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Performance studies of multilayer hard surface coatings ($TiN/TiCN/Al_2O_3/TiN$) of indexable carbide inserts in hard machining: Part-I (An experimental approach)

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ABSTRACT

In recent years, hard machining using CBN and ceramic inserts became an emerging technology than traditional grinding and widely used manufacturing processes. However the relatively high cost factors associated with such tools has left a space to look for relatively low cost cutting tool materials to perform in an acceptable range. Multilayer coated carbide insert is the proposed alternative in the present study due to its low cost. Thus, an attempt has been made to have an extensive study on the machinability aspects such as flank wear, chip morphology, surface roughness in finish hard turning of AISI 4340 steel (HRC 47 ± 1) using multilayer coated carbide ($TiN/TiCN/Al_2O_3/TiN$) insert under dry environment. Parametric influences on turning forces are also analyzed. From the machinability study, abrasion and chipping are found to be the dominant wear mechanism in hard turning. Multilayer TiN coated carbide inserts produced better surface quality and within recommendable range of 1.6 μm i.e. comparable with cylindrical grinding. At extreme parametric conditions, the growth of tool wear was observed to be rapid thus surface quality affected adversely. The chip morphology study reveals a more favorable machining environment in dry machining using TiN coated carbide inserts. The cutting speed and feed are found to have the significant effect on the tool wear and surface roughness from ANOVA study. It is evident that, thrust force (Fy) is the largest component followed by tangential force (Fz) and the feed force (Fx) in finish hard turning. The observations yield the machining ability of multilayer TiN coated carbide inserts in hard turning of AISI 4340 steel even at higher cutting speeds.

1. Introduction

The development of ceramic and CBN cutting tool materials has been taking place to enable the manufacture to machine hardened materials. Hard machining about 60 HRC workpiece are successfully performed by both ceramic and CBN inserts [1]. It replaces slow traditional grinding process for finishing of hardened parts such as transmission shaft, bearings and gears typically used for automotive industry. The advantages of hard machining over grinding process are substantial reduction of cost of manufacturing, decrease of time of finish machining; significantly improve surface finish and eco-friendly due to elimination harmful coolant. Hard machining eliminates the long manufacturing cycle time and hence improves productivity [2].

In spite of its effectiveness with respect to cost, time, environment and competitiveness with grinding processes, industrial application of this technology is somewhere limited. This is due to the uncertainties related to the surface integrity and part accuracy, tool wear pattern and tool life

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Nomenclature

d	depth of cut (mm)	HRC	Rockwell hardness
f	feed (mm/rev)	CNC	computerized numerical control
v	cutting speed (m/min)	CVD	chemical vapour deposition
VBc	flank wear at nose corner (mm)	r	nose radius (mm)
Ra	arithmetic surface roughness average (μm)	SS	sum of squares
DF	degrees of freedom	F	variance ratio
MS	mean square	ANOVA	analysis of variance
P	probability of significance	γ	back rake angle
Rz	maximum peak-to-valley height	PVD	physical vapour deposition
λ	inclination angle	TRS	transverse rupture strength
CBN	cubic boron nitride		
AISI	American iron and steel institute		

predictions and economical feasibility. Definitely, research is required for hard machining to become more competitive and economically effective than grinding. In order to achieve the objectives of this research, a literature review was conducted. Quiza et al. [3] investigated hard turning of D2 steel (60 HRC) using ceramic insert (70% Al_2O_3, 30% TiC). It was found that, for every combination of feed and speed, wear grows with time and significant influence on the tool wear. Özel et al. [4] investigated the surface finish and tool flank wear in finish hard turning of AISI D2 steels (60 HRC) using ceramic wiper inserts. Wiper insert produced lower surface roughness below 0.18–0.20 μm. Grzesik and Zalisz [1] investigated the wear behavior of mixed ceramic tool in hard turning of AISI 5140 steel (60 HRC). Wear mechanisms involved abrasion, fracture, plastic flow, material transfer and tribochemical effects which appear depending on the mechanical and thermal conditions generated on the wear zones in dry hard turning operations. Paiva et al. [5] studied the influence of the cutting parameters in turning hardened AISI 52100 steel with TiN coated mixed ceramic tool (Al_2O_3 + TiC). Maximum material removal rate with good surface quality was attained at a cutting speed of approximately 238 m/min, feed rate of 0.08 mm/rev and depth of cut of 0.32 mm. Gaitonde et al. [6] revealed that, the TiN coated wiper ceramic insert (Al_2O_3 + TiC) performed better with reference to surface roughness and tool wear, while the conventional ceramic insert was useful in reducing the machining force, power and specific cutting force during hard turning of D2 steel (59-61 HRC). Kamely and Noordin [7] obtained the better surface finish comparable to grinding during hard turning of AISI D2 steel (60 HRC) with PVD TiN coated ceramic tools (Al_2O_3 + TiCN). Davim and Figueira [8] compared the performance of wiper and conventional ceramic cutting tool in turning D2 steel (60 HRC). Cutting time and cutting velocity were the main parameters that affect the flank wear of ceramic cutting tools. The specific cutting pressures of ceramic tools strongly influenced by the feed rate. With wiper ceramics inserts, machined surface roughness less than 0.8 μm was achieved. Huang et al. [9] suggested that abrasion, adhesion and diffusion primarily govern the CBN tool wear in hard turning. Models have been proposed to predict the flank and crater-wear propagation and evaluate the relative importance of each wear mechanism. Tamizharasan et al. [10] proposed that as an alternative to grinding, the hard turning produced better surface finish, lower flank wear rate and high material removal on the selected crank pin material by low content CBN tool. Ozel and Karpat [11] observed that low CBN content insert with honed edge geometry performed better in terms of surface roughness and tool wear in finish hard turning of AISI H13 steel. Mahfoudi et al. [12] found that high speed machining (300 and 400 m/min) of a 50 HRC hardened steel (AISI 4140/ 42CrMo4) with a PCBN tool could be acceptable for industrial application providing very good surface roughness with significant tool life. Derakhshan and Akbari [13] obtained best surface quality in hard turning of AISI 4140 steel (45-65 HRC) with CBN tool with Ra being 0.175 μm. The feasibility of hard turning instead of grinding in many industrial applications was observed. Park [14] observed that PCBN insert performed better in cutting force and surface roughness than ceramic tool in turning hardened SKD 11 steel (58-60 HRC). The radial force was the largest force component regardless the type of tool used. The PCBN tools transferred the generated heat more effectively than the ceramic tools due to their higher thermal conductivity. Sahin and Motorcu [15] found that the surface roughness produced by CBN cutting tools were lower than those of mixed ceramic insert during turning AISI 1050 steel (484HV). Higher significance on the surface finish value was feed rate for all cutting tool materials. Sahin [16] indicated that the CBN cutting tool showed the best performance than that of ceramic based cutting tool during turning AISI 52100 steel (659HV). Cutting speed exerted the greatest effect on the tool wear, followed by the hardness of cutting tool, lastly the feed rate. Yallese et al. [17] investigated the effect of process parameters on ceramic and CBN tool wear in the hard turning of X200Cr12 steel (60 HRC). Cutting speed up to 180 m/min was found to be limiting factor for both cutting tool materials. Under limiting wear criteria, surface roughness was higher for ceramic tool than CBN tool. The optimal cutting speed was found to be 120 m/min using CBN tool and 60 m/min for ceramic insert. Noordin et al. [18] reported a comparative assessment of cutting performance while machining tempered martensitic stainless tool steel