Performance Enhancement During Dry Rough Turning of 16MnCr5 Steel Using Different Tool Rake Face Orientations

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Abstract: This research article aims to explore the influences of tool rake face orientations on surface roughness, chip morphology and chip thickness ratio during dry rough turning of 16MnCr5 steel workpiece. The experiments were conducted at fixed input parameters, i.e., cutting speed (500 RPMs), feed rate (0.171 mm/rev), depth cut (0.8 mm), whereas the tool rake face orientation was varied. Further, the approach angle (90°), tool nose radius (0.8 mm) and length (200 mm) of cut were kept constant. Chip thickness ratio, surface roughness and chip morphology were considered as output responses. The experiments were conducted with an upward tool rake face orientation and a downward tool rake face orientation. While comparing the output responses of both the experiments, it was found that the surface roughness improved by 53 % with downward rake face orientation. Similarly, the chip thickness ratio was improved from 0.27 to 0.65. The crater tool wear was reduced from 0.32 mm to 0.13 mm when results of upward and downward rake face orientation are compared. Further the chip morphology transformed from blackish toothed to garish ribbon type. From the above observations, it is concluded that the performance of dry turning can considerably be enhanced by holding the tool in an orientation with a downward rake face.

Keywords: Tool rake face orientation; Surface roughness; Chip thickness ratio; Morphology of chips; 16MnCr5 steel

1. Introduction

One of the established and most well-known manufacturing procedures popularly known as machining is metal cutting[1–8]. Metal cutting is frequently done to produce components with precise surface finishes and dimensions. The economics of a nation is greatly impacted by metal cutting[9–14]. The automotive, railroad, shipbuilding, aerospace, home- appliances, consumer electronics, and construction sectors are among the sectors, the metal-cutting is serving to[14,15]. According to an estimate, the machining operations account for 15% of the total worth of all mechanical assemblies manufactured globally,[16]. Therefore, while choosing the tool material, input variables, tool and machine design, an in-depth and scientific investigation is crucial. Work material properties greatly influence the overall performance of the metal-cutting process[17,18]. The cutting speed, feed rate, depth of cut, tool material, and tool geometry are equally significant[19]. Understanding the direct effects of different input parameters is challenging in a metal cutting operation; as a result, factors such as chip morphology, temperature, cutting forces, tool wear, workpiece surface roughness, and cutting forces are used to study these effects. Metal cutting makes use of mechanical power to shear metal (a byproduct) from the workpiece in the form of chips. Particularly in turning operation, approximately 90% of the mechanical energy is transformed to heat. Out of this, 70 % is taken away by the chip and 30% is distributed among the workpiece material, the cutting tool, the cutting fluid, or the environment, depending on the configuration. At first glance, having the chip absorb most of the heat seems like a good idea, but as it slides over the rake face surface of the cutting tool, most of the heat is transferred back to the tool[20-24]. There are mainly two sources of heat generation, the primary and secondary deformation zones. Further the friction prevalent between the chips and tool rake face, tool flank, and machined work surface also generate heat[25-30]. Consequently, the cutting tool receives the heat generated at multiple zones. The tool life, work-surface quality, and dimensional accuracy of the work are all affected by how well, this heat is controlled. This is why various researchers have been exploring the process of controlling or lowering the tool temperatures. Cutting fluids or coolants are the most used media[31)]. The purposes of all these coolants are the same, i.e., to cool the cutting zone, lubricate the work, tool and chip interface and wash away the chips. Disposal of cutting fluids after the accomplishment of the machining operation affects the soil and water and is also hazardous for the operators[14)]. The machining operations using no-cutting fluid are called dry marching and are becoming popular due to their lower cost and better workpiece quality. Enforcement of environmental protection laws for occupational safety and health regulations played a significant role in the popularity of dry machining[32)]. It is evident that dry machining will only be acceptable when it guarantees that the part quality and machining times are equal to or superior to wet machining. The major advantages of dry machining include no extra cost of cutting fluids, equipment, power consumption, water pollution and soil contamination, and a non-hazardous environment for operators[33)].

