PERFORMANCE EVALUATION OF CVD MULTILAYER COATING ON TOOL WEAR CHARACTERISTICS DURING DRY MACHINING OF NIMONIC C-263

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Abstract

Nimonic C-263 is one of most popularly used nickel-based superalloys particularly used in the field of hot section part of gas turbines, aerospace, power generators and heat exchangers. It is categorized under difficult-to-cut material because of its unique propertysuch as high hardness, fatigue strength, low thermal conductivity, high chemical affinity and tensile strength along with resistant to corrosion & oxidation. Machinabilitycan be improved with proper selection of cutting tool and cutting parameters. The present paper deals with comparative analysis of tool wear and chip characteristics when machining Nimonic C-263 with uncoated and multilayer coated carbide inserts. Dry turning operation was carried out at two different cutting speeds (51 m/min and 84 m/min) with a constant feed (f) of 0.2 mm/rev and depth of cut (t) of 1 mm. Chip reduction coefficient (ζ) and tool wear were observed during dry machining of Nimonic C-263. It was found that chip reduction coefficient decreased with increase in machining duration and cutting speed. Whereas flank wear increased with machining duration for both uncoated and coated carbide inserts. However, uncoated tool failed only after 90second (s) of machining at a cutting speed of 84 m/min, whereas machining was still possible with CVD multilayer coated tool after 120 s of machining duration.

*Keywords:*Nimonic C-263, CVD coated carbide, Chip reduction coefficient, Tool wear.

1 Introduction

In the recent years, nickel-based super alloys have assumed considerable research interest owing to their wide engineering applications particularly in strategic environment. The superior mechanical properties at elevated temperature such as high them very much suitable for to be used in highly corrosive and oxidized environment at elevated temperature hardness, fatigue strength and tensile strength along with resistant to corrosion & oxidation makes these alloys to be used in the field of aerospace, power plant, marine, defence and nuclear sectors (Arunachalam&Mannan (2000), Choudhury and El-Baradie (1998)). The property which makes nickel-based super alloys suitable for so many applications also hampers its machinibility and hence they are termed as difficult-to-cut material. Nimonic C-263 is one such alloy belonging to the family of nickel-based super alloy. Ezugwu and Okeke (2002) statedthat the higher content of Co and Cr with nearly Fe free makesthem very much suitable for highly corrosive and oxidized environment at elevated temperature. Ezilarasan*et al.*(2013) observed that the Nimonic C-263 is to be widely used in the hot section part of gas turbines, aerospace, power generators and heat exchangers. However, being a nickel-based alloy, Nimonic C-263 is very difficult to machine primarily due to its low thermal conductivity and work hardening tendency. The industryfaces a huge challenge ahead of them to machine these alloys, so judicious selection of cutting parameters is required to improve both productivity and quality in these sectors.

Tool wear is most commonly and popularly used criteria to access the machinability. Right selection of tool is very much necessary for the tool performance. Ezugwu*et al.* (1998) analyzed the ability of carbide tool to withstand high temperature generated makes it preferable to machine nickel-based superalloys.Ezugwu et al. (2004), Podder and Paul (2012) observed that flank wear, chipping and catastrophic failure to be most dominating tool failure modes.Ezilarasan*etal.*(2013) made use more advanced cutting tools such as whisker reinforced ceramic inserts for machining nickel-based superalloy at high speeds. Development of new coating technique and different coating layers has also enhanced the tool performance. Ezugwu and Okeke (2000a) investigated a comparative study of PVD coated (TiN/TiCN/TiN, TiAlN and TiZrN) and uncoated carbide tools in terms of tool life. Multilayer coated tool outperformed the others particularly at cutting speed of 68 m/min for different range of depth of cuts (0.635, 1.25 and 2.54 mm) and at a constant feed of 0.076 mm/rev.

