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INFLUENCE OF CVD MULTILAYER COATING ON MACHINABILITY CHARACTERISTICS OF AEROSPACE GRADE STAINLESS STEEL

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ABSTRACT
In the recent years, aeroengine superalloys have gained high amount of research interest owing to their wide engineering application particularly in strategic environment.17-4PH (precipitation hardened) stainless steel (SS) is one such grade of aerospace alloys used to manufacture mostly small parts and mainly stator of aircraft engine in place of Titanium alloy for material cost saving.17-4PH SS falls under the category of difficult-to-cut material because of its low thermal conductivity and high ductility. Although most of the research work was concentrated on machinability of Nickel-based and Titanium-based superalloy, no such work on the 17-4PH stainless steel has been reported so far. Today different coated tools are widely used in machining industries. Therefore it is also essential to select suitable coating material for machining such aeroengine alloys. In order to achieve some of the objectives, the research work has been under taken aiming at investigating the influence of cutting speed (140, 190 & 210 m/min) on various machining characteristics like cutting force, tool wear, chip thickness and machined surface roughness. The machining operation was carried under constant feed rate of 0.24 mm/rev, depth of cut of 1 mm and at dry environment. CVD multilayer coated (TiN/TiCN/Al2O3/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 CVD multilayer coated tool during dry machining of 17-4 PH stainless steel.

Keywords- *Machinability, 17-4 PH stainless steel, CVD multilayer coated, tool wear.*

I. INTRODUCTION

The precipitation hardened stainless steel makes use of chromium and nickel as their major constituent alloying elements. The matrix of these types of alloy could be either austenitic or martensitic depending upon the temperature and other working conditions. Hence, offering a perfect amalgamation of high strength property of the martensitic structure and corrosion resistant property of austenitic phase [1]. The hardness and strength of these precipitation hardened alloys are enhanced by the generation of nano-scale precipitates of another phase mainly at the grain boundaries of the original metal matrix. 17-4 PH stainless steel is basically a martensitic precipitation hardenable stainless steel whose microstructure is dominantly a austenitic at high annealing temperature but when brought down to room temperature at high cooling rate the austenitic phase changes to lath martensitic structure. The hardening of these alloys are achieved by addition one of alloying elements such as aluminum, niobium, molybdenum and copper. This whole process is accomplished after necessary heat treatment process and thus these alloys are known as precipitation hardened alloy [2]. The properties of 17-4 PH stainless steel which makes them used in various sector are high tensile strength, high hardness, good toughness, high corrosion resistance, good formability and weldability. The above combination of the high mechanical and chemical properties up to a temperature of 316°C makes them highly suitable industrial applications used to manufacture oil field valve parts, chemical process equipment, aircraft fittings, fasteners, pump shafts, nuclear reactor components, gears, paper mill equipment's, missile fittings, and jet engine parts [3]. Stainless steels are normally known as difficult to machine materials due to their high work hardening tendency, high tensile strength, high fracture toughness and relatively low thermal conductivity [4]. During machining process the machinability can be assessed through rate of metal removal, life of cutting tool or tool wear, power utilization and component forces, surface roughness obtained and surface integrity of the machined surface along with chip morphology [5]. The ultimate purpose of any machining process is to manufacture product with less cost of high dimensional accuracy and surface finish. For achieving sustainable machining trend goes towards dry or near dry machining because there are lots of environmental problem associated with the use of cutting fluid during wet machining at the same time hard machining, high-speed machining and machining hard-to-cut materials is very difficult with normal tool. To cope up with all these issues we use high-performance thin layer coatings. Due to outstanding performance of coated carbide cutting tool now-a-days 80% of all machining operations are performed with them [6].

The main problem related to machinability is due to built-up edge formation, work hardening and chip breakage. The low resistances to tool wear when machining SS with ceramic tools can be attributed to high temperature generation at rake surface with adhesion-spallation being dominant tool wear mechanism [7]. Tool wear is most commonly and popularly used criteria to access the machinability. The abrasion, adhesion, diffusion and fatigue induced wear mechanisms were responsible for the tool wear when machining stainless steels with TiN-coated cemented carbide inserts [8]. Flank wear and rake wear were most prominent wear observed in all tools. The adhesion wear mechanism was more responsible for the crater wear at the rake surface of the tool while it was abrasion and adhesion for the flank wear. Hard martensite structures of the workpiece were responsible for the abrasion at the flank face of the tool which acted as small indenters [9]. The surface roughness of both SS while machining with two different types of coated tool resulted in initial decrease in the surface roughness up to a cutting speed of 180 m/min. The decrease in surface roughness can be attributed to decrease in formation of BUE with increase in speed [10]. A separate investigation also reported that surface roughness decreased with increase in the cutting speed. At lower cutting speeds the formation of built-up edge (BUE) deteriorates the surface finish which improves gradually with increase in speed as at the high speeds the BUE formation is retarded due to less contact time between the chip-tool interfaces [11].

