LEVELS OF THE CUTTING PARAMETERS

Cutting parameter	***Level 1***	***Level 2***	***Level 3***
*Spindle speed (**N**) rpm*	1120	800	560
*Feed rate (**f**) mm/rev*	0.10	0.15	0.20
*Depth of cut (**a**) mm*	0.40	0.60	0.80

Therefore, the number of experiments could be calculated as 3^3. Based upon that, 27 experiments were approached. As mentioned earlier, this study aims to examine the effect of the cutting parameters with and without cooling. This means that the number of experiments will be doubled. i.e. 54 experiments will be conducted. In each trial, one factor kept constant while the other two factors were changed. For instance, when the aim is to study the effect of the spindle speed on the surface roughness, the spindle speed would remain constant while changing the other two factors (the feed rate and the depth of cut) to their three levels, sequentially, and likewise it will be for the feed rate and the depth of cut as shown in Fig. 2. This procedure was applied and repeated for the 54 experiments.

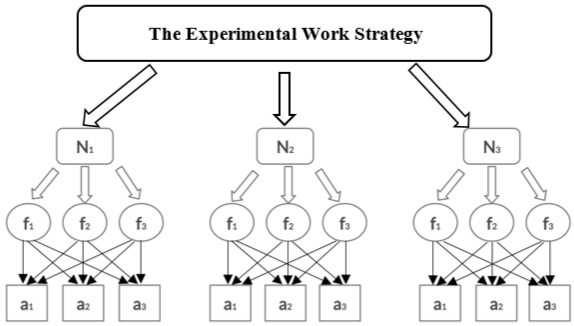


Figure 2. The flow work of experiments procedure

When experiments were completed, each sample's surface roughness was measured using a measuring instrument called ALPA-5M. Fig. 3 shows the used device.

Figure 3. The device used in measuring samples surface roughness

As mentioned above, the machined surfaces for all tested samples were measured, the recorded values of the surface roughness, together with the cutting parameters combinations were plotted in graphs and discussed as follow;

III. RESULTS AND DISCUSSION

Values of surface roughness were gathered and plotted in graphs, so it will be easier to illustrate and compare the influence of the three cutting parameters, and decide which factor effects the surface roughness more. Finally leading to an optimum coloration of the three of them.

A. Effect of Spindle Speed on Surface Roughness

Fig. 4, 5 and 6 show how spindle speed effects the surface roughness. Each graph shows the relationship between different levels of spindle speed and feed rate at a constant depth of cut. Where it indicates that the higher the spindle speed the lower the surface roughness, this comes as a result of two main reasons:

The first reason is that, the machined sample was made of a low carbon steel alloy; which has high ductility, then it will have a high friction coefficient. At the beginning of the machining process, this high friction coefficient leads to the appearance of the built up edge phenomenon (BUE) on the cutting tool surface and, probably, on the tool nose too. As the machining proceeds, the built up edge (BUE) grows and getting bigger until the point it breaks up. As a result, the BUE will definitely cause in an insufficient surface roughness. At higher spindle speeds, the BUE vanishes, the cutting temperature increases and the friction coefficient decreases, finally the surface roughness gets improved.

The second reason is that, when the spindle speed increases, it leads to increasing the shear angle value resulting in narrow shear plane. This narrow shear plane leads to decreasing the cutting force, which means less vibration and then better surface roughness.

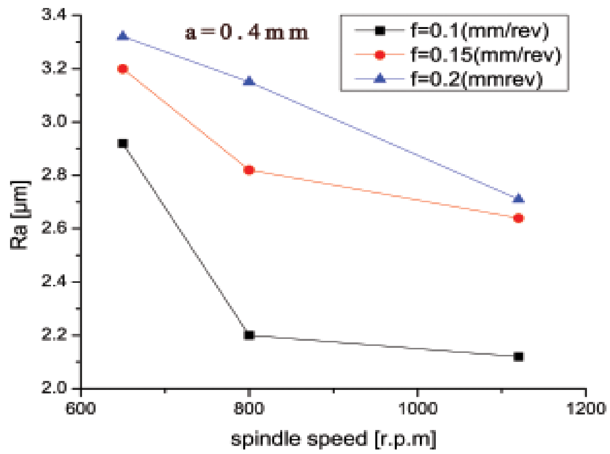


Figure 4. Spindle speed effect on surface roughness at various feed rates and a constant depth of cut a=0.4 mm

