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EFFECT OF CHEMICAL VAPOR DEPOSITION ON MACHINABILITY CHARACTERISTICS OF AEROSPACE GRADE STAINLESS STEEL

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ABSTRACT

In this paper work has been under taken aiming at investigating the influence of cutting speed (100, 140 & 190 m/min) and feed rate (0.16, 0.20 & 0.24) on various machining characteristics like chip morphology, chip reduction coefficient, tool wear, cutting force, cutting temperature and machined surface roughness. The machining operation was carried under constant depth of cut 0.5 mm and at dry environment. Chemical Vapor Deposition multilayer coated ($TiN/TiCN/Al_2O_3/ZrCN$) cemented carbide (ISO P30 grade) insert has been chosen for the current study. The performance of the coated tool has also been compared with that of uncoated carbide insert of similar grade and geometry in order to understand the effectiveness of Chemical Vapor Deposition multilayer coated tool during dry machining of 17-4 PH stainless steel.

Key Words: Cutting speed, Feed rate, Chip reduction, Tool wear, cutting temperature, machined surface roughness Chemical Vapor Deposition, 17-4 PH stainless steel, ($TiN/TiCN/Al_2O_3/ZrCN$) cemented carbide.

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1. INTRODUCTION

Machining is a primarily finishing process by which work piece of desired shape; size and surface finish are generated by gradual removal of extra material from the blank in form of chips by movement of cutting tool across the surface of work piece. Despite that the major development has been taken place in near-net shape forming techniques, the machining still exists as primary activity in the industries. The problem associated during machining operations are use of high cost tooling material, improper selection of cutting parameters leading to high ideal time along with wastage of material as scrap, dimensional inaccuracy etc.The machining system comprises of cutting tool , work piece and machine tool.. The cutting tool has greater role to play as the cutting parameters set largely depend upon the material of cutting tool. Hence the main motive of the machining is to explore the work piece tool interaction in order to get optimized set of cutting parameter to improve overall productivity of the industries along with improvement of quality of products produced.

During machining process the machinability can be assessed through rate of metal removal, life of cutting tool, power utilization and component forces, surface roughness obtained and surface integrity of the machined surface along with chip morphology. The mach inability index is significantly influenced by the properties and geometry of the cutting tool, material properties being machined, cutting parameters used along with factors such as cutting environment, machine tool rigidity etc. The proper combination of machining parameters, cutting tools and machine tool can lead to improvement in the productivity of any machining operations.

2. OBJECTIVE

The major objective of the current paper is to study the influence of the cutting speed, feed rates and tool coating on different machinability characteristics of 17-4 PH stainless steel during dry machining. The detailed objectives include the following:

1. To carry out comparative evaluation of performance of a commercially available Chemical Vapor Deposition coated tool having TiN, TiCN, Al_2O_3 and ZrCN in multilayer configuration with that of ISO P30 grade uncoated cemented carbide.
2. To investigate the influence of cutting speed, feed rate and tool coating on machinability aspects such as:

(a).Tool wear with primary emphasis on mechanisms.

(b).Chip characteristics with focus on macro morphology of chip and chip thickness.

(c).Cutting force

(d).Cutting temperature

(e).Surface roughness

3. EXPERIMENTAL METHODOLOGY

The detail aspect of machine tool used, equipment facilities, work piece material, cutting tool, machining parameters and experimental set-up has been discussed.

3.1. Work material (17-4 PH stainless steel):

17-4 Precipitation Hardening also known as Type 630 is a chromium-copper precipitation hardening stainless steel used for applications requiring high strength and a moderate level of corrosion resistance was used as work piece material. 17-4 PH stainless steel of dimension 80 mm diameter and 600 mm length was used for the purpose of experimentation. Chemical composition of the 17-4 PH stainless steel has been given in Table.1

Elements	C	Mn	Si	P	S	Cr	Ni	Cu	Nb + Ta
Wt %	0.07 max	1.0 max	1.0 max	0.04 max	0.03 max	15-17.5	3-5	3.0-5.0	0.15-0.45

Properties of 17-4 PH stainless steel

Mechanical Properties of Stainless Steel Sheets

1. Ultimate Tensile Strength: 1103 MPa
2. 0.2% Tensile Yield Strength: 1000 MPa
3. Elongation%:5
4. Hardness Rockwell C: 35

17-4 Stainless Steel Physical Properties

1. Melting Range: 1404-1440°C
2. Density: 0.2820 lb/in

3.2. Cutting tool material:

Two types of cutting tools were used for machining the work piece:

1. Uncoated cemented carbide inserts

The commercially available ISO P30 grade of WC- 6% Co uncoated insert Consisting composition WC, Co, TiC, TaC and NbC was used as one of the cutting tool.

