International Journal of Engineering, Management, Humanities and Social Sciences Paradigms (Volume 30, Special Issue of Nov 2018)
ISSN (Online): 2347-601X and Website: www.ijemhs.com

Investigation of flank wear during hard turning of AISI 52100 steel using multi-layer coated carbide and ceramic blends

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Abstract

Heat-treated carbon and chromium steel alloys are often used in the industry for pressing tools, dies, balls and rolls, etc. Ceramic is a well-known tool material for turning a heat-treated steel alloy. However, the performance of a low-budget tool compared to a ceramic tool is economically necessary. In this paper, multi-coated carbide and ceramic tools are used as cutting tool material for turning heat-treated AISI 52100 bearing steel, and the evaluation of the performance of both tools in terms of side wear is compared. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to compare the results of both tools. The resulting flank wear width was found to be less than 0.3 mm with both tools. Friction and adhesion are the most dominant wear mechanisms for coated carbide, while friction is most dominant for ceramic tools. For both tools, the most dominant feature of side wear is speed

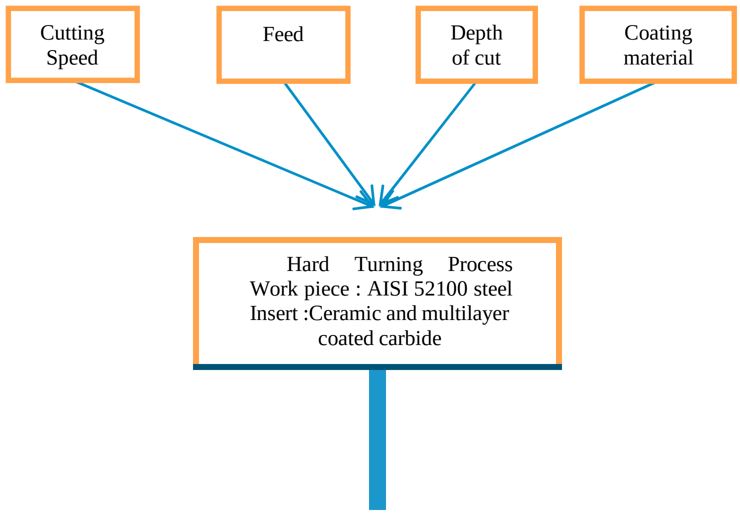
Keywords: Hard Turning; *SEM; EDS*

1. Introduction

The production process plays a key role in the manufacturing industry. This growing importance of processing technology certainly had an impact on economic development as well. Mechanical processing is an important activity in the manufacturing sector. This operation mainly concerned the finishing of the mechanical components. During the finishing process, hard turning occurs due to the generation of cutting force and higher temperature, which significantly affects process parameters such as surface integrity, tip wear, blade life, turned surface quality and geometric dimensions. Tool wear is a common observation in the machining process that significantly affects product size, quality, machining efficiency, production forecasts, and financial profitability. Blade wear has a significant impact on machining economy. At the same time, blade wear is caused by the contact between the cutter and the work material with sliding during the machining process [1]. A perfect combination of cutting factors and machining conditions ensures better performance during hard turning for finishing [2]. Cutting tool wear during the machining process is the industry's biggest challenge. In response to the demands of the manufacturing and mechanical industries, several researchers have conducted an analysis on tool wear. The hardness range of hard materials is considered to be 5-70 HRC. The main advantages are the complexity of cutting, less preparation, greater flexibility, time saving. This innovative technology was in demand in the manufacturing world due to its advanced process, in addition to achieving a highly enviable finish [3]. TIN coatings, TIAN, TICN, Al2O3 are commonly used on knives. Cutting factors, i.e., speed and power, mainly affect the tip wear and blade life, and the depth of cut is the determining factor in evaluating tool performance during machining. The increased industrial demand for cutting metals into hard materials and their wide range of applications requires significant analysis to improve their processing capabilities. An ideal cutting tool requires a combination of combination to improve wear resistance as well as good lubricating properties, durability, chemical stability and at the same time a suitable substrate added to the surface [ ]. Talib et al. [5] discussed the consequences of cutting speeds on flank wear and wear on TiAN-coated wear mechanisms when turning low carbon steel under a lubricating system. Side wear is reduced as the speed improves due to the excellent oxidation of the TiAlN coating layer at elevated temperature. Keblouti et al. [6] achieved a high surface quality when dry turning AISI 52100 steel using a PVD-coated cutter. The effect of cutting factors and coating material on surface roughness was investigated. Maruda [7] presented a study on carbide insert (P25) wear in turning AISI 10 5 steel in different cooling environments such as dry cutting and