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Experimental Investigation of Tool Wear Behavior of Multi-Layered Coated Carbide Inserts Using Various Sensors in Hard Turning Process

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Abstract: Tool wear analysis became a vital area of research in the current scenario of mass machining or mass production in industries especially in the event of machining of hard materials. The applications where hard steel replaces the less hard materials, multi-layered coated carbide inserts have shown better results in comparison with single-layered coated carbide inserts. Different sensors like cutting force sensor, roughness sensor, temperature sensors, etc. can be used to associate its particular output with tool wear. In this paper, a study has been carried out to report the tool wear behavior of multi-layered coated carbide inserts while machining hard steel of 55 HRC in dry cutting conditions. Different sensors have been used during experimentation and their outputs have been analyzed to investigate the behavior of cutting tool in real life situation for precision machining.

Keywords: Multi-layered coated carbide inserts, tool wear, precision machining.

1. INTRODUCTION

Machining of hardened steel especially known as hard turning has attracted many industries for mass machining or for mass production because it mostly found applications in making of bearing, gears, shafts etc. and offers an alternative to grinding operation. Multilayer coated carbide inserts are normally used for machining of hardened steel at or above 50 HRC. Extensive study has been performed by researchers for the selection of tool material to investigate its wear behavior. The primary reason being that the machining of hardened steel usually requires advanced or harder cutting tool. Different studies utilized different tool inserts made up of ceramic, CBN, diamond and carbides etc. But from the economic point of view, researchers as well as industries have started concentrating on cheaper tool material like carbide. From the production point of view, uncoated or single-layer carbide inserts have not turned out to be efficient in increasing tool life. On the other hand, use of multi-layer coated carbide inserts have not turned out to be efficient behavior because of their wear resistant and lubricious property, it also provides the economical beneficial aspect especially in terms of tool life, surface finishing, balanced edge sharpness and high toughness when compared with uncoated or a single-layer coated insert in machining. Therefore in order to cater the need of mass production and the machining of hard materials, multi-layer coated carbide inserts were investigated.

At the same time, tool wear monitoring has also gained popularity. In the machining process, cutting tool wear behavior is an important factor and needed online monitoring to make the process functionally automated. Many sensing techniques have been reported by researcher Dimla et al. (1997) for use of sensors to monitor the tool wear. The output signal of different sensors can be used for tool wear monitoring. Monitoring can be done in two ways: direct sensing and indirect sensing. In direct sensing wear on the cutting tool are measured only when the cutting tool is disengaged. Microscope, Profilometer, and similar such equipment are used for direct sensing. Whereas in case of indirect sensing, actual tool wear is sensed in a dynamic state by adapting sensors like vibration sensor, acoustic emission sensor, power sensor, strain gauge, cutting force sensor, roughness sensor, temperature sensor etc. But the cost involved in sensor application is high and needed one-time capital investment.

1.1 Literature Review

Chen and Chen (1999) have proposed a methodology for online detection of cutting tool failure based on cutting frequency. At low frequencies, frequency domain presents two important peaks which are compared to find the ratio that could be an indicator for monitoring tool breakage. When compared with other in-process method such as 3-axis sensor and acoustic emission sensor, their system was found to be advantages in terms of mechanism and is reliable with less cost. Sick (2002) has proposed a technique which involves a physical process model with an ANN in turning process. This physical wear model describes the influence of cutting conditions on measured force signals. The ANN model describes the relationship between the force signal and the cutting tool state. The performance of the best model was 99.4% for the learning step and 70% for the testing step. Dimla and Lister (2000) used the cutting force values, measured by dynamometer and vibrations obtained with an