2. Coated cemented carbide inserts

The multilayer coated insert with CVD deposited multilayer coating consisted of TiN/TiCN/Al_2O_3/ZrCN arranged from the substrate to top layer. ZrCN is used as a top layer owing to its excellent toughness and anti-friction properties.

3.3. Cutting parameters:

The machining operation was carried out under variable cutting speeds of 100, 140 and 190 m/min for the feed rates of 0.16, 0.20 and 0.24 mm/rev and at constant depth of cut 0.5 mm in dry environment i.e. without use of any coolant or cutting fluid has been given in Table.2

Parameters	Range considered
Cutting Speeds (m/min)	100,140,190
Feed rates (mm/rev)	0.16,0.20,0.24
Depth of cut (mm)	0.5
Cutting environment	Dry

3.4. Machining operation:

Heavy duty lathe (Make: Hindustan Machine Tools

(HMT) Ltd., Bangalore, India; Model: NH26) was used for turning of 17-4 PH stainless steel with uncoated cemented carbide tools. Fig.1 shows the photographs of machine tool used for turning of 17-4 PH stainless steel.

Fig.1 Experimental Set-up

The dry turning of 17-4 PH SS was carried out with both uncoated and coated carbide insert at variable cutting speed and variable feed rates for different machining duration. Each of the experimental run was carried out for machining duration of 60 s. During the machining different forces and temperature were noted. The chips formed during the machining were collected for the further analysis. Tool wear of each insert for different condition was also measured.

3.5. Tool wear estimation

After each interval of machining duration the state of the cutting insert was monitored with the help of stereo zoom optical microscope (Make: Radical Instruments) to determine the tool wear mostly flank wear as sown in fig.2

Fig. 2.Stereo zoom optical microscope

3.6. Chip morphology study:

During machining the chips were collected for the different machining duration for analysis purpose. The images of chip produced at each experimental run were captured to get the information regarding the shape, size and color of chip. Also the thickness of each chip collected was measured with the help of vernier caliper in order to determine the chip reduction coefficient.

3.7. Cutting force measurement:

Three component piezoelectric dynamometer (Make: Kistler Instrument AG, CH-8408 Winterthur, Switzerland; Model: 9257B) was used for the purpose of measuring various cutting forces during turning. A charge amplifier (Make: Kistler Instrument AG, CH-8408Winterthur, Switzerland; Model: Type 5814B1) connected to the dynamometer was used to give the required readings for the cutting forces as shown in fig.3.

(a) (b)

Fig..3. Cutting force set-up a) dynamometer b) charge amplifier

3.8. Temperature measurement

A thermocouple attached at the bottom of the tool was used for the measurement of temperature attained at the cutting insert during the machining operation. For this purpose a 2 mm hole was drilled at the bottom of the tool holder approximately at distance of 9 mm from shim and onto that drilled hole the thermocouple was fixed (Fig.4a).The thermocouple was attached to the recorder (Fig. 4 b) which gave the readings directly in terms of degree Celsius.

(a) (b)

Fig. 4 Temperature measurement set-up (a) Thermocouple (b) Temperature recorder.

3.9. Surface roughness measurement

Surface roughness of each experimental run was measured with Talysurf (Model:Taylor Hobson, Surtronic 3+) with parameters sample length, Lc=0.8 mm, cut-off length, Ln= 4 mm and filter=2CR ISO. The set-up below shows (Fig. 16) the measurement of the surface roughness for each run as shown in fig.5.

Fig. 5.Surface measurement set-up.

4. RESULTS

4.1. Condition of the tool after machining

The condition of flank surface for both uncoated and CVD multi-layer coated carbide inserts showing the extent of flank wear at the flank surface when machining 17-4 PH stainless steel at a constant feed rate of 0.16 mm/rev and for varying cutting speeds. The machining was although carried out at an interval of 60 s for up to 300 s but only few representative images have been shown only.

