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Machinability Studies in Milling of Hardened Custom 465 Steel

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Abstract

Cutting force variations during high speed milling of hardened steel is an important factor affecting the cutting tool life. The poor selection of machining parameters may cause excessive tool wear and increased work surface roughness. Hence, there is a need to study the machinability aspects during end milling of hardened steel components. In the present work, influence of cutting speed, feed rate and depth of cut during end milling of hardened custom 465 steel was investigated. A series of experiments was performed using a TiAlN carbide inserts in a dry environment. The experiments were carried out using different cutting speeds, depth of cut, feed rate. From the experiments, the lowest cutting force of 110.97 N was obtained at a cutting speed of 250 m/min, feed rate of 0.075 mm/rev and depth of cut of 0.2 mm because of the combination of high cutting speed, lower feed rate and depth of cut, which is essential to minimize the cutting force. The lowest average surface roughness of 0.16 μm was obtained at a cutting speed of 250 m/min, feed rate of 0.075 mm/rev and depth of cut of 0.1 mm. The surface roughness exhibits higher sensitivity to feed rate variations in the range from 0.075 to 0.1 mm/rev. The results suggested that the temperature increased with the cutting speed, feed rate, and depth of cut. The lowest temperature of 106.09 °C, was obtained at a cutting speed of 200 m/min, feed rate of 0.1 mm/rev and depth of cut of 0.1 mm.

Keywords: Machinability, Custom 465 steel, Cutting forces, Temperature variations, Surface roughness.

1. INTRODUCTION

Custom 465 steel are grades of chromium – nickel steel which exhibits a very high corrosion resistance in addition to wide range of mechanical properties such as high specific strength, high toughness and low density. Custom 465 steel offers greater applications in aerospace, bio-medical, chemical and many other industries because of its excellent mechanical properties, but these materials are categorized under "difficult to machine materials" because these materials have very low heat conductivity, low modulus of elasticity and high chemical reactivity. Machining hardened custom 465 steel is emerging as new process to reduce the cycle time, tool wear and obtain a better surface finish. Varying parameters such as cutting speed, feed rate and depth of cut can make the process more effective; however, there are some limitations owing to the fact that tool life decreases with the elevation of cutting speed. Studies related to the proper selection of the machining parameters can be conducted with the goal of maximizing the material removal rate and reduction of tool wear. Similarly, the study of cutting forces allows an overview of the machining process in order to evaluate the level of tool wear and resulting surface finish [1].

Machining of hardened steel provides substantial benefits in terms of reduction in manufacturing cost, production time and higher product quality [2,3]. Wang et al., [4] performed studies on high-speed milling (HSM) of hardened steel (SKD11) of harness 62 HRC using TiAlN and TiSiN PVD-coated carbide tools to determine the mechanism of cutting tool wear and breakage. The influence of tool angle, tool diameter, tool extended length, cutting force and cutting-induced vibration on the tools has been studied. Cutter with a small rake angle, appropriate clearance angle and large helix angle found to be beneficial for reducing the cutting force as well as tool wear. Further, Chengyong et al.,[5] carried out an extensive research on chip formation mechanism during high speed milling of hardened steels. An investigative study on tool wear mechanism and surface integrity in high speed end milling of hardened AISI A2 tool steel using coated tungsten carbide. Pu, Singh [6] revealed that the carbide tool is suitable for low speed, while the PCBN tool is appropriate for selected high speed machining range.

A comparative study on tool life of sintered carbide (TiAlN coating) with cubic boron nitride ball end mills on hardened steel X155CrVMo12-1 was presented by Wojciechowski, Twardowski [7]. Wojciechowski, Twardowski [8] also carried out further research on the analysis of tool's vibrations generated during ball end milling process of above work materials. The milling experiments on hardened AISI H13 steel were performed by de Aguiar et al., [9] using integral and indexable insert tools with different tool overhangs and different diameters. Tool wear, workpiece surface roughness and cutting forces were analyzed. Liao, Lin [10] reported that the tool life can be successfully enhanced using MQL application in HSM of NAK80 hardened steels by selecting the proper cutting parameters. A feasibility study on the minimum quantity lubrication (MQL) in high-speed end milling of NAK80 hardened steel by coated carbide tool was undertaken by Liao et al. [11]. MQL application improved surface finish in high-speed milling of die steels and also could delay welding of chips on the tool and hence prolongs tool life when compared to dry machining.

