

# Flank wear measurement of INCONEL 825 Using CVD and PVD carbide tools

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**Abstract:** In order to have elementary knowledge on machinability characteristics of Incoloy 825 which was so far unknown, in the initial stage of experiment, tool wear and its mechanism, chip characteristics and surface integrity during dry machining were first studied using uncoated and chemical vapour deposition (CVD) multilayer TiN/TiCN/Al<sub>2</sub>O<sub>3</sub>/ZrCN coated tool with different cutting speeds. The coated tool could not improve surface finish, but outperformed its uncoated counterpart in terms of other aspects. In the second stage of the study, the primary objective was to recommend suitable cutting tool for machining Incoloy 825. Detailed study was undertaken using commercially available uncoated, CVD and physical vapour deposition (PVD) coated carbide tools, the performance of which was comparatively evaluated in terms of surface roughness, cutting temperature, cutting force, coefficient of friction, tool wear and its mechanism during dry machining. Effect of cutting speed ( $V_c$ ) and feed ( $f$ ) was also studied. Although, CVD coated tool was not useful in decreasing surface roughness and temperature compared to uncoated one, significant decrease in cutting force and tool wear could be achieved with the same coated tool even under high cutting parameters. On the other hand, PVD coated tool consisting of alternate layers of TiAlN/TiN outperformed the other tools in terms of all machinability characteristics that have been studied. This might be attributed to excellent anti-friction and anti-sticking property of TiN and good toughness which is a salient feature of PVD technique as well as multilayer configuration, in combination with thermally resistant TiAlN phase. [1]

**Keywords:** Tool wear; machining; Inconel 825; PVD;CVD;

## 1. INTRODUCTION:

Worldwide recent research work is focused on development of advanced strategies for machining of nickel-based super alloys, so that superior surface quality can be achieved while maintaining reasonably high productivity and at the same time environmental

load can be curtailed. In order to accomplish these objectives, through understanding of the mechanical properties of different grades of nickel-based super alloys along with their chemical composition is essential. Recent research work is focused on development of advanced strategies for machining of nickel-based super alloys, so that superior surface quality can be achieved while maintaining reasonably high productivity and at the same time environmental load can be curtailed. In order to accomplish these objectives, through understanding of the mechanical properties of different grades of nickel-based super alloys along with their chemical composition is essential

### 1.1 Tool wear

Tool wear describes the gradual failure of cutting tools due to regular operation. It is a term often associated with tipped tools, tool bits, or drill bits that are used with machine tools.

### 1.2 Tool Geometry

A single point cutting tool is widely used in metal cutting industries for forming required shape. It is used on lathe and shaper machining for performing operation like turning, facing, chamfering, boring shaping etc. This cutting tool has a single cutting point which cut the work piece by rubbing over it.[15]

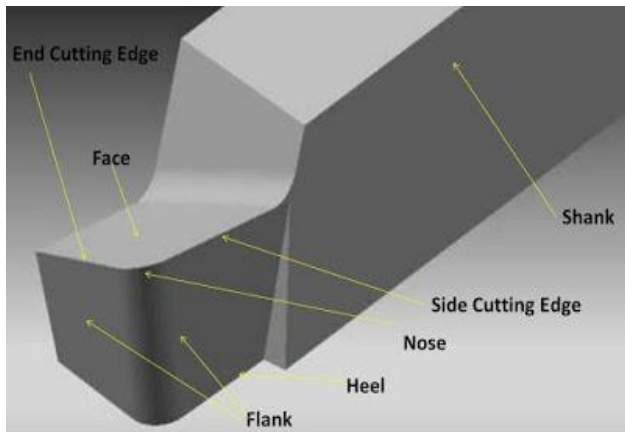


Fig.No.1[15]

### 1.3 Workpiece Material

Inconel 825 is a precipitation-hardenable nickel-chromium-iron alloy, and its chemical composition is given in Table 1.1.

Table 1.1 Chemical composition of Inconel 825.