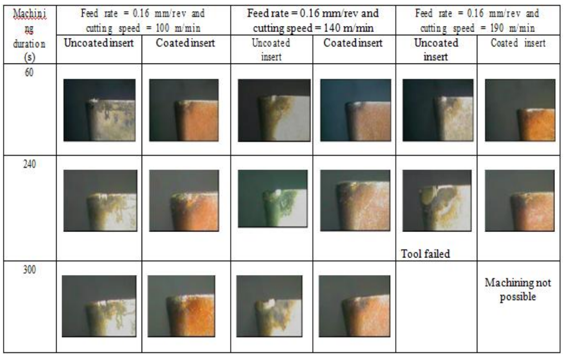

Fig. 6. Flank wear of uncoated and coated tool at feed rate of 0.16 mm/rev

From fig 6. Observing chipping of nose for uncoated tool was observed for machining duration of 240 s when machining at cutting speed of 140 m/min. However, due to lower wear resistance of the uncoated tool towards the hard particles (martensitic structure) present in the 17-4 PH stainless steel it could not perform well at the higher cutting speed of 190 m/min which eventually led to tool failure after 240 s of machining. High nose wear was also observed for the uncoated tool under the same machining condition.

4.1.2 Effect of cutting speed and machining duration under medium feed condition

For uncoated carbide inserts, high nose damage was noted at cutting speeds of 140 and 190 m/min. Nose damage was more severe in case of the higher velocities with wear occurring immediately after machining duration of 60 s, while the tool failure occurred after 180 s of machining with a cutting speed of 140 m/min. The nose wear can be attributed to high heat generation at the cutting region leading to softening of uncoated tool resulting and consequently premature failure. The delamination of the rake surface near the nose region can be observed as shown in fig 7.

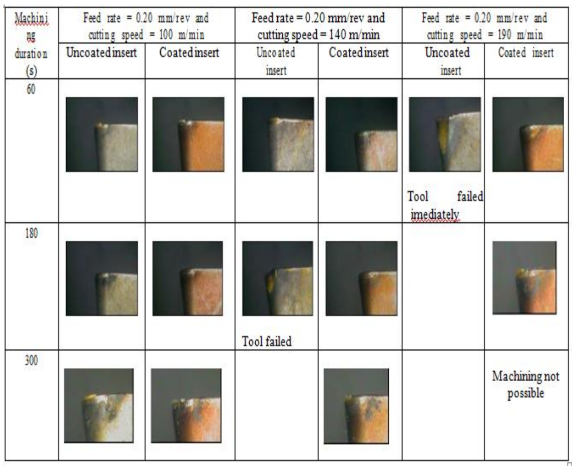

Fig.7. Flank wear of uncoated and coated tool at feed rate of 0.20 mm/rev.

Fig. 8 below shows the condition of the rake surface and the nose region for the failure state of the uncoated carbide tool at cutting speeds of 140 and 190 m/min.

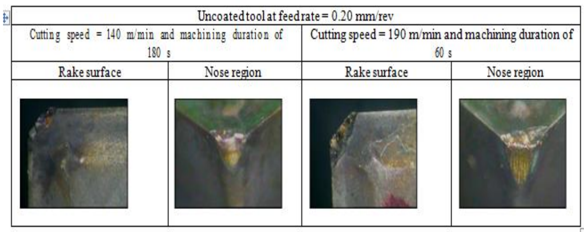

Fig. 8. Condition of rake surface and nose region after failure of uncoated tool at feed rate of 0.20 mm/rev.

4.1.3 Effect of cutting speed and machining duration under high feed condition

The tool wear at the high feed rate got intensified with increase in the feed rate to 0.24 mm/rev as can be observed from the Fig.9 as shown below

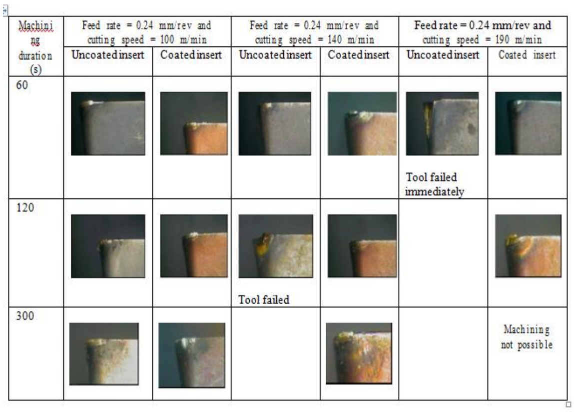

Fig. 9. Flank wear of uncoated and coated tool at feed rate of 0.20 mm/rev

At higher feed rate also of the nose damage was main failure mode for the uncoated carbide inserts. The condition of the rake surface and nose region for uncoated failure condition has been given in Fig. 10.