Experimental study on the high speed machining of hardened steel was performed by Begic-Hajdarevic et al. [12] The results indicated that the better surface quality could be achieved in high speed machining of examined steel but at the cost of rapid tool wear. The experimental studies were carried out by Durakbasa et al., [13] on the optimization of end milling parameters and the determination of the effects of edge profile for high surface quality of AISI H13steel using precise and fast

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measurements. The wear performance of end mill tools with different PVD coatings has been studied under the condition of hard wet machining of H13 tool steel by Beake et al. [14]. The use of nanoindentation, nano-impact and micro-scratch testing to predict the wear behaviour of studied coated tools was discussed in their studies. The experimental and theoretical studies on the workpiece temperature during end milling of AISI H13 and AISI D2 hardened steels using (TiAl)N-coated and PCBN-tipped tools were performed by Brandao et al. [15] The experimental investigations on hard milling of high strength steel 30Cr3SiNiMoVA (30Cr3) using PVD-AlTiN coated cemented carbide tool was performed by Qinglong A et al. [16] It was observed that the occurrence of oxidation on chip surfaces under high cutting temperature makes the chips show different colors which are strongly influenced by cutting speed. The cutting performance of the coated end mills was observed in high-speed dry milling hardened steel (P20, HRC 45) by Lu et al.[17] The coated end mills demonstrate noteworthy enhancement on tool life and a large amount lower cutting force as compared to the uncoated ones.

The development of new types of coatings has allowed an improvement in the mechanical and chemical properties of tungsten carbide tools, thus leading to increased lifetime and allowing not only increased production rate, but also decrease in consumption or elimination of cutting fluids. The investigation conducted by Kang et al., [18] on milling of AISI D2 tool steel also revealed that coated tools present superior performance in dry machining. They reported that under flooding, the cooling action causes severe tool wear by thermal fatigue wear thus resulting in increased tool wear rate compared with dry cutting or using minimal quantity lubrication (MQL). Okada et al., [19] compared the temperature for two tool materials, namely cubic boron nitride (CBN) and coated cemented tungsten carbide during milling of AISI D2 steel and lower temperatures were recorded when milling with CBN due to its higher thermal conductivity. Nurul Amin et al., 20 showed that preheating the workpiece above 150°C promotes lower levels of vibration and roughness during machining, thus improving the machinability of AlSI D2 steel. With regard to tool wear, preheating the workpiece caused higher initial wear; however, an exponential increase in wear was observed when the workpiece was machined at room temperature.

As can be seen from the literature, only few works have been carried in milling of harder materials. Further, no methodological study has been reported on machinability behavior of hard milling. Hence, the present investigation evaluates some aspects of milling of hardened custom 465 steel using end mill cutters with TiAlN coated tungsten carbide inserts. The influence of cutting speed, feed rate and depth of cut on various aspects of machinability such as temperature, surface roughness and cutting force has been performed.

2. METHEDOLOGY

2.1. Workpiece material

Hardened custom 465 steel workpiece material was used in the machining test. The workpieces were cut off from a bar and their surfaces were prepared through face milling to get rid of the original skin layer containing hard particles like oxides or carbides. The dimension of the workpiece was diameter 60 mm and thickness 30 mm. The microstructure of the materials is shown in figure 1. The chemical composition of hardened custom 465 steel is given in Table 1. The hardness of hardened custom 465 steel materials is 550-565 VHN at 1kg load.

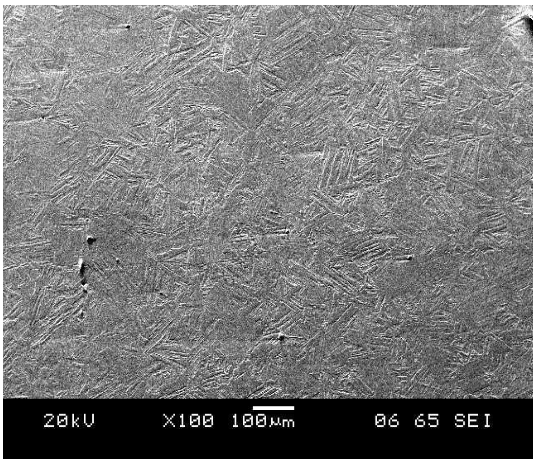

Fig. 1. Microstructure of hardened custom 465 steel

Table 1. Chemical composition of hardened custom 465 steel work material (wt %)