To the best of knowledge, very few research works has been reported with regard to various machining aspects of 17-4 PH stainless steel in turning. The effect of coatings with its uncoated counterpart on machining characteristics of 17-4 PH stainless steel under dry environment is yet to be reported. The major objective of the current research is to study the influence of the cutting speed and tool coating on different machinability characteristics such as cutting force, tool wear, chip thickness, and surface roughness of 17-4 PH stainless steel during dry machining.

II. EXPERIMENTAL SET-UP

2.1 Workpiece material

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 workpiece material. These types of PH stainless steel have chromium and nickel as its major constituent elements with slight percentage of copper and molybdenum as its precipitates in its structure [1-2]. Dimensions of the specimen were 80 mm diameter and 600 mm length. Chemical composition of 17-4 PH stainless steel is 0.048 C, 0.017 P, 0.002 S, 15.24 Cr, 4.66 Ni, 3.16 Cu, 0.45 Mn, 0.5 Si, 0.35 Nb + Ta and 74.84 Fe (all in wt.%).

2.2 Cutting tools

In this experiment both uncoated and coated cemented carbide inserts were employed through the cutting test. The commercially available (Make: Widia, India) ISO P30 grade of uncoated insert consisting composition WC, Co, TiC, TaC and NbC was used as one of the cutting tool. The commercially available (Make: Widia, India) multi-layer chemical vapor deposition (CVD) coated cemented carbide insert was used as another cutting tool. The multilayer coated insert with CVD 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. The both types of cutting tool i.e. uncoated and coated cemented carbide inserts were of SCMT 12 04 08 designation.

2.3 Experimental methods

Tests were conducted to investigate the effect of tool materials and cutting speed on cutting force, tool wear, chip thickness, and machined surface roughness. Tests were focused on turning operation with variation of cutting speed. The dry turning of 17-4 PH SS was carried out with both uncoated and coated carbide insert at variable cutting speed for different machining duration using a heavy duty lathe machine (Make: HMT Ltd., India and model:NH26) as shown in Fig. 1. Three different cutting speeds were selected during the machining as 140, 190 and 210 m/min along with a constant feed (f) of 0.24 mm/rev and depth of cut (t) of 1 mm. Each of the experimental run was carried out for machining duration of 60 s. Cutting force was measured using four-component piezoelectric dynamometer (Model: 9257B Make: Kistler, Switzerland) in combination with a charge amplifier (Make: Kistler Instrumente AG, CH-8408 Winterthur, Switzerland; Model: Type 5814B1). 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. 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

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mostly flank wear. The common failure criteria that have been used to estimate failure of cutting tools are catastrophic failure, average flank wear of 0.3 mm, maximum flank wear of 0.6 mm.

Fig.1 Photograph of experimental setup for turning of 17-4 PH Stainless steel.

During machining the chips were collected for the different machining duration for analysis purpose. The thickness of each chip was measured with the help of micrometer in order to determine the chip thickness.

III. RESULTS AND DISCUSSION

3.1 Cutting force

Variation of cutting force with progression of machining duration under variable cutting speed using uncoated and CVD coated tool has been depicted in Fig.2. Figure shows that increase in cutting force was obtained with increase in cutting speed. Increase in the cutting speed the tool wear increased leading to rise in the cutting force during machining [10]. Cutting force increased with machining duration for uncoated tool owing to high tool wear rate and machining was performed with rubbing whereas decrease in cutting force with machining duration was found with CVD coated tool owing to less tool wear and machining was performed by deformation. With increase of machining duration due to more heat generation which makes material soft at cutting zone resulted in decrease in cutting force for CVD coated tool whereas uncoated tool approaches to failure.

Fig.2. Variation of tangential cutting force with progression of machining duration with variable cutting speed for (a) uncoated and (b) coated tool.