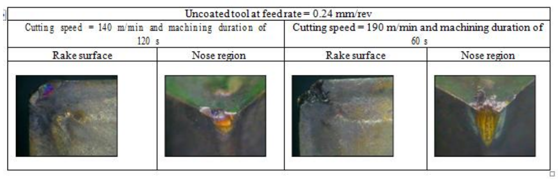

Fig. 10. Condition of rake surface and nose region after failure of uncoated tool at feed rate of 0.24 mm/rev.

4.2.Effect of feed rate on machinability characteristics of 17-4 PH stainless steel

4.2.1 Flank wear

The initial running in wear for CVD multi-layer tool under lower cutting condition is quite significant and more than that while machining with medium cutting speed for the same feed rate condition of 0.16 mm/rev. However, rate of flank wear stabilised subsequently with progression of machining duration. It is also of considerable interest that improvement of the coated tool during machining with lower cutting speed (Vc=100 m/min) gradually became more prominent when feed rate was increased from 0.16 to 0.24 mm/rev.as shown figures 11,12,&13 below.

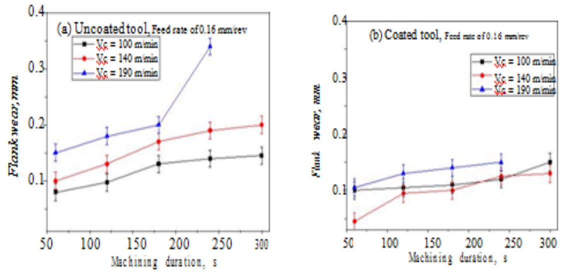

Fig. 11.Variation of flank wear with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

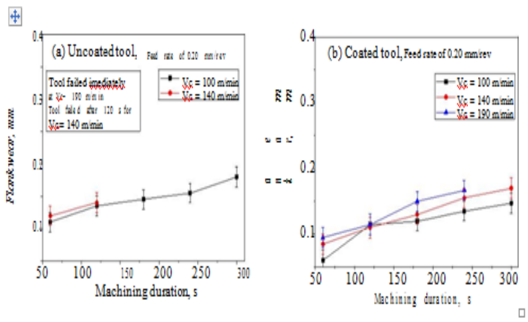

Fig. 12. Variation of flank wear with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

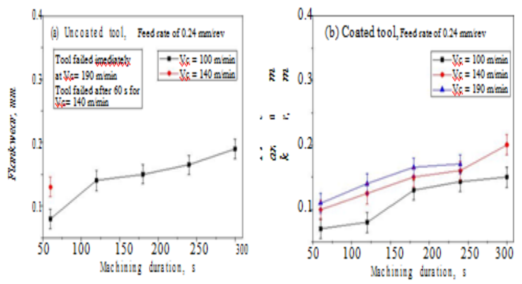

Fig13.Variation of flank wear with progression of machining duration with variable cutting speed at feed rate 0.24 mm/rev for (a) Uncoated and (b) Coated tool

Nearly 21 % improvement in average tool wear was obtained while machining with CVD coated tool for high feed rate 0.24 mm/rev at lower cutting speed (Vc=100 m/min) as compared to machining with uncoated tool during same cutting condition as can be noted from above Figures.

4.2.2 Nose wear

The nose wear for CVD multi-layer coated carbide inserts at low machining condition i.e. lower feed rate of 0.16 m/min and low cutting speed of 100 m/min was found to be higher than rest cutting speeds at same feed rate of 0.16 mm/rev due to higher friction generated. While the nose wear between the uncoated and coated tool for lower cutting speed of 100 m/min under feed rate of 0.20 mm/rev was comparable. While machining at higher cutting speed the coated tool showed a decrement of 14 % in terms of nose wear as contrast to its uncoated counterpart. as shown in figures 14,15,&16 below.