Comparable tool life was obtained when machined Nimonic C-263 with single layer TiAlN coated carbide inserts and multi-layer TiN/TiCN/TiN coated insert at lower cutting speed of 54 m/min. The higher thermal conductivity, hardness and friction coefficient of single layer TiAlN coated insert resulted in better tool life than that of multilayer at lower depth of cut of less than 1.25 mm. Ezugwu and Okeke (2002) observed thicker layer of multilayer coated tools provided high resistance to wear at high cutting speed of 68 m/min and at depth of cut 2.54 mm, hence outperforming single layer coated inserts.Cutting parameters and tool geometry do have great influence on tool performance. Multi-layer TiN/TiCN/TiN coated carbide insert with positive, chamfered and honed edges performed better in terms of tool life than that with similar tool having no edge protection and double positive edges.

Feed rate was found to have more influence on the tool life. Ezugwu and Okeke (2000b) observed that the tool wear rate was reduced at lower feed rate while it showed an increased trend with increase in depth of cut and as well cutting speed. Ezugwu and Okeke 2002 reported in an investigation thatthe cutting speed had greater impact on tool life than that of depth of cut. Ezugwu*et al.*(2004) found that the tool wear increased with increase in the cutting speed. Ezilarasan et al. (2013) in an experimentally investigation found the tool life to be lower at medium cutting speed and lower value of depth of cut as well feed rate when machining Nimonic C-263 with whisker reinforced ceramic inserts. Feed rate was found to be most dominating factor followed by depth of cut and cutting speed. The flank wear increased with increase in both feed rate and depth of cut.

While significant research work has been carried out with varying cutting conditions and using different coated tools on machining of Inconel alloys, very less work has been reported on the effectiveness of chemical vapour deposition (CVD) coating during machining of Nimonic C-263 alloy. Therefore, the objective of the current study is to investigate the capability of CVD multilayer coated (TiN/TiCN/Al_2O_3/ZrCN) cemented carbide (ISO P30 grade) inserts and the influence of cutting speed on tool wear mechanism with comparison to uncoated carbide inserts. Dry machining was performed at constant feed of 0.2 mm/rev and depth of cut of 1mm.

2 Experimental detail

A heavy duty lathe machine (MAKE: HMT Ltd., India and model: NH26) was used for the purpose of conducting experiment. A round bar of Nimonic C-263 with 60 mm diameter and 180 mm length was used as workpiece.Figure 1 shows photographic view of experimental setup for dry turning of Nimonic C-263.

Figure 1 Photograph of experimental setup for turning Nimonic C-263

Chemical composition of Nimonic C-263 is provided in Table 1 and corresponding energy dispersive spectrum (EDS) is given in Figure 2 in order to verify the composition. The turning operation was carried out with two different cutting speeds i.e. 51 and 84m/min with a constant feed (f) of 0.2 mm/rev and depth of cut (t) of 1 mm. The performance of uncoated ISO P30 grade cemented carbide insert was compared with that of multilayer coated insert with CVD deposited multilayer coating consisting of TiN/TiCN/Al_2O_3/ZrCNarranged from the substrate to top layer. Owing to its excellent toughness and anti-friction properties, ZrCN is used as a top layer. Both uncoated and coated inserts were commercially available tools (Make: Widia, India) with ISO insert designation of SCMT 120408. A tool holder with ISO designation of SSBCR2020K12 (Kennametal, India) was used for both uncoated and coated tools.

Table 1 Chemical composition of Nimonic C-263

Element	Ni	Cr	Mo	Co	Ti	Al
Weight %	54	18-21	2.5-3.5	15-21	2-3	1-2

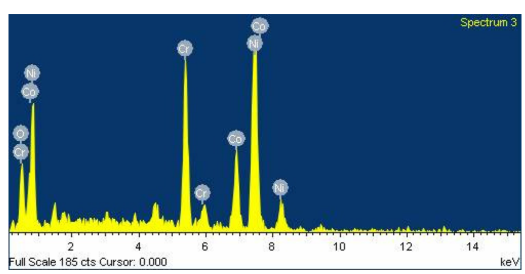


Figure 2 EDS spectrum of as received Nimonic C-263

The chip morphology and conditions of the tool after machining were analysed by a scanning electron microscopy (SEM, Make: JEOL JSM-6490). Stereo zoom microscope (Make: Radical Instruments) was used to measure the flank wear of tools after each machining conditions.