Numerous studies have been found in the literature, conducted to improve the machining quality using various types of cooling and lubrication environments. Despite of the many advantages of the different environments there are many environmental, health and economic impacts. Hence, the dry-turning method have also been explored through altering input parameters, such as the geometry of the tool. The investigations deliberated the influence on the workpiece dimensional accuracy, cutting forces, tool wear, and surface roughness. Nevertheless, none of the studies have considered the tool rake face orientation as an input parameter. As a result, in the current work, the tool rake face orientation with respect to base plane has been taken as main input parameter. It has been believed that the tool rake face orientation with respect to the horizontal reference plane will affect how quickly the chip will be removed under the effect of gravitational force, which will increase the efficacy of dry machining. Thus, cutting forces, tool wear, and surface roughness would all be decreased as a result of less friction between the tool rake face and chip.

2. Materials and methodology

2.1 Material and characteristics

The raw material selected for the study is a case hardening steel (16MnCr5) often used for manufacturing shafts, axles, etc. The spectrometer was used to evaluate the elemental compositions at CITCO Lab, Industrial Area, Phase I, Chandigarh, India. The material's mechanical properties were tested by tensile testing on a universal testing machine at the Department of Mechanical Engineering, National Institute of Technology Hamirpur, HP, India. The detailed elemental composition of the work material is given in Table 1.

Table 1. Chemical Composition of 16MnCr5 Steel.

Elements	Fe	C	Si	Mn	P	S	Ni	Cr
Wt.%	97.3	0.2	0.3	1.1	0.02	0.01	0.03	1.01

Hardness was also tested by Brinell Hardness tester and came as 240.242 BHN; also, the conversion to Rockwell C scale came as 22.24 HRC. The tensile strength of the material influences its machinability very much, therefore, it is essential to understand the test material's tensile strength. A completely computerized UTM machine was used to perform the tensile test. The sample measured 6 x 5 x 65 mm. Figure 1 shows the test outcomes graphically. This tensile test yielded several characteristics and constants, including an elongation of 26.50% and a UTS of 473 MPa.

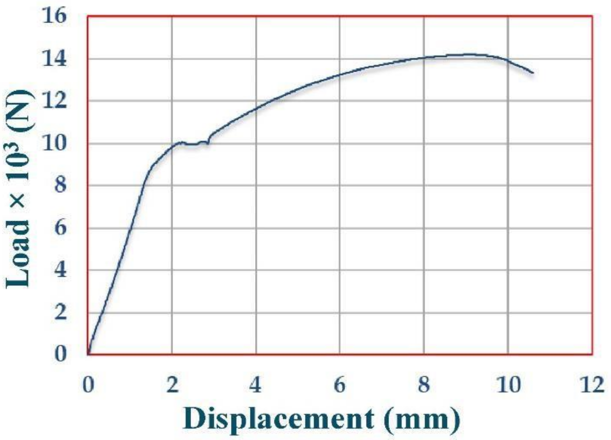

Fig. 1: Load-displacement curve of work material.

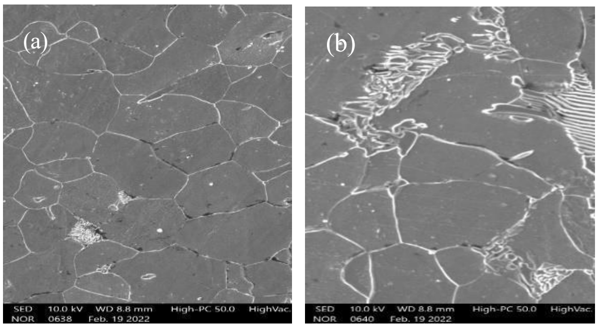

Fig. 2: Microstructure of 16MnCr5 steel: (a) chunks of pearlite and (b) pearlite structure.

Further, the microstructure of the work material was explored by scanning electron microscopy (SEM) micrographs. The clear pearlite chunks in the ferrite matrix can be seen in Fig. 2(a) and (b). Since the steel is not heat treated, the microconstituents are alpha iron with cementite present; the amount of hard cementite is not very high and dispersed uniformly in the soft ferrite. Owing to this microstructure, the material behaved sufficiently ductile, as shown in Fig. 1, and rendered the material sufficiently machinable.

2.2 Tool specifications and input parameters

The tool holder & cutting tool used for performing the experiments are shown in Fig. 3(a) and (b). The tool holder is a rigid rectangular bar with different hands, i.e., left hand (SVJBL202016) and right hand (SVJBR202016). Meanwhile, the insert is coated carbide, having an overall angle of 35° with a 7° clearance angle and 3.9 mm thick with a 0.8 mm nose radius.