Element	Ni	Fe	Cr	Mo	Cu	Ti
Content	45.9	25.6	19.9	3.26	1.53	2.60
%	4	2	4			

### 1.4 Nickel-based super alloys

The major advantages of nickel-based super alloys include their resistance to thermal deformation and corrosion. Iron, chromium and cobalt are typically used as major alloying elements. In addition to these, other elements such as molybdenum, niobium, copper, titanium, aluminium and tungsten along with small quantity of carbon, magnesium, zirconium etc. are present in different grades of nickel-based super alloys. Inconel 825 possesses excellent combination of different properties such as high mechanical strength, resistance to oxidation and corrosion at elevated temperature, good precipitation hardening ability and remarkable capability to withstand chemical attack especially under sulphuric acid, phosphoric acid and marine (chloride) environments.

Nickel, which is the major alloying element, has excellent resistance to chloride ion stress corrosion cracking. Chromium resists to oxidizing substances such as nitric acid, nitrates and oxidizing salt. It reacts with the atmospheric oxygen to form a protective scale layer of chromium oxide (Cr<sub>2</sub>O<sub>3</sub>). This layer prevents outward diffusion of metallic element. Molybdenum has

resistance to pitting and crevice corrosion. Combination of Ni, Cr, Mo and Cu provides outstanding resistance to reducing environment. [16]

## 2. LITERATURE REVIEW

Nickel based super alloys are widely employed in aerospace industry, in particular for the hot sections of gas turbine engines due to their high temperature strength and high corrosion resistance. Their ability to maintain their mechanical properties at high temperatures severely hinders the machinability of these alloys. They are generally referenced as difficult-to-cut materials. We focus our attention in this study on the Inconel 825 alloy. [17]

## 3. METHODOLOGY

### 3.1 Equipments

#### 3.1.1 CNC Machine

The CNC machine comprises of the computer in which the program is fed for cutting of the metal of the job as per the requirements. All the cutting processes that are to be carried out and all the final dimensions are fed into the computer via the program. The computer thus knows what exactly is to be done and carries out all the cutting processes. CNC machine works like the Robot, which has to be fed with the program and it follows all your instructions.



Fig. 3.1 CNC Machine

### 3.1.2 Conventional Lathe Machine



Fig 3.2 Conventional Lathe Machine

The lathe was very important to the Industrial Revolution. It is known as the mother of machine tools, as it was the first machine tools that lead to the invention of other machine tools. The lathe is a machine tool which holds the workpiece between two rigid and strong supports called canters or in a chuck or face plate which revolves. The cutting tool is rigidly held and supported in a tool post which is fed against the revolving work. The normal cutting operations are performed with the cutting tool fed either parallel or at right angles to the axis of the work. The cutting tool may also be fed at an angle relative to the axis of work for machining tapers and angles.

### 3.1.3 Optical Microscope



Fig.3.3 Optical Microscope

The optical microscope, often referred to as light microscope, is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. The image from an optical microscope can be captured by normal light-sensitive cameras to generate

a micrograph. Originally images were captured by photographic film but modern developments in CMOS and charge-coupled device (CCD) cameras allow the capture of digital images. Purely digital microscopes are now available which use a CCD camera to examine a sample, showing the resulting image directly on a computer screen without the need for eyepieces. The objective lens is, at its simplest, a very high-powered magnifying glass, i.e. a lens with a very short focal length.

### 3.2 Tool Material



CVD

PVD

Fig.3.4: Tool insert used during experimentation

### 3.3 Experimental Details

#### 3.3.1 First Stage of Experiment

A round bar of 32 mm diameter and 110 mm length was cut for machining. Dry turning operation was performed on CNC lathe machine. (Make:- Gurudatta CNC machines) as depicted in fig.3.1

Experimental conditions are provided in table 3.1. The trial runs were carried out under varying cutting conditions at first stage of experiment.