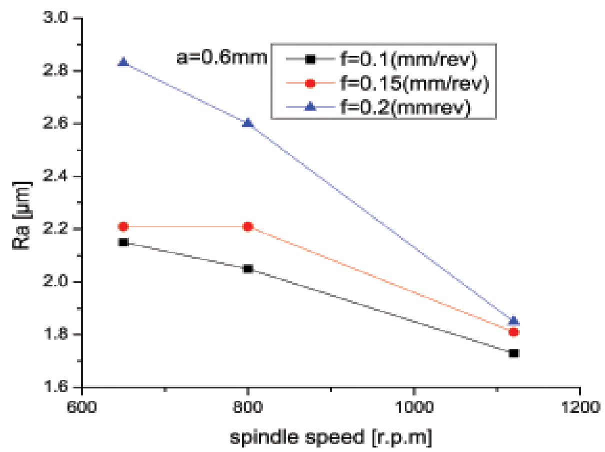


Figure 5. Spindle speed effect on surface roughness at various feed rates and a constant depth of cut a=0.6 mm

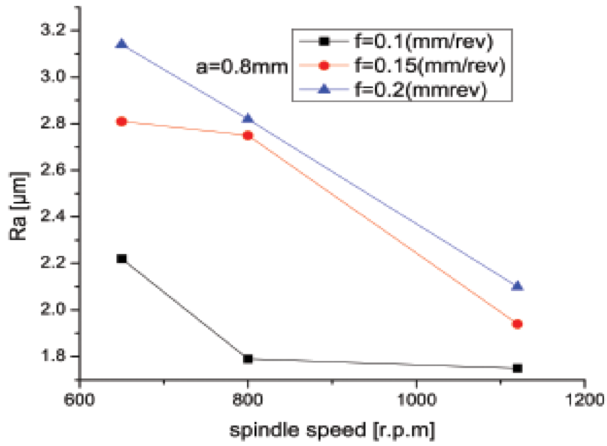


Figure 6. Spindle speed effect on surface roughness at various feed rates and a constant depth of cut a=0.8 mm

B. Effect of Feed Rate on Surface Roughness

Fig. 7, 8 and 9 show the effect of the feed rate on the surface roughness at different spindle speed levels and a constant depth of cut in each time. Whereas graphs show that the surface roughness decreases with the decrease of the feed rate. Higher feed rates mean more material in contact with the cutting tool hence higher cutting force evolution. This force causes in the appearance of the vibration, which leads to an insufficient surface roughness. Higher feed rates also cause in increasing the cutting temperature, which leads to the appearance of the tool wear hence undesired surface roughness.

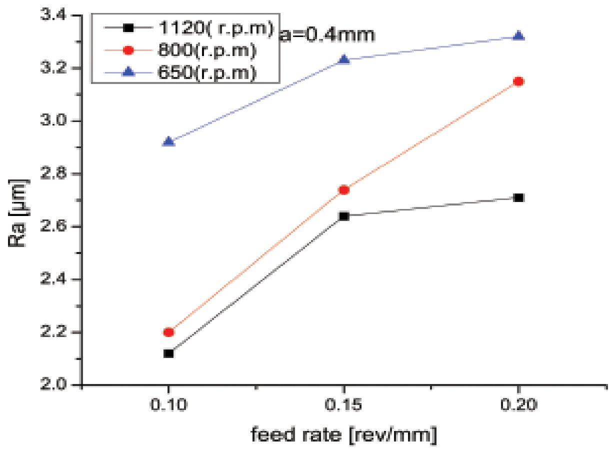


Figure 7. Feed rate effect on surface roughness at various spindle speeds and a constant depth of cut a=0.4 mm

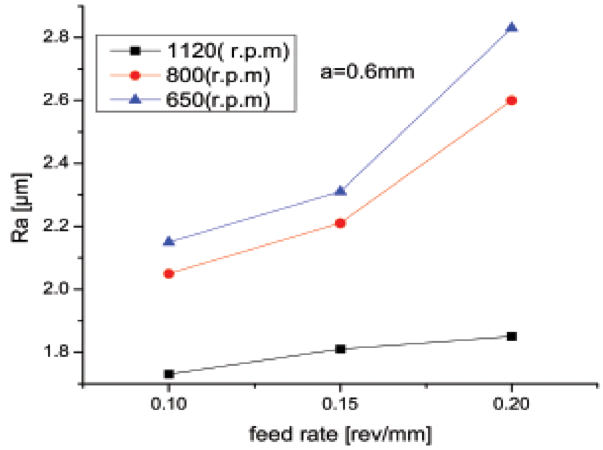


Figure 8. Feed rate effect on surface roughness at various spindle speeds and a constant depth of cut a=0.6 mm

