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ORIGINAL ARTICLE

Investigations on surface quality characteristics with multi-response parametric optimization and correlations

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Abstract This paper presents the parametric optimization on surface quality characteristics (Ra, Rz and Rt) in hard turning of EN31 steel using multilayer coated carbide insert (TiN/TiCN/Al_2O_3) and also finds correlations. The experiments have been conducted based on Taguchi's L_9 orthogonal array. Multiple linear regression analysis has been utilized to find the correlations. The integrated multi-response optimization approach using CQL concept in WPCA coupled with Taguchi technique has been implemented. Based on the S/N ratio, the optimal process parameters for surface roughness i.e. Ra and Rz are the depth of cut at level 3 (0.5 mm), the cutting speed at level 3 (140 m/min), and the feed at level 1 (0.04 mm/rev). The optimal process parameters for Rt are found to be the depth of cut at level 3 (0.5 mm), the cutting speed at level 2 (100 m/min), and the feed at level 1 (0.04 mm/rev). Feed and depth of cut are found to be the significant cutting parameters affecting the responses at 95% confidence limit from ANOVA study. The first order model presented high correlation coefficient between the experimental and predicted values. The optimal parametric combination for multi-response (Ra, Rz and Rt) becomes *d*3–*v*3–*f*1 and is greatly improved.

1. Introduction

Due to the development of newer engineering materials and targets to obtain higher productivity with good surface quality, the research in the area of cutting tool materials is continuing. The essential requirements or desirable properties for cutting tool materials include high hardness, high hot-hardness, high mechanical strength, stiffness and transverse rupture strength (TRS), high fracture toughness, chemical stability, high fatigue resistance, high heat resistance, high thermal shock resistance, adequate lubricity, resistance to adhesion and diffusion respectively. The thermal conductivity property of the tool material should be low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered. High performance in all of these attributes simultaneously is generally not possible. The variation in the requirement of thermal conductivity has caught the attention of researchers for development of coated carbide tools. This has brought a revolution in metal

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cutting industry over last 30 years and developed bilayer and multilayer coated carbide inserts.

Nowadays, hardened steels about 60 HRC are successfully machined by both mixed ceramic and CBN tools and slowly replace traditional grinding operations. The main advantages of hard turning include reduction of manufacturing cycles and costs, decrease of setup time, reduction of number of necessary machine tools, achievement of comparable surface finish, elimination of part distortion caused by heat treatment, elimination of environmentally harmful coolant, low capital investment cost and low energy consumption [1]. Despite the high potential of hard machining with respect to time, cost and environment, industrial application of this technology is still limited. This is due to the uncertainties related to the surface integrity, part accuracy and economical feasibility. Considering these challenges, research in field of hard turning will definitely be worthwhile.