**Table 3.1:-** Experimental conditions during first stage of research

Cutting tool	CVD Bi-layer coating consist of TiCN/Al <sub>2</sub> O <sub>3</sub> Cemented Carbide tool
Tool Designation	ISO Designation of TNMG 160408
Tool Holder Designation	ISO Designation MTJNR 2020 K16 WIDAX
Spindle Speed, (RPM)	300,400,500,600,700,800,900
Feed, mm/rev	0.06, 0.08 & 0.1
Depth of cut (a <sub>p</sub> ), mm	0.5
Environment	Dry

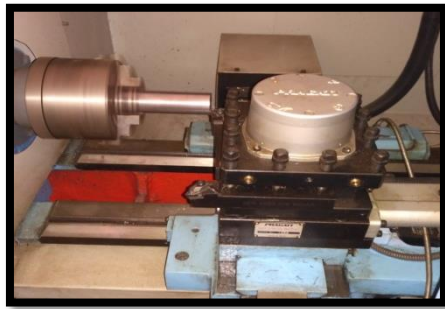


Fig.3.5: Photograph of experimental setup for turning of Inconel 825.

### 3.3.2 Second Stage of Experiment

A round bar of 32 mm diameter and 110 mm length was cut for machining. Dry turning operation was performed on CNC lathe machine. (Make:- Gurudatta CNC machines) as depicted in fig.3.1

Experimental conditions are provided in table 3.2. The trial runs were carried out under varying cutting conditions at second stage of experiment.

Table 3.2:- Experimental conditions during second stage of research

Cutting tool	PVD Multilayer coating of TiAlN/TiN Cemented Carbide tool
Tool Designation	ISO Designation of TNMG 160408
Tool Holder Designation	ISO Designation MTJNR 2020 K16 WIDAX
Spindle Speed, (RPM)	300,400,500,600,700,800,900
Feed, mm/rev	0.06, 0.08 & 0.1
Depth of cut ( $a_p$ ), mm	0.5
Environment	Dry

### 3.3.3 Third Stage of Experiment

A round bar of 32 mm diameter and 110 mm length was cut for machining. Dry turning operation was performed on Conventional lathe machine.

Experimental conditions are provided in table 3.3. The trial runs were carried out under varying cutting conditions at third stage of experiment.

Table 3.3: Experimental conditions during second stage of research

Cutting tool	CVD Bi-layer coating consist of TiCN/Al <sub>2</sub> O <sub>3</sub> PVD Multilayer coating of TiAlN/TiN
Tool Designation	ISO Designation of TNMG 160408
Tool Holder Designation	ISO Designation MTJNR 2020 K16 WIDAX
Spindle Speed, (RPM)	400
Feed	Manual
Depth of cut ( $a_p$ ), mm	0.5
Environment	Dry

## 4 RESULTS AND DISCUSSION

### 4.1 Flank Wear while machining on CNC machine

Tool wear during dry turning of Inconel 825 with PVD and CVD carbide insert was characterised by flank wear. Tool wear mechanism during dry turning of Inconel 825 is investigated using optical microscope. It is evident that increase in the cutting speed the average value of flank wear also increased. Initially up to 500 RPM there was no significant difference in wear pattern of CVD and PVD tool.

The CVD coated tool has moderate wear after 500 RPM of spindle and losses its machinability at 800 RPM of spindle speed. PVD coated tool has minimum wear and retain its machinability after 800 RPM.

In case of CVD coated carbide tool which has bilayer coating of TiCN/Al<sub>2</sub>O<sub>3</sub>, it is observed that maximum wear at feed 0.06 mm/rev is 0.3 mm and when feed is 0.08 mm/rev maximum wear is 0.34 mm occurs at 900 RPM of spindle speed. The CVD coated tool losses its machinability at 800 RPM when feed is 0.1 mm/rev.