MQCL. In addition, the SEM study revealed that the living compounds enclosed in the tribofilm reduce the adhesion and propagation of the knife wear process. Attanasio et al. [8] discussed the effects of blade wear and cutting factors on the formation of dark and white layers in orthogonal end turning of AISI 52100 hardened steel characters according to PCBN steels. Finite element (FE) models are correlated with research results to investigate the effects of machining environment and tool wear on microstructure changes. In addition, flank wear is usually caused by abrasives that vary greatly with the cutting speed. Ghani et al. [9] investigated tool wear in minimum life CBN internal turning of H13 grade steel and experimental and finite element thermal modeling techniques. Spalling was found to be the dominant wear mechanism and can be reduced by reducing heat penetration into the cutter. Ventura et al. [10] checked the cutting edge geometry for CBN-specific tool wear during hard turning of 16MnCrS5 steel (60 ± 2 HRC). A special oblique cutting tip is suitable to minimize side wear. A term called friction was found to be the most important wear mechanism. Dogra et al. [11] found that hard turning research achieved multifaceted progress using CBN inserts related to tool surface wear, chip morphology, turned surface finish quality, white layer microhardness change, and residual stresses. The prediction of the residual stress in the finish of a difficult-to-cut material is very reliable. In addition, the logic model is important for predicting the residual stress of turned parts considering various dynamic effects such as tool wear and vibration. Quiza et al. [12] discussed the evolution of tool wear in turning hardened D2 steel with a ceramic insert and developed a prediction model using statistical regression and multilayer perceptron neural network technique with different cutting speed, feed and cycle parameters. The neural network model has been shown to be effective in accurately predicting tool wear in difficult machining. Camargo et al. [13] developed a computer model for tool wear during turning of AISI D6 steel (57 HRC) with a PCBN cutter. The developed model was good enough to estimate the ideal cutting conditions for hard machining of D6 steel. Shalaby et al. [1] illustrates the wear mechanism of different cutter materials used in turning medium hardened D2 steels. A mixed ceramic insert was found to provide longer tool life and fewer power components than a PCBN insert. The present research focuses on the analysis of tool wear at the edge of turning with AISI 52100 steel using multilayer coated carbide inserts CNMG 120 08 and mixed ceramics.

2. Methodology

The tests were conducted on 40 mm diameter and 120 mm long AISI 52100 steel (0.940 % C, 0.227% Si, 0.491% Mn, 0.046 %P, 0.022%S, 1.210 % Cr, 0.076 % Ni, 0.0.58% Cu balance Fe) with hardness of 55±1 HRC. Turning of heat treated AISI 52100 grade steel has been performed on a computerized numerical control lathe having specification (Model: JOBBER XL, Make: AMS-ACE Designers, INDIA, Power: 16 kW, Max RPM: 3500) under dry environment. Hard turning tests has been performed using two types of commercially available cutting inserts (WIDIA make) i.e. moderate temperature chemical vapour deposition (MTCVD) multilayer coated carbide inserts ($TiN/TiCN/Al_2O_3$) of HK 150 grade and K-type application range of Al_2O_3 top layer and mixed ceramic insert (Al_2O_3 + TiCN) of CW2015 grade respectively. The hard turning methodology is as presented in Fig. 1.



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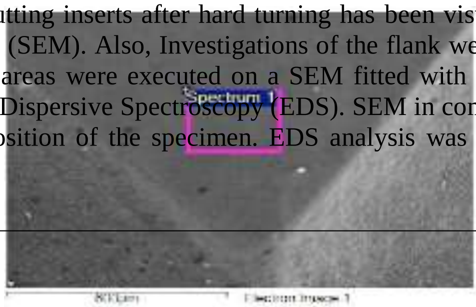
Tool Wear Analysis (SEM/EDS)

Fig. 1.Hard turning methodology

3. Experimental details

The flank wear of cutting inserts after hard turning has been visualized by HITACHI make SU3500 Scanning Electron Microscope (SEM). Also, Investigations of the flank wear along with chemical composition in certain surface of the worn areas were executed on a SEM fitted with INCA software by OXFORD Instruments act model make Energy Dispersive Spectroscopy (EDS). SEM in combination with EDS makes possible to identify the elemental composition of the specimen. EDS analysis was carried out on a thin coating layer on top of carbide substrate.