3 Results and discussion

3.1 Chip reduction coefficient

The cutting parameters have a vital role to play on the chip reduction coefficient. Figure 3 shows the effect of machining duration and cutting speed on chip reduction coefficient during dry turning of Nimonic C-263 by both uncoated and coated cemented carbide inserts, at a constant feed rate of 0.2 mm/rev and 1 mm depth of cut. Chip reduction coefficient has direct association with chip-tool interface friction and tool wear. It is evident that chip reduction coefficient decreased with increase machining duration at both cutting speed. This decrease in chip reduction coefficient can be attributed to the gradual exposure of anti-friction coating materials like TiN (intermediate layer) and also gradual removal of built-up layer with the progression of machining duration. A decrease in the chip reduction coefficient was observed when cutting speed was increased from 51 m/min to 84 m/min due to decrease in the chip thickness. Similarkind of observations was reported by(Thakur *et al.*, 2009b).

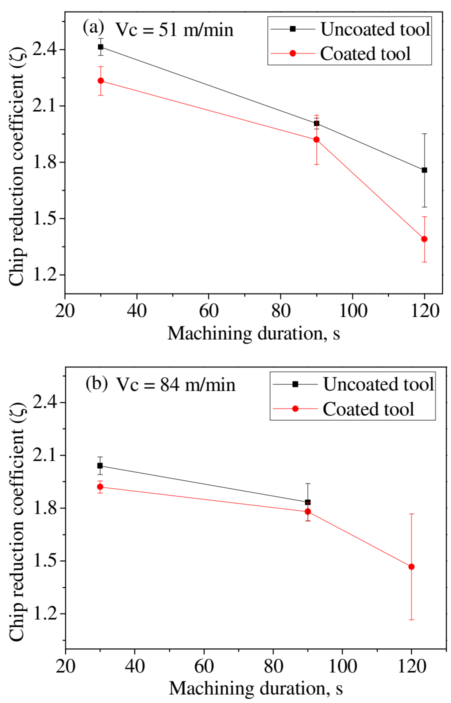


Figure 3 Variation of chip reduction coefficient with machining duration using uncoated and coated carbideinserts with cutting speed of (a) 51 m/min and (b) 84 m/min

3.2 Tool wear

Tool wear characterised by crater and flank wear was investigated using optical microscopy and SEM after dry machining of Nimonic C-263 with both uncoated and coated carbide inserts. Figure 4shows the optical microscopic images of flank surface depicting the growth of wear at the flank surface of the uncoated and coated carbide inserts as the machining duration progresses and for two different cutting speeds. It is obvious from the figure that with increase in both cutting speed and machining duration the flank wear increases.

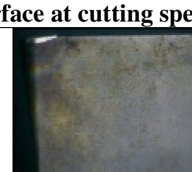
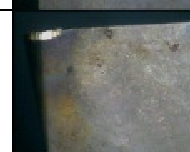
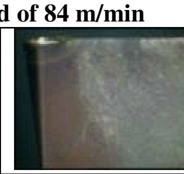
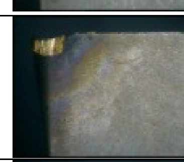
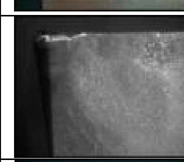
Machining Duration, s	Uncoated tool	Coated tool
Flank surface at cutting speed of 51 m/min		
30		
90		
120		
Flank surface at cutting speed of 84 m/min		
30		
90		
120		

Figure4 Optical microscope images of flank surface (With 20X magnification) of uncoated and coated inserts with progression of machining duration and variable cutting speed at constant feed of 0.2 mm/rev and depth of cut of 1 mm.

Figure 5 shows the variation of flank wear with machining duration of Nimonic C-263 for uncoated and coated inserts during machining with the cutting speed of 51 and 84 m/mingraphically. Uncoated tool failed at cutting speed of 84 m/min after machining duration of 90 s whereas machining was still possible after 120 s of machining with coated tool. However, both toolperformed well while machining with a cutting speed of 51 m/min.It was also noticed that CVD multilayer coated tool have less value of tool wear than its counterpart uncoated tool. The higherresistance to wear of different layers of CVD coated carbide insert resulted in better tool wear characteristics than that of uncoated carbide insert.