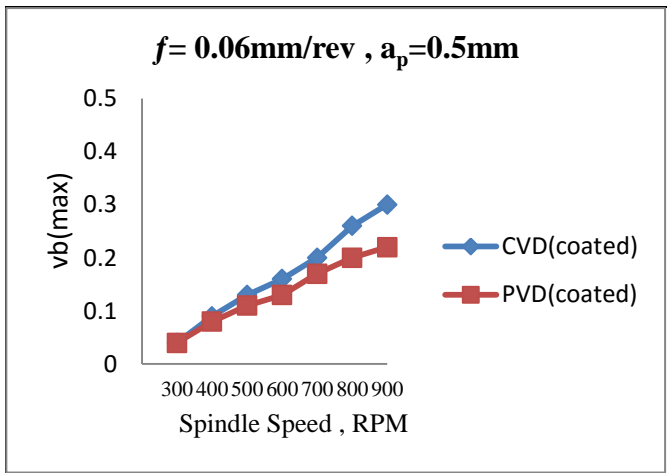


Fig 4.1: Variation of flank wear with different spindle speed for CVD and PVD carbide insert at constant feed=0.06mm/rev and depth of cut=0.5 mm.

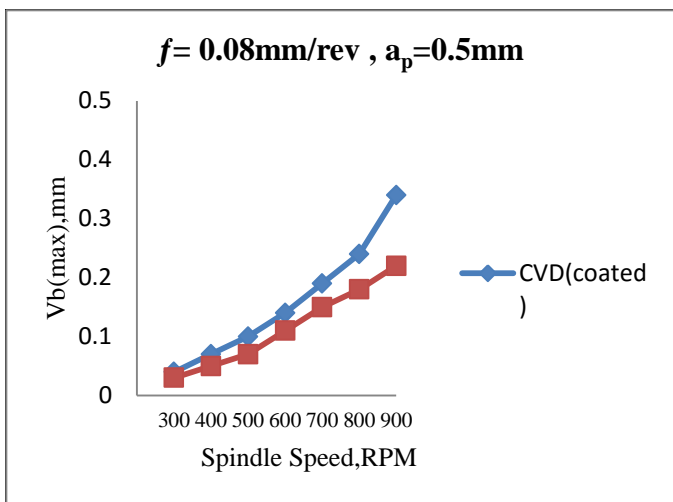


Fig 4.2: Variation of flank wear with different spindle speed for CVD and PVD carbide insert at constant feed=0.08mm/rev and depth of cut=0.5 mm.

Table.4.1 Flank wear when f=0.06 mm/rev & ap= 0.5 mm

Spindle Speed, (N)	CVD Vb(max),mm	PVD Vb(max), mm
300	0.04	0.04
400	0.09	0.08
500	0.13	0.11
600	0.16	0.13
700	0.20	0.17
800	0.26	0.20
900	0.3	0.22

Table.4.2 Flank wear when f=0.08 mm/rev & ap= 0.5 mm

Spindle Speed, (N)	CVD Vb(max),mm	PVD Vb(max), mm
300	0.04	0.03
400	0.07	0.05
500	0.1	0.07
600	0.14	0.11
700	0.19	0.15
800	0.24	0.18
900	0.34	0.22

Table.4.2 Flank wear when f=0.1 mm/rev & ap= 0.5 mm

Spindle Speed, (N)	CVD Vb(max),mm	PVD Vb(max), mm
300	0.09	0.05
400	0.15	0.12
500	0.2	0.15
600	0.28	0.20
700	0.35	0.23
800	0.47	0.27
900	Tool fail	0.30