C	Cr	Ni	Ti	Fe	Mo	V
0.015	11.23	13.95	1.775	71.56	0.929	0.018

2.2. Cutting tool

The cutting tool used in the machining test was a Kennametal 12A01R020A16ED10 end milling cutter with a EDCT10T302PDFRLDJ - K313 TiAlN coated carbide insert. The tool diameter was 16 mm. The insert had a cemented carbide substrate, with an inner coated layer of TiN featuring low friction and adhesion layer and an outer coated layer of TiAlN featuring high hot hardness and high oxidation resistant. The insert had a flat rake face. Its nose radius was 0.2 mm.

2.3. Machine tool

The machine tool used in the cutting test was a three-axis vertical milling machine center of make MAKINO S33 with a maximum rapid speed of 20,000 rpm and cutting feed rate of 40,000 mm/min with a PC-based NC controller. A Kistler quartz three-component dynamometer was mounted on the machine table to measure the cutting forces. The workpiece was mounted on the dynamometer through a specially designed fixture. The setup of the machining experiment is shown in Fig. 2.,

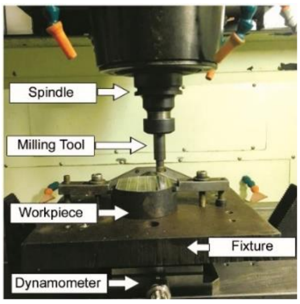

Fig. 2. Experimental setup

2.4. Experimental procedure

The machining test were conducted with a cutting speed of 150, 200, 250 m/min along with varying feed rate of 0.050, 0.075 & 0.1 mm/rev and depth of cut of 0.1, 0.2 & 0.3 mm which was used as the input parameters. The forces fx, fy and fz are obtained using a Kistler Milling dynamometer and the maximum temperature at the tool-chip interface was investigated for different cutting combinations using FLIR IR thermal imaging camera. The surface roughness was measured using Mitutoya surface roughness tester.

3. RESULTS AND DISCUSSION

3.1. Analysis of cutting force

From the analysis, it is clearly seen that for a higher values of feed rate, an increase in cutting speed greatly reduces the cutting force for all values of depth of cut. Besides, it is obvious that for fixed values of cutting speed, an increased feed rate and increased depth of cut resulted in increased cutting force values. At higher values of feed rates, the workpiece material presents more resistance to cutter in the cutting direction and hence friction increases, thus leading to increased cutting force. With a further increase in depth of cut, the material removal rate increases contributing to higher cutting force. It is also observed that the increase in cutting force is larger when the feed rate is increased from medium to the highest value. It can be concluded that a combination of low cutting speed, feed rate and depth of cut is essential to minimize the cutting force, as seen from Figure 3.

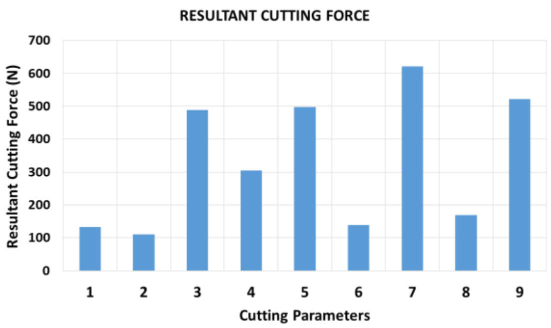

Fig. 3. Resultant Cutting force

3.2. Analysis of temperature

In machining, the workpiece, cutting tool and chip warm up in the cutting zone. The mechanical energy is converted into thermal energy owing to plastic strain and friction between of the chip and the rake and clearance surfaces of the cutting tool and hence temperature increases. Figure 4 illustrates the variation of maximum temperature as a function of cutting speed with three different values of feed rate and depth of cut. It is observed that temperature linearly increases with cutting speed for any specified value of feed rate and depth of cut. This is due to the fact that with increased cutting speed, friction increases, which in turn increases the temperature in the cutting zone. The influence of depth of cut on temperature is quite evident from this figure. Accordingly, for a given feed rate and cutting speed, adopting smaller values of depth of cut could reduce the temperature. It is quite obvious that if both feed rate and depth of cut simultaneously increase, the shear plane area increases and hence plastic strain and friction increase; this leading to higher temperature. It can be also seen from Figure 4 that the temperature rise is more sensitive to cutting speed variation when the depth of cut is fixed at larger values. A similar situation exists when the feed rate is fixed at low values. Therefore, it can be concluded that minimum temperature can be achieved by adopting lower values of depth of cut and cutting speed with medium value of feed rate.