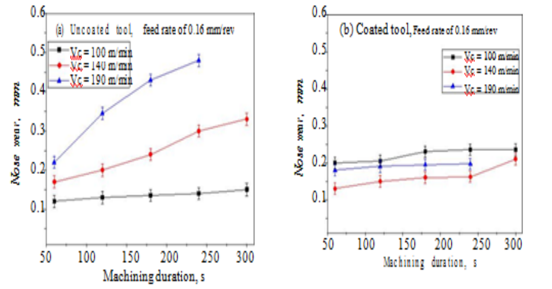

Fig. 14.Variation of nose wear with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

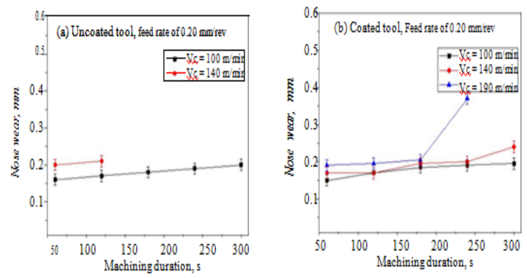

Fig. 15. Variation of nose wear with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

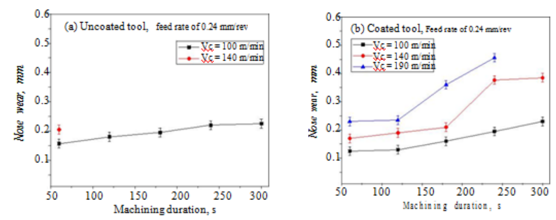

Fig. 16.Variation of nose wear with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated tool and (b) Coated tool.

4.2.3. Chip thickness

The variation of chip thickness with progression of machining duration for variable cutting speeds at constant feed rate when machining 17-4 PH stainless steel with uncoated and CVD multi-layer coated carbide insert is illustrated Figs. It is evident from the graph that CVD multi-layer coated tool helped in significant reduction of chip deformation compared to uncoated tool as shown in figures 17,18 &19 below.

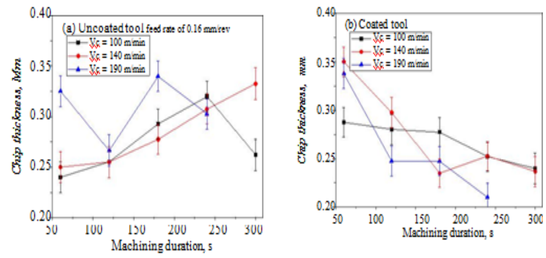

Fig. 17 Variation of chip thickness with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

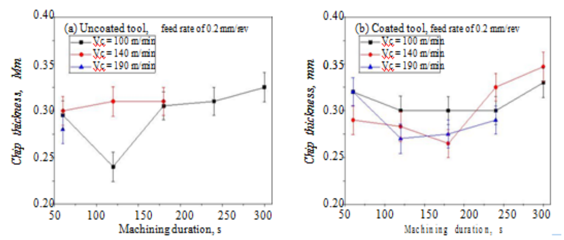

Fig. 18. Variation of chip thickness with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

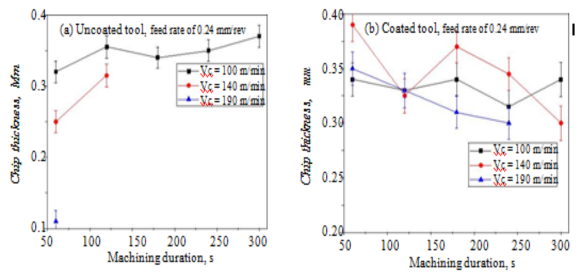

Fig. 19. Variation of chip thickness with progression of machining duration with variable cutting speed at feed rate 0.24 mm/rev for (a) Uncoated and (b) Coated tool

Comparing all the above figures, with increase in feed rate, the chip deformation was found to rise when machining 17- 4 PH stainless steel with uncoated and CVD multi-layer coated carbide inserts. The increasing tendency of chip thickness can be attributed to higher tool wear with increase in feed rate.

4.2.4. Surface roughness

The fluctuation of surface roughness obtained under specific feed rate at variable cutting speed with progression of machining duration when machining 17-4 PH stainless steel with uncoated and coated carbide inserts are demonstrated by Figures..Increase in the surface roughness with increase in the feed rate was observed for both types of tool. Machining under the higher feed rates leads to more heat generation, wearing the tool early leading to poor machined surface quality. The surface roughness was comparable between two types of tool for lower and medium cutting speed under low feed rate of 0.16 mm/rev as shown in figures 20,21&22 below.

