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INVESTIGATION INTO THE MACHINABILITY CHARACTERISTICS OF AISI 304 AUSTENITIC STAINLESS STEELS USING MULTILAYER TiN/TiAlN COATED CEMENTED CARBIDE INSERTS

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ABSTRACT

In this paper, the results of experimental work in dry and high speed turning of AISI 304 austenitic stainless steels using multilayer TiN/TiAlN coated cemented carbide insert are presented. The coating was deposited on fine-grained K-grade (K-20) cemented carbide cutting insert using Cathodic Arc Evaporation (PVD) technique. Micro-hardness of TiN/TiAlN coating was found to be 34 GPa for the thickness of 3.8 µm. The turning tests were conducted for cutting speeds in the range of 100 to 340 m/min, feed in the range of 0.08 to 0.20 mm/rev keeping depth of cut constant at 1 mm. The influences of cutting speed, feed and tool coating were investigated on the cutting force and average chip-tool interface temperature. The interface temperature 938°C was observed at 180 m/min cutting speed and 0.16 mm/rev feed. Cutting speed was found to be the dominant parameter for the chip-tool interface temperature whereas feed is the dominant parameter for cutting force. Built-up edge was not observed during turning. Cutting force was found decreasing with the increase in cutting speed.

Keywords*: Mulilayer TiN/TiAlN Coating, AISI 304 Machinability, Cutting Temperature and CAE-PVD Coatings.*

1. Introduction

In the last 20 years, titanium nitride coatings have been widely used in many industrial applications. In spite of its enhanced performance, titanium nitride shows limited oxidation resistance at temperatures above 500 °C [1]. It has been reported that with addition of aluminium, the oxidation resistance of the coatings are greatly improved up to working temperatures as high as 900 °C [2-3]. TiAlN coatings are used in dry cutting operations because of their high oxidation [4-5] and good wear resistance [6]. It is commonly used for machining of austenitic stainless steel AISI 304. Since then several research groups have investigated the microstructure and property development of the coatings. It has been suggested that with increasing aluminum content in the TiAlN coatings, phase changes occur, resulting in TiN/TiAlN. To further improve the hardness and the oxidation resistance, multilayer coatings with layer dimensions on the nano-scale have been utilized. Multilayer coatings have new structural features and improved mechanical properties responding to specific service requirements. Many researchers have investigated the surface properties of single layer, multilayer and gradient (Ti, Al)N coatings and found that the TiN/TiAlN multilayer coating have better properties than TiAlN monolayer coating[5-9]. It can be the better substitute for TiAlN coating for improving the performance and tool life of the cutting tool with same cost. AISI 304 austenitic stainless steel is the most widely used grade among the other grades of austenitic stainless steel. It is consumed in large volumes (72%) among the other grades of stainless steels [10]. It is used for aerospace components and chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for milder chemicals. They are generally more difficult to machine than carbon and low alloy steels because of their high strength, high work hardening tendency and poor thermal conductivity. Considerable research and development efforts are directed worldwide towards improving the machining operations to ensure efficient and economic machining of austenitic stainless steels by proper understanding of the behavior of the exotic material austenitic stainless steels during machining. However, difficulties in machining of austenitic stainless steels remained unchanged. An effective approach is still not available. Also machining of AISI 304 austenitic stainless steel using TiN/TiAlN coated tool deposited by "Cathodic arc evaporation" technique is not reported. Considering all the above facts the present work aims to study the influence of different machining parameters on the machinability characteristics using TiN/TiAlN hard coating deposited with Cathodic arc evaporation" technique on cemented carbide tools.

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Table 1: Chemical Composition of the Workpiece Materials

Elements	C	Si	Mn	P	S	Cr	Mo	Ni	Al	V
% by Wt	0.07	0.59	1.20	0.03	0.02	18.53	0.21	8.75	0.001	0.03

2. Experimental Details

The machining tests were performed by TiN/TiAlN coated inserts for continuous turning of 18/8 AISI 304 austenitic stainless steel with chemical composition shown in Table 1. The workpiece specimens were 300 mm long and 80 mm in diameter. ACE CNC LATHE JOBBER XL was used for conducting the machining trials. The machining tests were performed as per the recommendations of ISO 3685.