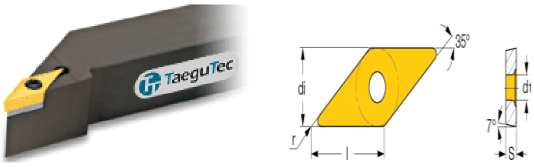

Fig. 3: (a)Tool holder and (b) cutting tool.

The main aim of this work was to explore the influence of tool rake face orientation; hence, other parameters are kept constant in both experiments; the details of the variables are given in Table 2.

Table 2. Input variables and their levels.

Experiment No.	Cutting Speed (Vc) RPM	Feed Rate(f) Mm/rev	Depth of cut (ap) mm	Approach Angle	Rake Face Orientation
1	500	0.171	0.8	90°	upward
2	500	0.171	0.8	90°	downward

2.3 Methodology

The Experiments were conducted using a geared precision lathe machine fitted with a digital read out (DRO) system. One right-hand tool holder (SVJBR202016) and one left-hand tool holder (SVJBL202016) were used to hold the tool insert (VCMT 16T308 TK15) at different orientations in the tool holding arrangement. A 16MnCr5 Steel of 200 mm length having 21 mm diameter was plain rough turned at low cutting speeds in dry conditions. First, the turning experiments were done by holding the cutting tool (insert) with an upward rake, as shown in Fig. 4(a).

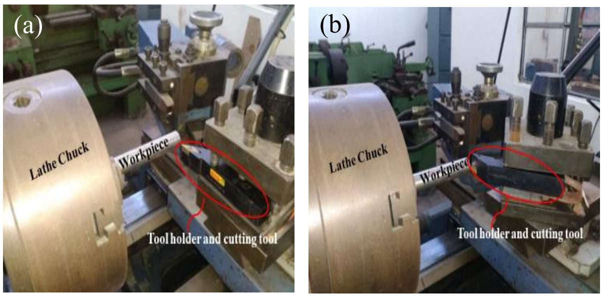

Fig. 4: Different tool rake face orientations: (a) upward and (b) downward.

Secondly, the same experiments were conducted with the rake face downward with the help of a modified tool holding arrangement as per Fig. 4 (b). Both experiments measured the surface roughness of the surface and chip thickness ratio. The chips were collected and their morphological aspects, such as shape and color, were studied.

3. Results and Discussions

Chip morphology, workpiece surface roughness, chip thickness ratio and tool wear were considered significant output responses in these experiments. In experiment no 1, keeping the rake face upward, the chip morphology revealed the formation of segmented chips and blackish in color as shown in Fig. 5 (a).

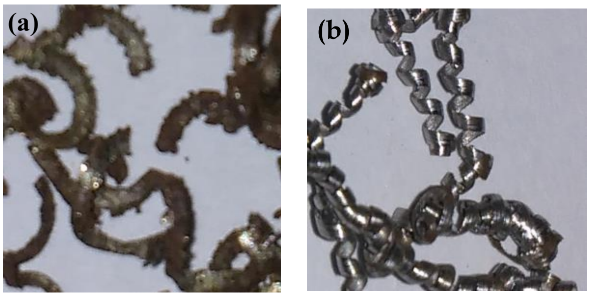

Fig. 5: Chip morphology: (a) Short-toothed blackish chips and (b) Long-curled lustrous chips.

The surface roughness was measured as 3.64 μm and the chip thickness ratio was calculated as 0.27 shown in Fig. 6. The crater wear of cutting tool was recorder as 0.32 mm. On the other hand, in experiment no 2, where the rake face was kept downwards the chips were found to have shiny and ribbon like morphology as shown in Fig. 5 (b). The surface roughness was found to be 3.32 μm and chip thickness ratio of 0.65 was obtained as shown in Fig. 6. The tool crater wear was measured as 0.13 mm.

