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Experimental investigation into machinability of hardened AISI 4140 steel using TiN coated ceramic tool

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ABSTRACT

The concerns with some machinability aspects on surface roughness, flank wear and chip morphology in hard turning of AISI 4140 steel using PVD-TiN coated Al_2O_3 + TiCN mixed ceramic inserts under dry environment. The machined surface characterization, tool wear mechanism and chip morphology are investigated in this study, along with optimization and development of mathematical models for surface roughness and flank wear. By adopting combined techniques such as orthogonal array and analysis of variance, the consequences of cutting parameters (cutting speed, feed and depth of cut) on surface roughness (R*a*, Rq and Rz) and flank wear (VB) are explored. The results show that feed is the principal cutting parameter influencing surface roughness, followed by cutting speed. However, flank wear is affected by the cutting speed and interaction of feed-depth of cut, although depth of cut has not been found statistical significant, but the flank wear is an increasing function of depth of cut. Thereafter, observations are made on the machined surface, worn tool and the generated chips by scanning electron microscope (SEM) to establish the process. Abrasion was the major wear mechanism found during hard turning within the studied range. Chip morphology indicates the formation saw-tooth/serrated chips at higher feed due to reduction of chip thickness, results in degradation of surface finish. Additionally, effect of tool wear on surface roughness has been studied. The experimental data were further analyzed to predict the optimal range of surface roughness and flank wear. Finally, based on response surface methodology (RSM) mathematical models are developed for surface roughness (R*a*, Rq and Rz) and flank wear (VB) with 95% confidence level. Effectiveness, adequacy, statistical significance and validity, and fit of data of the developed model has been checked using ANOVA analysis (depending on P value, F value and R^2 value), Anderson–Darling test and normal probability plot. The proposed experimental and statistical techniques initiate authentic methodologies to optimize, model and improve the hard turning process, which can be prolonged effectively to analyse other machining processes.

1. Introduction

Manufactures ultimate aim is to manufacture high quality product with a reduction of cost and time constraints in the highly competitive machining industries. To meet this challenge, in recent past hard turning has been established as an effective and emerging metal cutting process of steel with hardness above 45 HRC, which is explored as profitable alternative to cylindrical grinding because of reduced setup time, greater process flexibility, increased productivity, reduced power consumption, lower production costs, improved surface

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Notation

v	cutting speed (m/min)	ANOVA	analysis of variance
f	feed (mm/rev)	RSM	response surface methodology
d	depth of cut (mm)	BUE	build-up-edge
Ra	average surface roughness (μm)	CBN	cubic boron nitride
Rq	root mean square roughness (μm)	DF	degree of freedom
Rz	maximum peak-to-valley height (μm)	Seq SS	sequential sum of squares
V_{error}	error variance	Adj SS	adjusted sum of squares
AISI	american iron and steel institute	Adj MS	adjusted mean of squares
CNC	computerized numerical control	F	variance ratio
CCD	central composite design	P	statistical parameter
PVD	physical vapor deposition	N	number of experimental tests
CVD	chemical vapor deposition	R^2	coefficient of determination
HRC	Rockwell hardness	CI	confidence interval
OA	orthogonal array	η_{eff}	effective number of replications

integrity and insignificant environment disputes exclusion of cutting fluid [1–4].

Surface roughness and tool wear are classified among the most important aspects in hard turning. Because surface roughness affects the corrosion resistance, fatigue strength, wear rate and tribological properties of machined parts whereas, tool wear affects dimensional accuracy of the finished product, surface finish, residual stress, surface integrity (white layer) and tool life. Since tool wear changes the surface quality enhancement, recent development has provided coated ceramic tool which has improved the properties like thermal shock resistance, fracture strength, toughness and hardness in order to obtain less tool wear. Many experimental research works have been executed to consider the performance of coated ceramic tool during the turning of different hardened steels. Davim and Figueira [5] assessed the effect of wiper inserts by comparing with traditional inserts on machinability parameters such as surface roughness, tool wear and cutting forces in turning AISI D2 hardened steel. It was noticed that, wiper ceramic accomplished more competently concerning to surface finish (Ra < 0.8 μm) and tool wear compare to traditional ceramic, which exhibits that hard turning is a profitable replacement of cylindrical grinding operation. In the similar way, machinability of hardened AISI 52100 steel (63 HRC) with regard to tool wear, tool life and surface finish of the workpiece and the performance of Al_2O_3/TiCN mixed ceramic tools coated with TiN were evaluated by Aslantas et al. [6]. Gaitonde et al. [7] reported that the performance of wiper ceramic insert is better as compared to conventional ceramic insert with response to surface roughness and tool wear during hard turning of AISI D2 steel. Recently, Karpuschewski et al. [8] evaluated the performance of uncoated and PVD TiN coated ceramic inserts in hard turning and their outcomes were associated to machined work surface and tool edges as well as expenditure related to tool insert price and tool life. The outcomes showed that, coated tool edge reduces machining cost as well as improved surface finish.

In hard turning, there are various factors which affect the tool wear and surface roughness for example: tool variables (nose radius, cutting edge geometry, rake angle, tool point angle, tool materials, tool overhang, etc.), workpiece variables (material and hardness) and cutting conditions (cutting speed, feed rate and depth of cut). Successful implementation of hard turning is essential to select most suitable machining conditions for to appreciate cutting efficiency and develop high-quality machined parts at minimum processing cost. The techniques used for optimizing process parameters by means of experimental procedures and mathematical (statistical) models have increased considerably with time to accomplish a general objective of enhancing productivity and advancing cutting process efficiency.

2. Literature review

Several experimental studies have been executed in order to determine the influence of various process parameters on surface roughness, tool wear and cutting forces using different workpieces in hard turning. The following section relates to study of chip morphology, assessment, modeling and optimization of responses by varying process parameters (cutting parameters, workpiece hardness, tool geometry, tool materials and tool vibrations) which have been reported. Aslan et al. [9] applied Taguchi technique and analysis of variance to explain the effects of cutting parameters for optimizing flank wear and surface roughness when machining a AISI 4140 grade hardened (63 HRC) steel using mixed ceramic inserts. Their results explained, flank wear (VB) value reduced because of the cutting speed increased. On the other hand, the surface finish was improved as cutting speed was elevated and impaired with feed. Boucha et al. [10] experimentally investigated the impact of machining parameters (i.e. cutting speed, feed rate and depth of cut) on the cutting forces and surface roughness during hard turning of AISI 52100 bearing steel (64 HRC) with CBN tool using RSM. Results showed that depth of cut exhibited the most significant role on the cutting force components and surface roughness is largely influenced by feed rate. Later, Asilturk and Akkus [11] observed that feed rate was the highest influential cutting parameter for surface roughness (Ra and Rz) in turning AISI 4140 steel hardened at 51 HRC with Al_2O_3 and