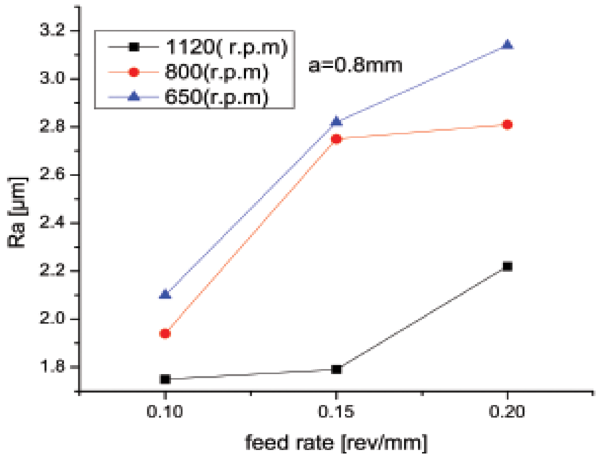


Figure 9. Feed rate effect on surface roughness at various spindle speeds and a constant depth of cut a=0.8 mm

C. Effect of Depth of Cut on Surface Roughness

As the previous procedure for the feed rate and the cutting speed, Fig. 10, 11 and 12 show the effect of depth of cut on the surface roughness. Each figure illustrates the relationship between the depth of cut and the surface roughness, with constant feed rate values at three spindle speed levels. At higher depths of cut, higher cutting forces are demanded to remove the bigger amount of the material. As mentioned earlier, increasing cutting forces leads to the appearance of the vibration. Which, eventually, affects negatively upon the surface roughness. In this study, when the depth of cut level increased from 0.4 mm to 0.6 mm, the surface roughness decreased by rates higher than they were at the depth of cut of 0.8 mm. Also in this study, it could be noticed that surface roughness increased at small depth of cut values. This phenomenon was interpreted by Cemal et al. [7] by saying that, at small depths of cut the material supposed to be machined will not be machined, that comes as a result of the friction occurred between the ductile material and the cutting tool. This friction causes what so called: the alignment of the metal along with the sample's surface which resulting in rough surfaces. In this study, as the depth of cut increased from 0.6 mm to 0.8 mm, there was no clear influence on the surface roughness, especially at higher spindle speeds (1120 rpm) as shown in Fig. 10, 11 and 12.

Generally, in this paper, all graphs show a fluctuating pattern which do not match the general curves behaviour. This phenomenon could be returned to a number of reasons, such as; the manual grinding of the cutting tool edges, where it demands a high skilled operator otherwise it could lead to changing -even slightly- in the cutting tool dimensions (cutting angles and the tool nose radius). Another reason could have caused this phenomenon is the different setup of the turning process experiments, whereas the process has been approached on different times. Also, the vibration during the cutting process which causes the chatters on the cutting surface should not be neglected. Mistakes in measuring should also be taken into consideration.

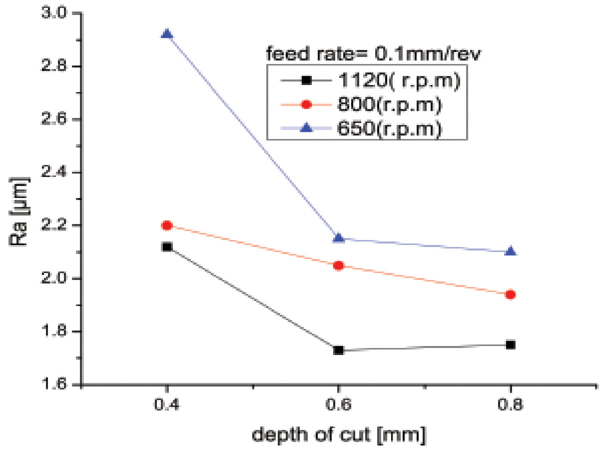


Figure 10. Depth of cut effect on surface roughness at various spindle speeds and a constant feed rate of cut f=0.1 mm/rev