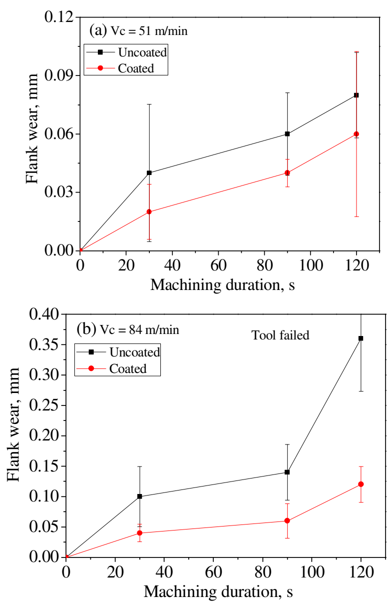
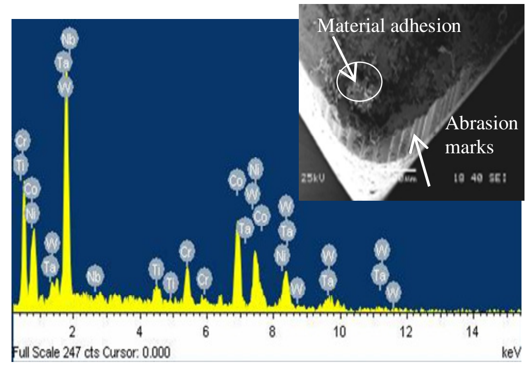
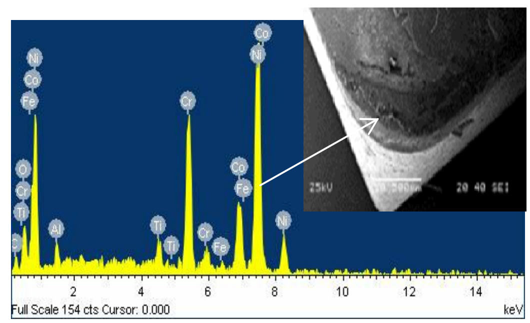


Figure 5 Variation of flank wear with machining duration during dry turning of Nimonic C-263 with uncoated and coated inserts using cutting speed of (a) 51m/minand (b) 84m/min

Figure 6 shows EDS spectra and SEM images of rake surface of both uncoated and coated carbide inserts after machining with a cutting speed of 84 m/min for machining duration of 30s. Deep crater (on the rake face) and high abrasion wear (on flank surface) were observed for the uncoated tool. Both types of wear could be restricted using CVD multilayer coated tool due to higher hardness, thermal stability combined with anti-friction propertiesof different layers of coatings. The EDS pattern confirms transfer of some of the elements of workpiece such as Ni, Cr, Ti and Co.



(a)



(b)

Figure 6EDS spectrum and corresponding SEM image of rake surface at Vc= 84 m/min after 30 s(second) of machining duration with (a) uncoated and (b) coated inserts

4 Conclusions

The current research work investigated the effect of cutting speed and tool coating on chip characteristics and tool wear during dry machining of Nimonic C-263. From this study, following conclusions may be drawn:

1. Chip reduction coefficient decreased with increase in machining duration and cutting speed.
2. Flank wear increased with machining duration for both uncoated and coated carbide inserts. However, uncoated tool failed after 90 s of machining at cutting speed of 84 m/min.
3. Tool wear during dry machining of Nimonic C-263 was characterised by adhesion and diffusion.The average flankwear increased with both cutting speed as well as machining duration.
4. The multilayer coating consisting of $TiN/TiCN/Al_2O_3/ZrCN$ plays a major role in improving resistance to wear particularly at higher cutting velocity.
5. From results it can be concluded that uncoated tool ISO P30 grade is not recommended for cutting speed higher than 51 m/min,whereas CVD multilayer coated inserts performed well within the range of cutting speed of 51-84 m/min with constant feed of 0.2 mm/rev and depth of cut of 1 mm.

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