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accelerometer, to report a tool wear state by neural network. The developed system was capable to determine tool state upto 90 % accuracy. But system fails when cutting conditions changes. Work done by Caken et al. (2008) has described the behavior of tool wear on TiN and CrN coated insert. The study involves a dynamometer and opto-electronic sensor that monitors the change of tool state behavior without interrupting machining process. Their study involves the indirect measurement of tool wear by correlating it with the dimension of workpiece, they verified the results with the change of cutting force during machining. Results showed that TiN coated had higher wear resistance than Cr-N coated insert. Trejo-Hernandez et al. (2010) has developed a fused smart sensor based on Field Programmable Gate Array to improve the online quantitative estimation of flank wear for coated carbide CNMG 433Ma in a CNC machine. Measurement involved two primary sensors: cutting force sensors and current output of servo amplifier. Experimentation has showed that fusion of both signals makes 3 times better accuracy as compared with individual sensor signal. Sahoo and Sahoo (2012) have done a comparative study to determine the cutting tool state, surface roughness, chip morphology and cutting force in finish hard turning of AISI 4340 steel using uncoated and multi-layer TiN and ZrCN coated carbide inserts at higher cutting speed range. Experimental results showed that the abrasion, chipping and catastrophic failure are the principal wear mechanism. The turning forces were observed to be lower using multi-layer coated carbide insert than that of uncoated carbide insert. Choudhury et al. (2001) have developed a non-contact displacement optical fibre transducer to monitor the tool wear. The result shows that the dimensional inaccuracy of the machined surface can be maintained below 0.03 mm using the newly developed sensor. Reliable and sensitive techniques to detect tool wear and breakage during cutting have indicated that the force dynamometer signals, i.e., cutting force signals works more efficiently than any other sensors. According to Kinnander (1981), the cutting force is the parameter which seems most likely to provide a solution to monitor flank and crater wear, being the most appropriate criterion to determine the exact time to replace worn out tool. Park and Kwon (2011) have measured the flank wear and surface roughness on turning AISI 1045 steel using multi-layer TiCN/Al2O3/TiCN coated insert. They found that multilayer coating did not prove to be much effective in showing the tool state conditions because of the hardness of the coating layer which unable to resist the abrasion wear in their cases and followed by adhesion due to the expose of substrate material on the cutting insert. This reason may be the possibility of selecting cutting parameter away from the permissible limit and the tribological behavior between the matting surfaces. Noordin et al. (2007) have observed that the multi-layer TiCN/Al2O3/TiN coated carbide have shown better performance as compared with TiCN coated cermet. It was also concluded that the longest tool life for cermet insert was found during machining at low speed and feed at side cutting edge angle of -5^0. However, in all other instances multi-layer coated carbide inserts performed better. Lim (1995) has investigated the influence of the cutting conditions on the measured vibration signal and developed a strategy for detecting the tool wear state. It is said that vibration signal produce two peaks during one time machining. First peak is about the start of the wear and the second peak is the indication that tool is near to the limiting criteria, and this signal was fed into the program for an online monitoring of tool wear state as a function of vibration.

In this paper, a study has been carried out to report the tool wear behavior of multi-layered coated carbide inserts while machining hard steel of 55 HRC at two different cutting conditions by varying the cutting speed in a dry environment. Different sensors have been used during experimentation and their outputs have been compared analyzed to investigate the behavior of cutting tool in a real life situation for precision machining.

2. EXPERIMENTAL DETAILS

2.1 Cutting Conditions

Turning passes were taken on the HMT centre lathe with fresh coated carbide inserts in the dry cutting environment. Experiments were carried out at constant values of cutting parameters viz. cutting speed, feed and depth of cut. According to literature review, capability of the machine and recommendation from insert manufacturer, the values provided in Table 1 were used as cutting parameters for the experimentations.

Table 1. Cutting Parameters

Parameters	Values
Cutting Speed, V (m/min)	100, 150
Feed, f (mm/rev)	0.15
Depth of Cut, d (mm)	0.25

2.2 Workpiece material and cutting insert

In this study, 55 HRC EN24 hardened steel of diameter 65 mm was used for turning operation. The hardness was assured to be constant (± 2 HRC) throughout its cross section by uniform hardening and tempering process. The length of the workpiece was 150 mm. The chemical composition of EN24 is given in Table 2. The turning operation has been carried out using commercially available multi-layer PVD coated Ti-Al-N nano-layer carbide inserts of the Kyocera brand with specification as CNMG120408 (80^0 diamond shape with 0.8 mm nose radius). Fig. 1 shows the schematic of chemical composition of the insert. A left hand side tool holder designated by ISO as PCLNR 2020 K12 was used for mounting the insert (Chinchanikar and Choudhury (2013, 2014)).

Table 2. Chemical composition of EN24 Steel by its weight percentage

C	Mn	Si	S	P	Cr	Mo	Ni
0.4	0.65	0.21	0.012	0.015	1.05	0.3	1.36