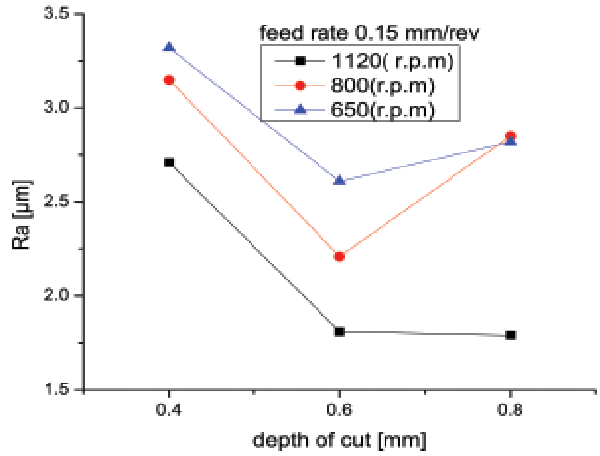


Figure 11. Depth of cut effect on surface roughness at various spindle speeds and a constant feed rate of cut f=0.15 mm/rev

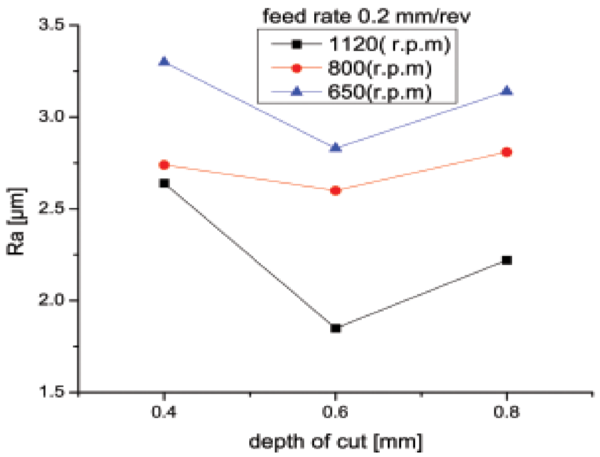
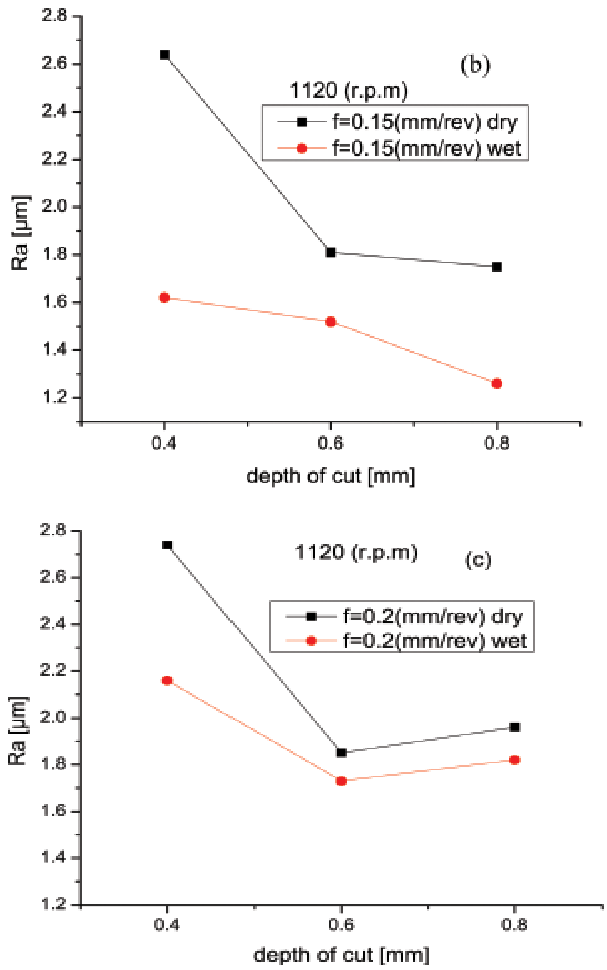


Figure 12. Depth of cut effect on surface roughness at various spindle speeds and a constant feed rate of cut f=0.2 mm/rev