3.2 Tool wear

3.2.1 Flank wear The Fig.3 depicts the variation of flank wear with progression of machining duration with variable cutting speed at a particular feed rate when machining 17-4 PH stainless steel with uncoated carbide inserts and CVD multi-layer coated carbide inserts. The hard abrasive particles from martensitic structure of 17-4 PH stainless steel led to wear out the uncoated carbide tool at faster rate than the coated tool. It can be attributed to anti-friction property and high resistance to abrasion of CVD multi-layer coating which provided higher wear resistance to the coated tool, hence outperforming its uncoated carbide insert. It can be deduced from all figures that the flank wear rate increased with increase in cutting speed for both types of cutting tools. The influence of increase in cutting speed was more prominent for the uncoated tool. The generation of high cutting temperature at chip-tool interface at higher cutting velocities leads to softening of the tool, as a result high tool wear than at lower cutting velocity [12]. A maximum increment of 58 % in tool life for coated tool was obtained in contrast to uncoated tool when machining under cutting speed of 190 m/min. uncoated tool failed only after 120 s of machining duration using medium cutting speed of 190 m/min whereas tool failed immediately using high cutting speed of 210 m/min and therefore machining was not performed. On the other hand, CVD multilayer coating consisted of TiN/TiCN/Al_2O_3/ZrCN performed even at high cutting speed because its excellent toughness and anti-friction properties make it resistance to wear.
Fig.2. Variation of flank wear with progression of machining duration with variable cutting speed for (a) uncoated and (b) coated tool.

3.2 Chip thickness

Fig.3 shows the variation of chip thickness with machining duration and cutting speed using uncoated and coated tool. It was found that chip thickness decrease with increase in cutting speed. Due to presence of BUE at the lower cutting speeds the friction between the chip–tool interface increased leading to more deformation of the chip. As the cutting speed increased the chip thickness decreased [10]. It is evident from the graph that CVD multi-layer coated tool helped in significant reduction of chip deformation compared to uncoated tool at high speed. For the uncoated carbide inserts, the predominant effect of tool wear led to higher chip deformation with progression of machining duration. One can observe that the chip deformation at the lower cutting velocity was found to be more in comparison with medium cutting speed of 190 m/min. The higher chip deformation at the lower cutting velocity can be assigned to the tendency of BUE formation on the cutting inserts and high residence time during machining of 17-4 PH stainless steel. This BUE formation increases the friction along with slight reduction in the rake angle which aggravates the chip deformation, hence increasing the chip thickness. It can be noticed that chip thickness increase with machining duration for uncoated tool owing to high tool wear rate whereas it decrease with machining duration using CVD coated tool owing to gradual exposure of anti-friction layers i.e. TiN and TiCN [13].

Fig.3. Variation of chip thickness with progression of machining duration with variable cutting speed for (a) uncoated and (b) coated tool.

3.3 Surface roughness

Variation of surface roughness with machining duration and cutting speed has been illustrated in Fig.4 using both uncoated and coated tool. It was found that initially CVD multilayer coated tool has higher value of surface roughness than uncoated one. It can be attributed to higher edge radius due to multilayer coating and rougher surface morphology of CVD coating technique are responsible for higher surface roughness. With machining duration fall in surface roughness was found with CVD coated tool whereas increase in surface roughness was found with uncoated tool. It can be attributed to high tool wear rate with uncoated tool in comparison to CVD coated tool. CVD coated tool shows increase in surface roughness followed by decreasing trend with machining duration. Increase in surface roughness can be attributed to formation of BUE whereas decrease in surface roughness can be attributed to the softening of the material with machining duration. Initially surface roughness was increased with cutting speed for CVD coated tool owing to higher drag force [14].

Fig.4. Variation of surface roughness with progression of machining duration with variable cutting speed for (a) uncoated and (b) coated tool.

IV. CONCLUSION

The current study aimed at investigating 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 research work:

1. Improvement in tool life up to a maximum of 58 % for coated tool compared to its uncoated counterpart was observed under constant velocity of 190 m/min.
2. The uncoated tool performed reasonably well under low cutting speed (Vc= 140 m/min) but failed during maching of medium and high cutting speed.
3. With increase in the cutting speed uncoated tool exhibited increase in chip thickness and coated tool exhibited decrease in chip thickness.
4. CVD coated tool significantly reduces the flank wear than uncoated one.
5. Tangential cutting force increases with increase in velocity and decreases with increase of machining duration.

In summary for better productivity during machining of 17-4 PH stainless steel CVD multilayer consisting of TiN/TiCN/Al_2O_3/ZrCN coatings is always recommended for improving the machining performance.

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