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Comparative evaluation of performances of TiAlN, AlCrN, TiAlN/AlCrN coated carbide cutting tools and uncoated carbide cutting tools on turning Inconel 825 alloy using Grey Relational Analysis

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ABSTRACT

This study evaluates the machining performance of nanostructured Titanium Aluminium Nitride (TiAlN), Aluminium Chromium Nitride (AlCrN) and TiAlN/AlCrN bilayer coated and uncoated carbide tools used for machining Inconel 825 alloy. Taguchi's L9 orthogonal experimental design was used in the turning operation by fixing machining parameters namely, cutting speed (v), feed rate (f) and depth of cut (d) at different levels. Taguchi's Response Graph (TRG), Analysis of Variance (ANOVA) and Grey Relational Analysis (GRA) were used for examining the effects of machining parameters and their contributions to the cutting force, tool wear and surface roughness. The optimal cutting parameters were evaluated for "Smaller-the-Better" (STB) quality characteristic of all the three output responses. The GRA results, show AlCrN and TiAlN/AlCrN coated tool having obtained high Grey Relational Grade (GRG) at L1 trial when v = 50 m/min, f = 0.14 mm/rev and d = 0.15 mm. The TiAlN coated tool and uncoated tool obtained high GRG at v = 100 m/min, f = 0.25 mm/rev and d = 0.15 mm for L8 trial. The feed rate showed a high percentage contribution, followed by the depth of cut and cutting speed for TiAlN and AlCrN coated cutting tools based on the ANOVA obtained for GRG values. But, the TiAlN/AlCrN coated and uncoated tool have shown the depth of cut obtaining a high percentage contribution followed by feed rate and cutting speed based on ANOVA obtained for GRG results. Machining studies show a better performance of the TiAlN/AlCrN bi-layer coated tool when compared to TiAlN, AlCrN coated and uncoated carbide tool for machining Inconel 825 alloy.

1. Introduction

Aircraft and nuclear industries have witnessed increasing use of Inconel alloys in recent years because of its numerous beneficial properties such as excellent corrosion resistance, high strength and greater wear resistance. Inconel alloys are considered as difficult to machine materials due to their high mechanical properties [1,2]. During the machining of Inconel alloys, the cutting tool is subjected to severe thermal and mechanical loads near the cutting edge, causing earliy tool failure. Many researchers have attempted to improve the machinability of Inconel alloys for overcoming these issues by using advanced tool materials including coated carbide inserts, new cutting fluids, hybrid machining, and process optimization [3,4]. Cemented carbide tools are used mostly as cutting tool materials for machining hard materials. But, the high tool wear of cemented carbide tools during machining of hard materials makes the process uneconomical. The production of cutting tool with different hard coating is emerging for the machining of hard materials for meeting high productivity and high precision [5,6]. These hard coating possesses have very attractive properties such as high temperature stability and greater wear resistance. Therefore, the development of suitable coatings on cutting tools for machining of hard materials is the prime concern for cutting tool manufacturers. However, conventional hard ceramic coatings, such as nitrides, carbides, borides, and oxides (TiN, TiC, TiB2 and TiO2) are not capable of retaining all the required properties under critical working conditions. Researchers have been continuously striving to develop new composite multi-layer coating materials for overcoming these problems and to achieve combined advantages [7].

Experimental investigation using physical vapour deposition (PVD)-TiAlN coated and uncoated carbide tools under different

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Table 1
Chemical Composition of Inconel 825 (%wt).

C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**
0.026	0.340	0.720	0.0170	0.0047	20.630	3.050	40.030
Al	**Co**	**Cu**	**Nb**	**Ti**	**V**	**W**	**Fe**
0.0430	0.1300	2.0500	0.0440	0.7600	0.0025	0.0020	balance

machining environments was done on Inconel alloy. The results showed the performance of coated carbide tool as good with reasonable tool life at low and moderate cutting velocities [8,9]. Shuho koseki et al., studied the performance of PVD-TiN coated carbide tools during the turning operation on Inconel 718 under dry condition. The results indicated the significant influence of the depth of cut on tool wear in terms of crater wear, flank wear, nose wear and notch wear. The worn cutting tools indicate different types of wear mechanisms such as abrasion, attrition, and adhesion wear. During the initial stage, the tool wear increased rapidly due to the chip welded as built-up-edge (BUE) at the nose edge of the tool and almost at the end of the tool life, with the occurrence of severe chipping at the nose edge [2]. Shuho koseki et al., studied the wear mechanism of PVD coated carbide tool for machining Ti-6Al-4 V material. The damage rate of the TiN coated tool was higher in the rake face due to the brittle fracture at the early stage of machining [3]. Sampath kumar et al., studied the performance of TiAlN, AlCrN, and TiAlN/AlCrN coated carbide tools and compared it with that of uncoated tools by carrying out machining trials on EN24 steel material. The TiAlN/AlCrN coated tool had only a minimum tool wear, cutting force and surface roughness when compared to other coated and uncoated tools. [10]. During machining of Inconel 718 using TiAlN/TiN bilayer coated carbide cutting tool, decrease in flank wear and cutting force components, and increase in chip breakability which in turn improved surface finish under high pressure cooling were observed [11]. Amini et al. investigated the performance of ceramic and carbide tools on machining Inconel 718. The predominance of the cutting speed and the feed rate was seen in determining the surface roughness than the depth of cut. Ceramic tools outperformed the carbide tool in achieving better surface finish at a higher cutting velocity [12].