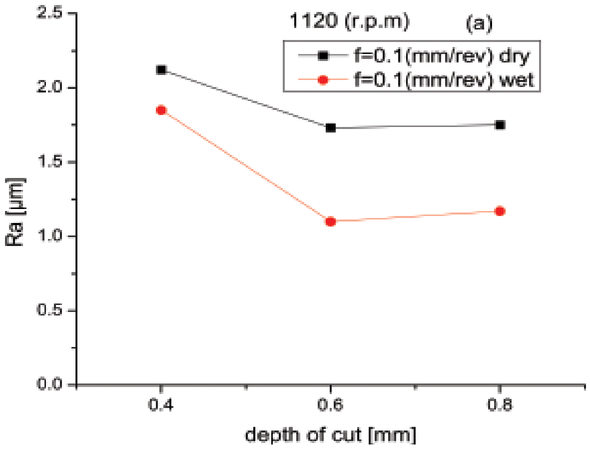
D. Wet Cutting

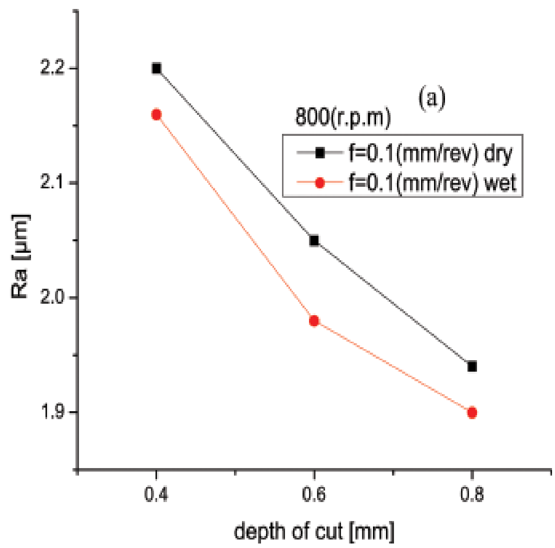
After the 27 experiments were finished, another 27 experiments were conducted, but this time with the use of a coolant liquid. Results showed that using the coolant liquid improves (reduces) the surface roughness significantly. This could be returned to the fact that; coolant liquid plays an essential role in cooling the cutting tool, reducing the mechanical friction between the cutting tool and the workpiece and improving the cutting tool life. Moreover, using the coolant liquid might assist in thrusting the chips away from the workpiece surface, which contribute in avoiding the appearance of the built up edge (BUE) that causes producing low surfaces finishing. Fig. 13, 14 and 15 show the positive effect of the use of the coolant liquid.

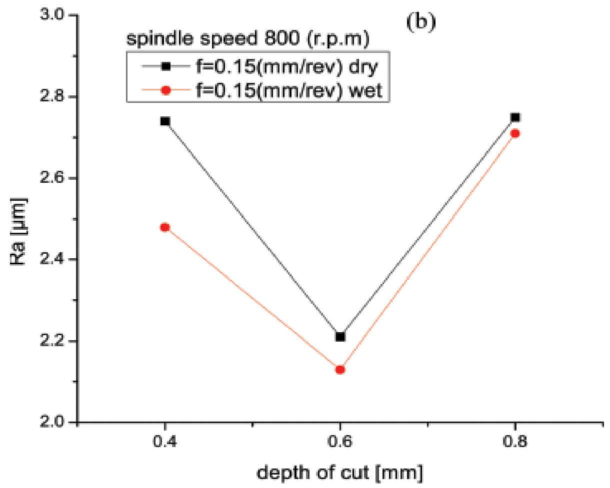


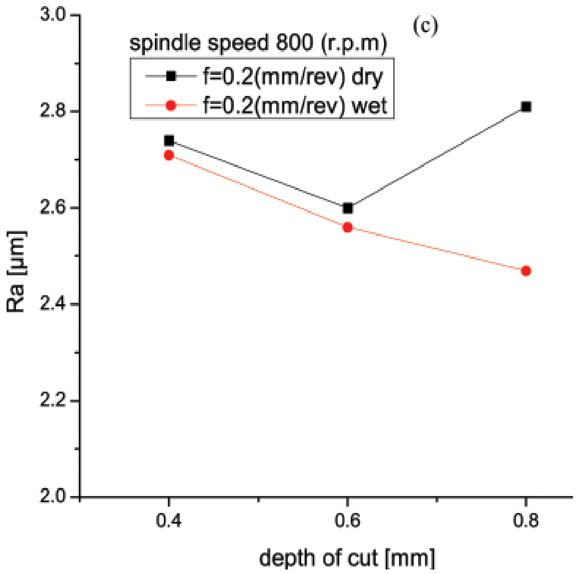
$a)\ f = 0.1\ ^{mm}/_{rev}\ \&\ b)\ f = 0.15\ ^{mm}/_{rev}\ \&\ c)\ f = 0.2\ ^{mm}/_{rev}$

Figure 13. Coolant liquid effect on surface roughness at various depths of cut and a constant spindle speed N=1120 rpm