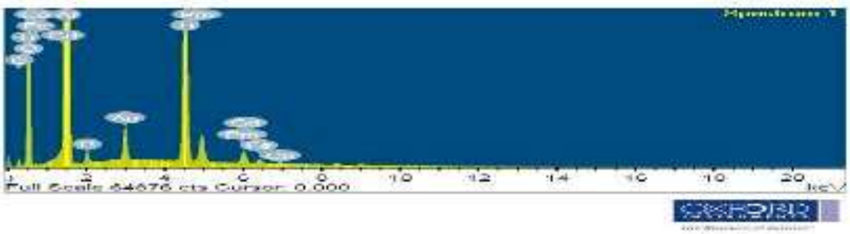
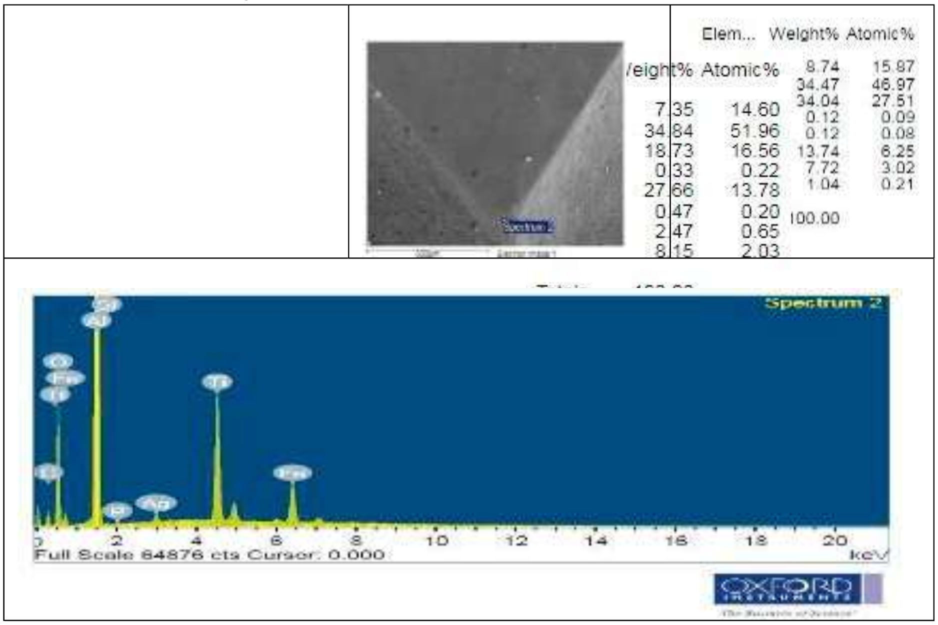


Fig.2. EDS view and elemental composition of multilayer Al_2O_3 coated carbide, HK 150 (without worn surface)

Fig.3. EDS view and elemental composition of multilayer Al_2O_3 coated carbide, HK 150, worn tool (Cutting speed = 190 m/min, feed = 0.08 mm/rev and depth of cut = 0.3 mm)



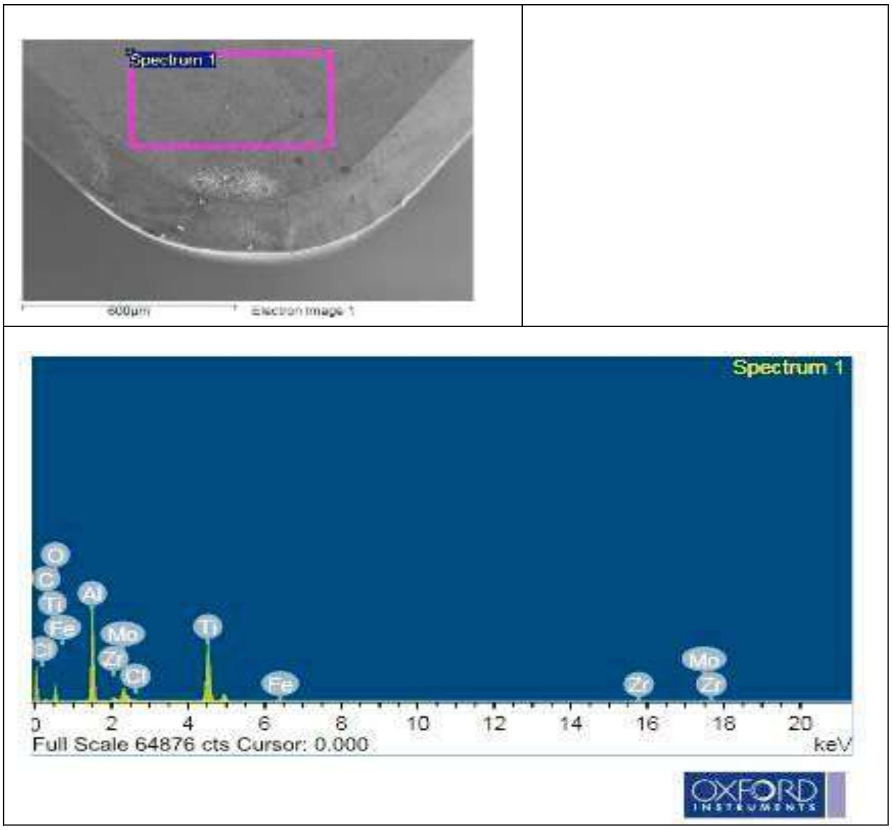
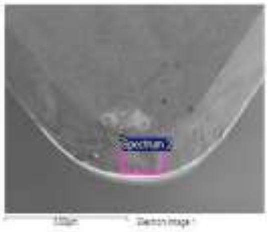