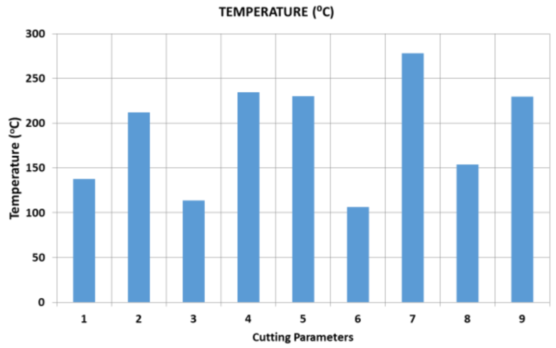

Fig. 4. Temperature

3.3. Analysis of surface roughness

The behavior of surface roughness with the process parameters during milling hardened custom 465 steel is given in Figure 5. The surface roughness is nonlinearly related to cutting speed variations for any values of feed rate and depth of cut. For specified values of feed rate and depth of cut, minimum surface roughness occurs at a medium cutting speed value of approximately 150 m/min. Moreover, surface roughness increases with depth of cut for all fixed values of cutting speed and feed rate. As can be seen from Figure 5, for a specified value of cutting speed and depth of cut, surface roughness increases with feed rate. In general, with increased feed rate, the contact area between the cutting tool and workpiece increases, causing higher thrust force and vibration and hence increased surface roughness. Additionally, with increased depth of cut the surface roughness also increases because more heat is generated at the cutting zone due to higher thrust force. It is also observed that with the elevation of feed rate the increase in surface roughness is not substantial when the depth of cut is fixed at the lowest value (0.1 mm) compared with medium (0.2 mm) and high (0.3 mm) depths of cut. Thus, surface roughness exhibits higher sensitivity to feed rate variations in the range from 0.050 to 0.1 mm/rev. Therefore, good surface finish can be obtained by adopting low values of both feed rate and depth of cut while operating with medium value of cutting speed.

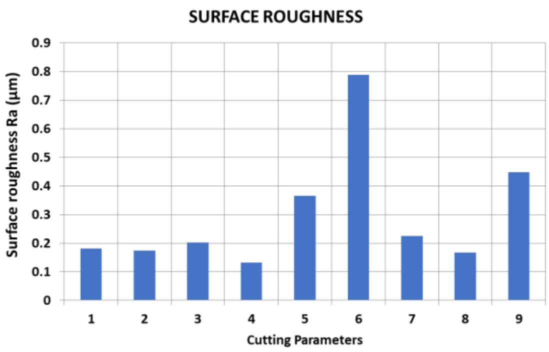

Fig. 4. Surface Roughness

4. CONCLUSIONS

The influence of cutting speed, feed rate and depth of cut on various machinability characteristics such as maximum temperature (T_{max}), surface roughness (Ra) and cutting force (F_r) have been analyzed during milling of hardened custom 465 steel with TiAlN coated tungsten carbide insert and the following conclusions are drawn:

- The increase in cutting force is large when the feed rate is increased from medium to high value. A combination of low cutting speed, feed rate and depth of cut is essential to minimize the cutting force.

- For specified values of feed rate and cutting speed, smaller depth of cut is essential to reduce the temperature. Minimum temperature can be achieved by adopting lower values of depth of cut and cutting speed with medium value of feed rate.

- The increase in surface roughness is not significant for lower depth of cut as compared to medium and higher depth of cut values. The surface roughness exhibits higher sensitivity to feed rate variations in the range from 0.050 to 0.1 mm/rev.

- Better surface quality can be obtained by employing lower values of feed rate and depth of cut while operating at medium cutting speed.

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