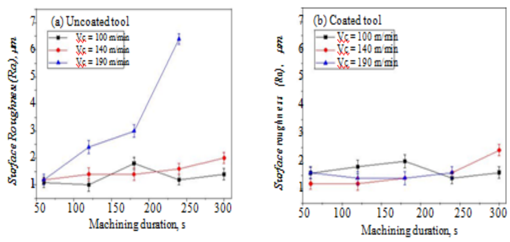

Fig. 20.Variation of surface roughness with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

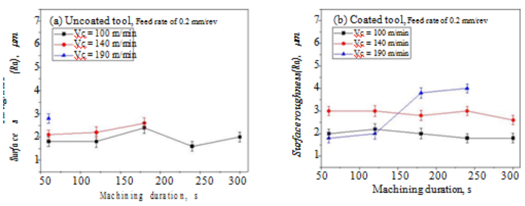

Fig. 21.Variation of surface roughness with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

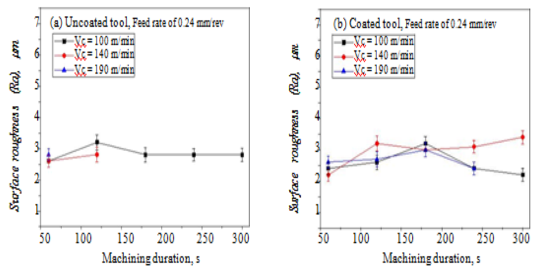

Fig. 22. Variation of surface roughness with progression of machining duration with variable cutting speed at feed rate 0.24 mm/rev for (a) Uncoated and (b) Coated tool

Overall it can be recommended to use CVD multi-layer coated tool can be used at lower feed rate for improvement of surface roughness.

4.2.6 Cutting temperature

With increase in the feed rate the cutting tool temperature for the uncoated and coated tools diminishes or rather say the difference lowers for machining done under low cutting speed of 100 m/min. This lowering of difference in cutting tool temperature can be attributed to higher tool wear rate of the uncoated tool compared to the coated counterpart as sown figures.

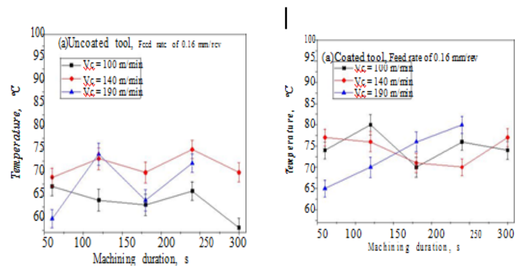

Fig. 23.Variation of cutting temperature with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

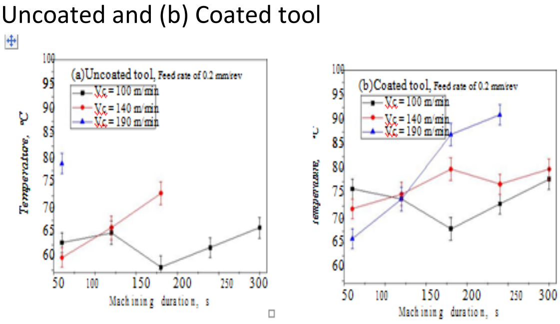

Fig..24.Variation of cutting temperature with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

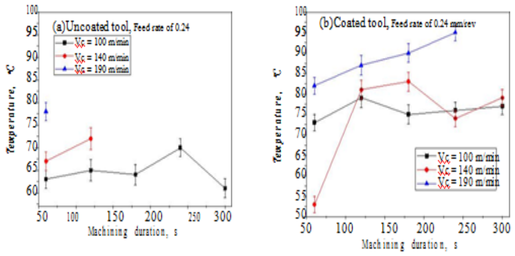

Fig.25. Variation of cutting temperature with progression of machining duration with variable cutting speed at feed rate 0.24 mm/rev for (a) Uncoated and (b) Coated tool

4.2.7 Cutting Force

Figures 26,27 and 28 demonstrates the variation of tangential cutting force (Fz) with progression of machining duration with variable cutting speed under constant feed rates while machining 17-4 PH stainless steel with uncoated and CVD multi-layer coated tool. The cutting force data has been plotted for only few machining duration, as for further machining duration there was some problem with regard to dynamometer.