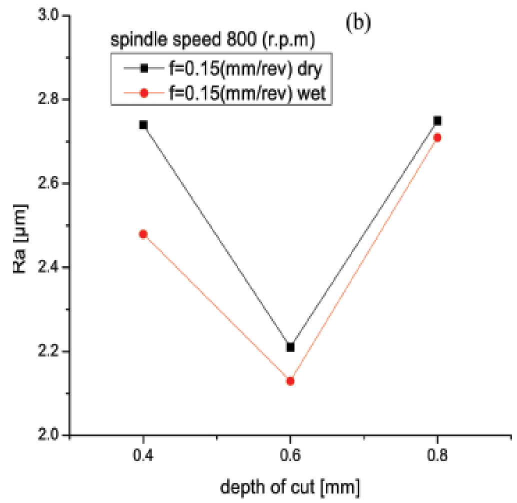


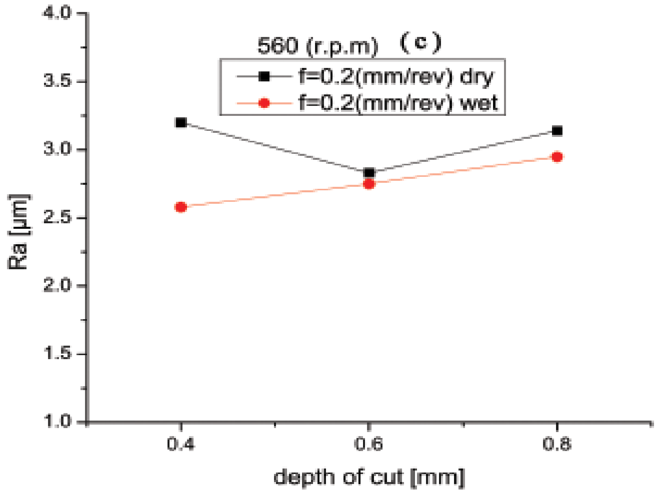




$a)\ f = 0.1\ ^{mm}/_{rev}\ \&\ b)\ f = 0.15\ ^{mm}/_{rev}\ \&\ c)\ f = 0.2\ ^{mm}/_{rev}$

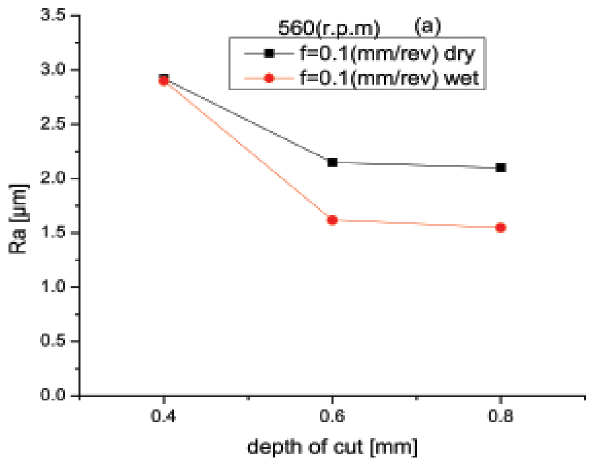
Figure 14. Coolant liquid effect on surface roughness at various depths of cut and a constant spindle speed N=800 rpm





$a)\ f = 0.1\ ^{mm}/_{rev}\ \&\ b)\ f = 0.15\ ^{mm}/_{rev}\ \&\ c)\ f = 0.2\ ^{mm}/_{rev}$

Figure 15. Coolant liquid effect on surface roughness at various depths of cut and a constant spindle speed N=560 rpm



IV. Conclusion

In this paper, low carbon steel samples were employed in studying the influence of the cutting parameters (spindle speed, feed rate and depth of cut) on the surface roughness. Three levels for each cutting parameter were set in 27 experiments in dry conditions. Moreover the 27 experiments were repeated once more in a wet environment. Results revealed that surface roughness decreases at higher cutting speeds, and it increases by the increase of the feed rate. Depth of cut showed the least effect on the surface roughness. It showed that surface roughness was effected negatively at depths of cut less than 0.4 mm, then it improved at depth of cut values up to 0.6 mm. Afterwards, there was no clear influence of higher depth of cut values on the surface roughness. It could be conclude that, the best surface roughness obtained was at the following cutting parameters values: spindle speed of 1120 rpm, feed rate of 0.1 mm/rev and depth of cut of 0.6 mm, which was 1.73 µm at the dry cutting, while it was improved to be 0.85 µm in the wet cutting. Hence, to sum up, the best surface roughness could be obtained at lower feed rates and higher spindle speeds with the presence of coolant.

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