Fig. 4. EDS view and elemental composition of mixed ceramic insert, CW 2105 (without worn surface)



Elem	Weight%	Atomic%
C K	8.00	16.70
O K	29.87	46.83
Al K	14.16	13.16
Si K	0.53	0.47
S K	0.36	0.28
Cl K	0.92	0.65
Ti K	27.96	14.64
Mn K	2.80	1.28
Fe K	8.47	3.80
Zn K	2.90	1.11
Zr L	1.14	0.31
Mo L	2.87	0.75
Totals	100.00	

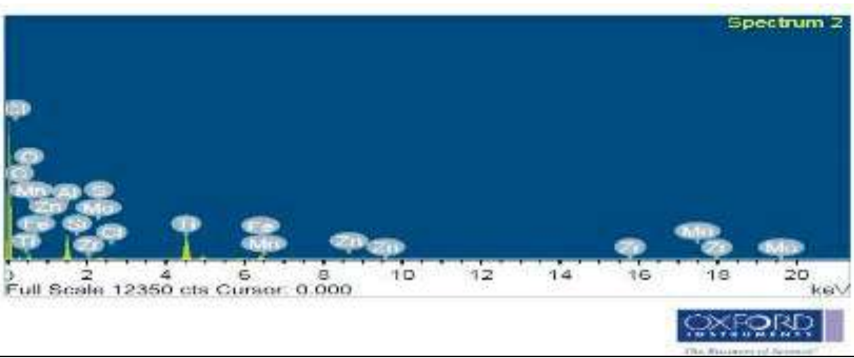


Fig.5. EDS view and elemental composition of mixed ceramic insert, worn tool
(Cutting speed = 190 m/min, feed= 0.08 mm/rev and depth of cut = 0.3 mm)

4. Result and discussion

The flank wear of two types i.e. multilayer coated carbide and mixed ceramic insert after hard turning process in dry condition using AISI 52100 steel by the SEM and EDS method at the peak rank of chosen speed= 190 m/min, feed = 0.08 mm/rev and depth of cut = 0.3 mm were analyzed. The mapping of elements by this method aids in better consideration of coating layer performance. Energy dispersive spectroscopy (EDS) analysis has been carried out at micro area of without worn surfaces to verify the elements present in the cutting inserts along with their weight and atomic percentages at the relevant EDS spectrum. It validates the existence of elements in the cutting tools (Fig. 2 and Fig. 4).

EDS result represents all compositional elements of coated carbide insert like as Ti, Al, O and C. It was observed that (Fig. 3) hard turning of AISI 52100 bearing steel with aluminium oxide multilayer coated carbide insert is regarded as steady and stable machining without any premature tool failure as weightage of Aluminium remains almost same. Further, tungsten is not exposed in EDS analysis and all coating element presents after machining thus indicates that delamination of coating layers do not occur. The Al_2O_3 layer delays the diffusion of oxygen into the flank surface. Moreover, this endows with finer oxidation resistance. Also, the intense hardness at elevated temperature and low thermal conductivity provided necessary for stable in dry turning [15].