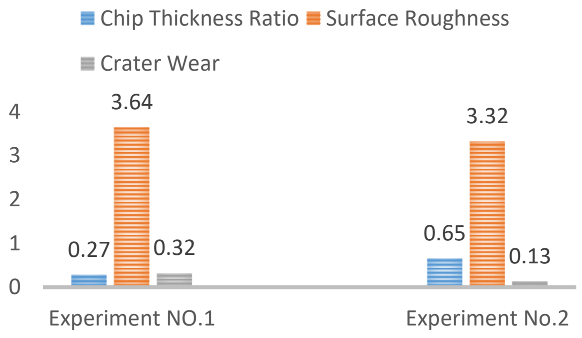

Fig. 6: Output responses of surface roughness and chip thickness ratio.

The change in the chip color and morphology tends to be attributed to the high heat generated in the first experiment both in the primary and secondary deformation zones. Since the chip slides on the rake face for a sufficient time under the effect of gravity, chip is pulled downward to stick to the rake face as shown in Fig. 7(a). Since the chip is already contains a major amount of heat produced in the primary deformation zone, will take sufficient time to transfer this heat to the rake surface of the cutting tool. Not only this, owing to the increased coefficient of friction between the chip and rake face of tool the crater wear is found. Being at higher temperature, cutting force and friction force, the chip thickness got enhanced owing to the combined effect of thermal expansion and deformation. This resulted in lower values of chip thickness ratio, which is not considered favorable condition in metal cutting. But in experiment no. 2 as per Fig. 7 (b) the effect of gravity is helping to reduce the transfer of heat from the chip to the tool rake face. Consequently, the morphology of chips produced is entirely different i.e. shiny and ribbon like. Due to lower temperature the chip thickness did deform much, hence chip thickness ratio increased. Further, the lower values of temperature, friction and time of contact the crater wear got reduced significantly.

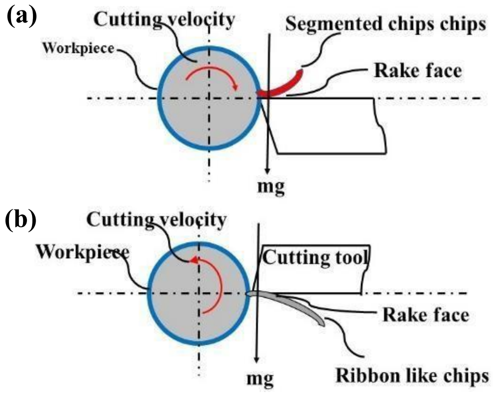

Fig.7: Rake face orientations, chip and effect of gravity,(a) upward and (b) downward.

This heat is transferred to the tool as the tool is at a lower temperature[34)]. Due to higher temperatures being generated in the secondary deformation zone, the chips get burned and segmented due to the presence of a normal force of gravity acting to stick the chips.

These terms increase the value of the coefficient of friction between the rake face and chip, which is directly responsible for the generation of heat. As in the first experiment, the high temperature was generated in the secondary deformation zone; the tool wear is high due to the softening of tool material, followed by more tool wear[35)]. The surface roughness value in the first experiment is also higher because the worn-out tool failed to remove the material efficiently. Since the chip takes away a tremendous amount of heat generated during the deformation of chips only, this overheats the chips and changes their color to blackish, as shown in Fig. 7 (a)[36)].

The results in the second experiment seem more satisfactory than those of the first. Figure 7 (b) exhibits a long ribbon type with a greyish color, as found in the machining of ductile materials at optimum input parameters. It can be attributed to the tool's rake face being directed downward[37)]. The chips do not remain in contact with the tool rake face for much time, because of gravity, the chips fall immediately. This helped in the generation of lower temperatures in the secondary deformation zone. Due to the lower temperatures generated, the tool wear is less; consequently, the surface roughness value was also less[38-41)].

3. Conclusions

Through the literature survey, the present work seems unique as none of the research groups has undertaken the study to explore the influence of tool rake orientation on machinability. The successful planning, experimentation, and analysis presented some significant findings as follows:

I. The surface roughness values reduced to 1.79 µm with a downward tool rake face compared to an upward tool rake face at 3.32 µm.
II. Gravity adversely affects the surface roughness and chip morphology with tool upward tool rake face.
III. A comparison of chip colors indicates that a considerable amount of heat might have been generated during the upward rake face compared to the downward rake face.
IV. The chips were found to be severely deformed to take a toothed shape while in upward rake orientation.
V. The machining experiment with a downward rake face exhibited acceptable surface roughness, chip thickness ratio and chip morphology.
VI. It is evident that in dry machining, the tool rake face orientation significantly influences machining outputs.

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