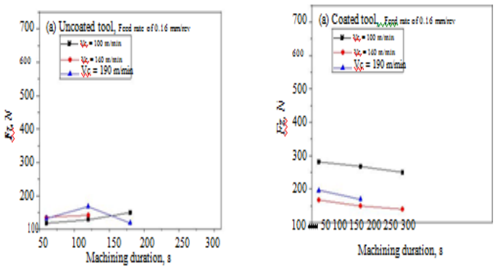

Fig.42 Fig.26.Variation of tangential cutting force with progression of machining duration with variable cutting speed at feed rate 0.16 mm/rev for (a) Uncoated and (b) Coated tool

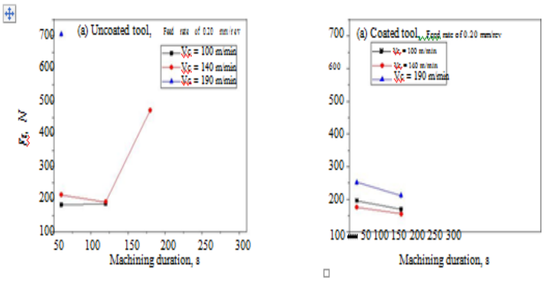

Fig. 27. Variation of tangential cutting force with progression of machining duration with variable cutting speed at feed rate 0.20 mm/rev for (a) Uncoated and (b) Coated tool

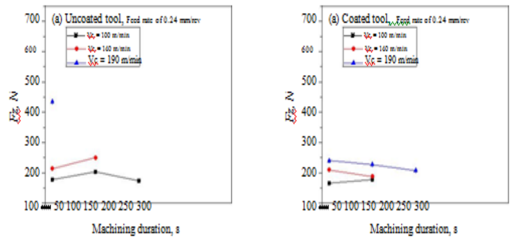

Fig..28. Variation of tangential cutting force with progression of machining duration with variable cutting speed at feed rate 0.24 mm/rev for (a) Uncoated and (b) Coated tool.

CONCLUSION

The influence of CVD multilayer (TiN/TiCN/Al_2O_3/ZrCN) coating and cutting parameters like cutting speed, feed rate and machining duration on various aspects of machinability characteristics of 17-4 PH stainless steel. Following conclusions can be drawn from current project work:

1. Nose wear was found to be prominent tool failure mode for the uncoated carbide inserts under high feed rates (0.24 mm/rev) and medium feeds (0.20 mm/rev) for cutting conditions of medium and high cutting velocity.

2. The chips obtained were mostly of long continuous and snarled type. The chips obtained at initial machining duration were of golden colour which later changed to silver light colour with progression of machining.

3. Flank wear and nose wear increased with progression of machining duration for both uncoated and CVD multilayer coated carbide insert for all cutting conditions.

4. Under minimum machining condition of minimum feed (0.16 mm/rev) and cutting speed (100 m/min), there was no improvement in average flank wear for coated tool as compared to its uncoated counterpart. However the improvement got more prominent with increase in feed rate and cutting speed.

5. The rate of flank wear for uncoated tool could also be brought down with the help of CVD multilayer coating under the medium and high feed

condition. Improvement in tool life up to a maximum of 55 % for coated tool compared to its uncoated counterpart was observed under constant velocity of 190 m/min and for feed rate of 0.16 mm/rev at machining interval of 300 s.

6.Increase in both speed and feed resulted in increase in the temperature. CVD multilayer coated tool exhibited higher cutting temperature than its uncoated counterpart for all cutting conditions.

7.The anti-friction CVD multilayer coated tool resulted in less chip deformation as compared to uncoated carbide insert under any cutting condition.

8.The chip thickness for both uncoated and coated carbide insert increased with progression of machining duration with increase in feed rate for constant cutting velocity.

9.With increase in the cutting speed uncoated tool exhibited increase in chip thickness, whereas the average value of the chip thickness did not change significantly for CVD coated tool.

10. The quality of machined surface for 17-4 PH deteriorated with increase in feed rate. For obtaining better surface finish CVD multilayer coated tool is recommended with a feed rate of 0.16 mm/rev. Reduction of surface roughness up to a maximum of 76 % for CVD multilayer coated insert was noted during machining of 17-4 PH stainless steel under a high cutting velocity of 190 m/min and lower feed rate of 0.16 mm/rev.

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