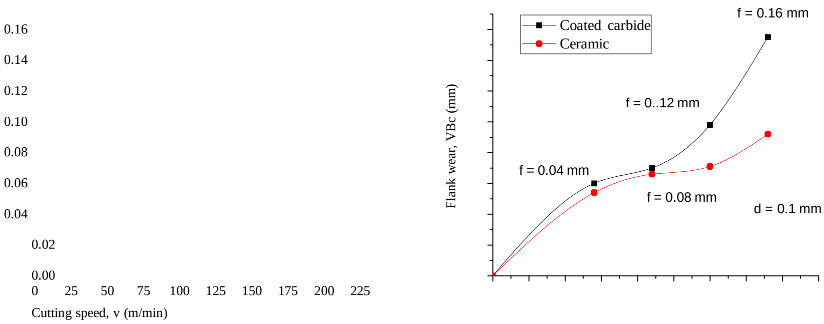


Fig.6. Influence of speed and feed on tool wear

No untimely failure like tip breakage and/or catastrophic collapse, plastic deformation on the cutting tip has occurred. The foremost consequence of flank wear is anticipated to be caused by abrasion. The enhanced performance is endorsed owing to the existence of top thermal barrier coating of aluminium oxide. Further, for this property more generated heat is gathered on the specimen than insert. Therefore, impedes the augmentation of flank wear of the cutting tool. Similar case has been observed in ceramic insert as per A SEM with EDS analyses (Fig. 5). However, iron content is increased after machining and clearly observed through EDS analysis of both inserts. It is transformed element from the workpiece to the cutting insert at elevated temperature through diffusion mechanism. Abrasion is the most important wear mechanism perceived. The better interpretation is endorsed owing to the presence of thermal barrier property of ceramic insert. Hence, further prevents the development of flank wear of the cutting tool. From the Fig. 6, it is noticed that at constant depth of cut when speed along with feed increases wear at flank surface of both the tool increases but coated carbide tool always produce higher flank wear as compared to ceramic insert.

5. Conclusion

The production process plays a key role in the manufacturing industry. This growing importance of processing technology certainly had an impact on economic development as well. Mechanical processing is an important activity in the manufacturing sector. This operation mainly concerned the finishing of the mechanical components. During the finishing process, hard turning occurs due to the generation of cutting force and higher temperature, which significantly affects process parameters such as surface integrity, tip wear, blade life, turned surface quality and geometric dimensions. Tool wear is a common observation in the machining process that significantly affects product size, quality, machining efficiency, production forecasts, and financial profitability. Blade wear has a significant impact on machining economy. At the same time, blade wear is caused by the contact between the cutter and the work material with sliding during the machining process [1]. A perfect combination of cutting factors and machining conditions ensures better performance during hard turning for finishing [2]. Cutting tool wear during the machining process is the industry's biggest challenge. In response to the demands of the manufacturing and mechanical industries, several researchers have conducted an analysis on tool wear. The hardness range of hard materials is considered to be 5-70 HRC. The main advantages are the complexity of cutting, less preparation, greater flexibility, time saving. This innovative technology was in demand in the manufacturing world due to its advanced process, in addition to achieving a highly enviable finish [3]. TIN coatings, TIAN, TICN, Al2O3 are commonly used on knives. Cutting factors, i.e., speed and power, mainly affect the tip wear and blade life, and the depth of cut is the determining factor in evaluating tool performance during machining. The increased industrial demand for cutting metals into hard materials and their wide range of applications requires significant analysis to improve their processing capabilities. An ideal cutting tool requires a combination of combination to improve wear resistance as well as good lubricating properties, durability, chemical stability and at the same time a suitable substrate added to the surface. Talib et al. [5] discussed the consequences of cutting speeds on flank wear and wear on TiAN-coated wear mechanisms when turning low carbon steel under a lubricating system. Side wear is reduced as the speed improves due to the excellent oxidation of the TiAlN coating layer at elevated temperature. Keblouti et al. [6] achieved a high surface quality when dry turning AISI 52100 steel using a PVD-coated cutter. The effect of cutting factors and coating material on surface roughness was investigated. The tool face wear of multilayer coated and ceramic materials Maruda was analyzed in dry scenario machining of heat treated AISI 52100 steel alloy.

The following conclusions were drawn:

• Wear on the sides of both tools was found to be less than 0.3 mm. Friction and adhesion are the most dominant wear mechanisms for coated carbide, while friction is most dominant for ceramic tools. For both tools, the main controllable characteristic of side wear is speed.

• Al2O3 (top layer) slows oxygen diffusion to the side surface, improving finer oxidation resistance. The high hardness of the coated tool at high temperature and low thermal conductivity also ensures stable dry turning.

• Smooth and stable machining without premature tool failure was observed for both tools.

• Multi-coated carbide inserts work great because they are economically accessible and environmentally friendly for turning hardened materials.

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