2. Literature review and objectives

2.1. Performance of coated carbide, ceramic and CBN insert in hard machining

Rech [2] studied various uncoated and coated carbide inserts such as PVD TiN, TiAlN and TiAlN + MoS_2 and its tribological performance during machining. The TiN and (Ti,Al)N + MoS_2 coatings were observed to be best for enhancement of tribological characteristics compared to uncoated carbide tools i.e. reduction of the tool-chip contact area, reduction of secondary shear zone thickness and of the interface temperature during the machining of 27MnCr5 steels. Lim et al. [3] revealed that coating on cutting tool surface provides higher crater wear resistance at high cutting speed and feed. Reduction of tool wear has been observed for TiN coated HSS tool than uncoated tool in turning hot rolled medium carbon steel. Gökkaya and Nalbant [4] studied various coated and uncoated carbide insert in dry turning AISI 1015 steel. The result revealed that lower surface roughness was obtained using CVD multilayer coated tool outermost with TiN compared to uncoated, coated with AlTiN and coated with TiAlN using the PVD technique. Wang [5] observed that marginal reduction of cutting force occurred during turning mild steel with the use of multilayer hard surface coatings CVD (TiC + Al_2O_3 + TiN) compared to uncoated carbide insert. Grzesik and Zalisz [6] observed that abrasion, fracture, plastic flow, material transfer and tribochemical effects involved in dry hard machining of AISI 5140 steel (60 HRC) using mixed ceramic insert. Singh and Rao [7] found that feed rate is the significant factor for surface roughness followed by nose radius and cutting velocity during finish hard turning of AISI 52100 steel using mixed ceramic inserts (Al_2O_3 + TiCN). Yusof et al. [8] compared the machining performance of wiper coated ceramic tool (TiN coating with mixed Al_2O_3/TiCN substrate) and conventional ceramic for D2 steel (54–55 HRC). Wiper tool provides slightly shorter tool life but with good finer surface finish compared to conventional tool. Paiva et al. [9] performed hard turning of AISI 52100 steel using TiN coated mixed ceramic tool (Al_2O_3 + TiC). Parametric conditions such as cutting speed of approximately 238 m/min, feed rate of 0.08 mm/rev and depth of cut of 0.32 mm provide maximum material removal rate with good surface quality during machining. Gaitonde et al. [10] experimentally observed that TiN coated wiper ceramic insert (Al_2O_3 + TiC) performed better in context to surface roughness and tool wear, while the conventional ceramic insert was beneficial in decreasing the machining force, power and specific cutting force during hard turning of D2 steel (59–61 HRC). Zhang et al. [11] investigated the surface integrity of hardened bearing steel (62–63 HRC) using CBN insert and superior surface integrity was generated. For surface roughness, feed rate was found to be the most influencing impact in machining. Özel et al. [12] studied on hard turning of AISI H13 hot work tool steel (55 HRC) using CBN inserts. For surface roughness, workpiece hardness, cutting edge geometry, feed rate and cutting speed were found to be statistically significant. Particularly, honed edge geometry and lower workpiece surface hardness yield better surface roughness, lower tangential and radial forces during machining. Jacobson [13] studied the surface integrity aspects during hard turning of M50 steels (61 HRC) using ceramic and CBN insert. Effective rake angle and tool nose radius influence on residual stress. Higher negative rake angle and smaller nose radius create a more compressive residual stress profile. The hot pressed ceramic produced a better surface than the whisker ceramic. Yallese et al. [14] investigated on hard turning of X200Cr12 steel (60 HRC) using ceramic and CBN insert and 180 m/min cutting speed was found to be limiting factor for both inserts. CBN tool induced lower surface roughness than ceramic insert under limiting criteria of wear. The recommended optimal cutting speed was observed to be 120 m/min implementing CBN tool and 60 m/min cutting speed for ceramic insert respectively. Sahoo and Sahoo [15] studied some comparative performance of uncoated and outer multilayer TiN and ZrCN coated carbide insert during hard machining of AISI 4340 steel and also economically justified.

2.2. Optimization and modeling aspects in machining

Noordin et al. [16] performed turning operation of AISI 1045 steel (187 BHN) using multilayer coated carbide insert (TiCN/Al_2O_3/TiN) of two types i.e. CNMG120408-FN and TNMG120408-FN through Central composite design (CCD) and response surface methodology (RSM). Most significant factor for surface roughness and the tangential force is observed to be feed during analysis. Risbood et al. [17] studied during turning operation using TiN coated tools and revealed that neural network model sufficiently predicts the surface finish with reasonable degree of accuracy. Suresh et al. [18] performed turning operation of mild steel workpiece using TiN coated carbide inserts and developed surface roughness prediction model through RSM. Experimental findings revealed that surface roughness decreases with an increase of cutting speed and increased as feed increases. Surface roughness increases as the depth of cut and nose radius increases. Using genetic algorithm (GA) technique, optimal machining condition was obtained. Davim [19] studied machining operation using carbide insert on surface roughness using Taguchi method and found a correlation with multiple linear regression analysis. Study concluded that cutting speed and interaction between cutting speed/feed had the higher impact on surface roughness followed by feed. Depth of cut did not show significance on surface roughness. Dabnun et al. [20] conducted dry machining