Literature has instances of a better importance for the coated carbide tools in machining of hard materials than uncoated tools in terms of better machinability. The development of PVD coating on carbide cutting tool has been seen an attractive area of research. The focus of this work is the evaluation of the performance of PVD coated TiAlN, AlCrN and TiAlN/AlCrN carbide tools in comparison with uncoated carbide tools during machining of Inconel 825 alloy.

2. Materials and methods

Inconel 825 alloy of solid cylindrical bar of 30 mm diameter and 400 mm length was used as the work piece material. The chemical composition of Inconel 825 alloy is given in Table 1. CNC lathe machine (Make: ACE Micromatic Simple Turn 5075-SPM) in a dry environment was used for conducting the experiments. The experimental trials were planned on the basis of Taguchi's design of experiments (L_9) as shown in Table 2. A triangular insert (60°) with a clearance angle of 7° and corner radius 0.8 mm was used as a cutting tool insert. The ISO specifications of cutting tool insert and cutting tool holder are TNMA 160,408 and MTGNR2525M16 respectively. In the present investigation, TiAlN, AlCrN and TiAlN (Top layer)/AlCrN (Bottom layer) bilayer coatings were deposited on the K10 tungsten carbide cutting tool inserts, using the PVD under cathodic arc vapour deposition process in a Balzer's Oerlikon coating machine, Make - Oerlikon Balzers Ltd., India. During the coating process current, substrate temperature, voltage and deposition pressure were maintained at 80 A, 450° C, 200 V and 4.5 E-4 bar respectively.

Table 2
L_9 orthogonal array for experimental trials.

Experiment Trials	**Cutting Speed (m/min)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**
L1	V1	f1	d1
L2	V1	f2	d2
L3	V1	f3	d3
L4	V2	f1	d2
L5	V2	f2	d3
L6	V2	f3	d1
L7	V3	f1	d3
L8	V3	f2	d1
L9	V3	f3	d2

Table 3
Design of experiments for the present study.

FACTORS	Unit	LEVELS		
		1	2	3
Cutting speed	m/min	v1 = 50	v2 = 75	v3 = 100
Feed rate	mm/rev	f1 = 0.14	f2 = 0.25	f3 = 0.4
Depth of cut	mm	d1 = 0.15	d2 = 0.35	d3 = 0.55

Hardness was measured using the nanoindentation-Oliver and Pharr method while the adhesive strength was measured using the scratch test-ASTM-C1624–05. The measured hardness value and adhesive strength of the TiAlN/AlCrN coating were 33 GPa and 45.5 N respectively. The hardness measured for TiAlN and AlCrN coatings were 26.76 GPa and 31.26 GPa respectively. The adhesive strength of TiAlN and AlCrN coatings were 41.5 N and 45 N respectively. The higher hardness value in the coating was due to the smaller crystallite size, which ranged from 30 nm to 50 nm, and a dense structure of the coating. The developed TiAlN/AlCrN coating showed better hardness value and adhesive strength, compared to monolayer coatings such as TiAlN and AlCrN respectively. The surface roughness value of the TiAlN/AlCrN bilayer coated insert measured using AFM, showed the value as 120 nm, when compared to the conventional monolayer coatings such as TiAlN (258.20 nm) and AlCrN (255.45 nm). This was due to a smaller number of surface irregularities and pits. The variations in surface roughness of cutting tool were due to differences in coating elements, coating process parameters and disorientation of grains/droplets [13]. The total machining length was taken as 200 mm. The factors and their levels for the design of experiments are listed in Table 3. The experimental trials were conducted for the evaluation of the coating performance on machinability based on the tool wear, cutting force, surface roughness and chip formation. An optical microscope (i.e., 50X to 1500X magnification) equipped with Image Analysis Software was used for measuring tool wear, and a surface roughness tester (Mahrsurf GD 120) was used for measuring the surface roughness of the workpiece. The machining forces such as feed force (Fx), radial (or) thrust force (Fy) and cutting force (Fz) were measured using a Kistler force dynamometer. The schematic representation of force components is shown in Fig. 1. The effect of cutting parameters were analysed and optimized using grey relational analysis (GRA) for the cutting force, tool wear and surface roughness of the workpiece.