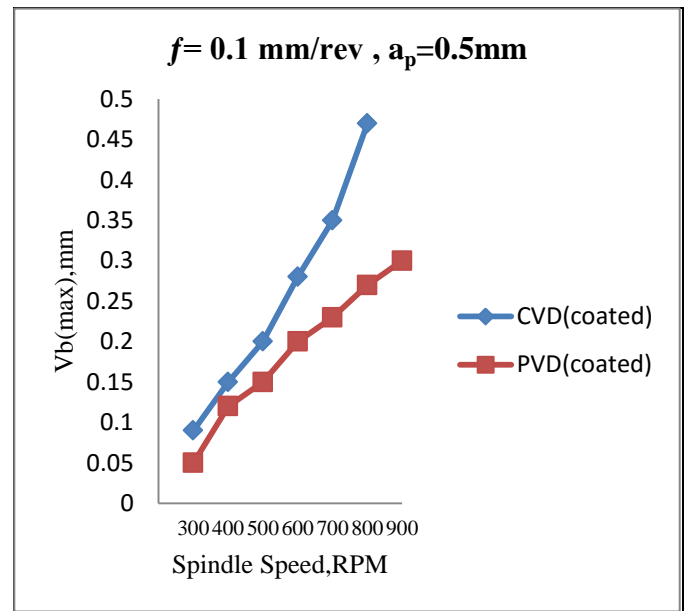


Fig 4.3: Variation of flank wear with different spindle speed for CVD and PVD carbide insert at constant feed=0.1mm/rev and depth of cut=0.5 mm.

## 4.2 Flank Wear While Machining on Conventional Lathe

Tool wear of uncoated tool is observed while machining of Inconel alloy 825. The machining process was carried out at constant spindle speed of 350 RPM and feed is given manually. The cutting length and depth of cut of 100 mm and 0.25 mm was kept constant.

The Uncoated tool fails after 3 passes. The tool wear is observed by visual inspection. Surface Finish of workpiece is reducing with the worn out tool. Fig: 4.4(A) shows the surface finishing of workpiece when machined with worn out tool. Fig: 4.4 (B) shows surface finishing of workpiece machined with tool which does not loosen its machinability.

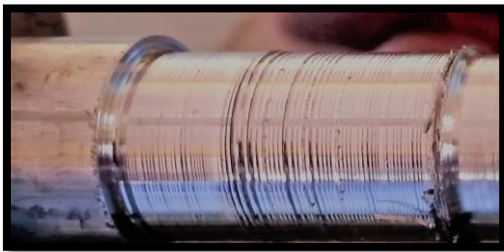


Fig.4.4(A): Variation in surface finishing of workpiece when it is machined with worn out tool

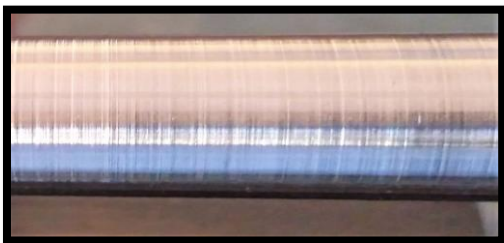


Fig.4.4 (B): Variation in surface finishing of workpiece when it is machined without worm out tool

When workpiece is machined with the worn out tool poor surface finishing is observed on the workpiece. Where as Smooth surface finish is observed when machining without worming tool.

### Conclusion:

In this study the work compared the machinability characteristics of Incoloy 825 while adopting CVD and PVD coated tool inserts. The major conclusions from the study can be summarised as follows

1. Surface roughness increased with cutting speed for both coated tool inserts. Average flank wear of PVD coated tool was less than its CVD coated tool
2. Initially upto 500 RPM there was no significant difference in wear pattern of CVD and PVD tool. The CVD coated tool has moderate wear after 500 RPM of spindle and losses it's machinability at 800 RPM of spindle speed. PVD coated tool has minimum wear and retain its machinability after 800 RPM.
3. In case of CVD coated carbide tool which has bilayer coating of TiCN/Al<sub>2</sub>O<sub>3</sub>, it is observed that maximum wear at feed 0.06 mm/rev is 0.3 mm and when feed is 0.08 mm/rev maximum wear is 0.34 mm occurs at 900 RPM of spindle speed. The CVD coated tool losses its machinability at 800 RPM when feed is 0.1 mm/rev.
4. PVD multilayer tool coated with TiAlN/TiN has good resistance to the wear. Tool wear observed in the PVD coated tool is significantly less than that of CVD coated tool.
5. PVD coated has good performance at all speeds and feed. It has better machinability characteristics other than CVD tool. Therefore, outstanding resistance to flank wear could be established with the TiAlN/TiN multilayer coated tool.

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