The fine-grained uncoated K20 grade cemented carbide turning inserts (KENNAMETAL Make) were coated with TiN/TiAlN hard coating obtained from Hrithik Tools Pvt. Ltd, India. Cathodic arc evaporation technique is used to for deposition of TiN/TiAlN coating on the cutting insert. The ISO designation of insert and tool holder were CNMG12408 and PCLNR2525M12.

Figure 1(a) shows the EDAX profile of TiN/TiAlN hard coating. The calo-test was used for coating thickness measurement, which is shown in Fig.1 (b). The length of the specimen was 250 mm and diameter was 90 mm. The cutting temperature at the interface was measured specially developed work tool thermocouple and calibration setup. Also, forces in the turning were measured using Kistler 9257A three-component piezoelectric dynamometer. The turning tests were conducted at cutting speeds in the range of 100 to 340 m/min, feed in the range of 0.08 to 0.20 mm/rev keeping depth of cut constant at 1 mm.

2.1 Tool-work thermocouple and calibration set-up

The tool-work thermocouple method was used to determine the thermal e.m.f. signals generated at a hot junction produced by the top layer of the coating and the workpiece as shown in Fig. 2(b). In this experimental set-up tool and workpiece contact point acted as the hot junction and the other end of the workpiece and the tool acted as a cold junction. One wire was connected to the rear end of the workpiece (cold junction) through carbon brush and was taken to multi-meter. Another wire was screwed to the cutting insert (hot junction) and was connected to multi-meter. Circuit is completed when tool and workpiece came in contact. In order to avoid the generation of secondary e.m.f., both tool and workpiece was insulated properly during machining and calibration process.

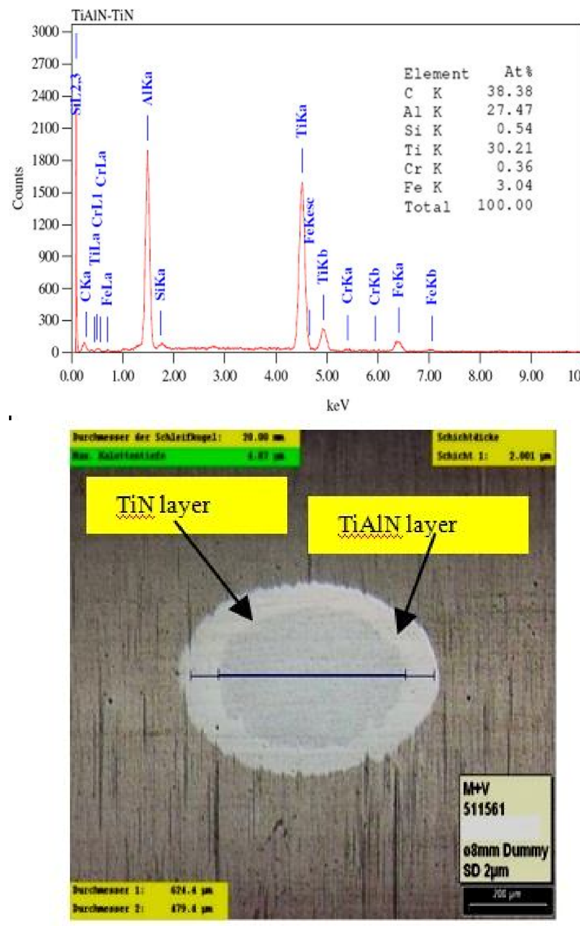

Fig.1. (a) EDAX Profile and (b) Calo-test Image for Coating Thickness of TiN/TiAlN Coating

3. Result and Discussion

3. Average chip-tool interface Temperature

Experiments were conducted at cutting speeds in the range of 100 to 340 m/min, feed in the range of 0.08 to 0.20 mm/rev keeping depth of cut constant at 1 mm. For each cutting test thermo-electric e.m.f. was measured. In order to establish the relationship between the e.m.f. generated and the corresponding temperature, a calibration set-up was developed as shown in Figs. 2(a) and (c). In this set-up tool-work thermocouple junction was formed using a TiN/TiAlN coated carbide insert and long continuous chip. A heating coil was used for heating the junction point of coated insert and chip. A standard K-type thermocouple wire was mounted just near the junction point and connected to temperature indicator. E.M.F. generated between the hot junction and cold junction was monitored by a digital multi-meter. The linear relationship obtained for the TiN/TiAlN coated carbide tool and AISI 304 austenitic stainless steel is shown in Fig. 3.

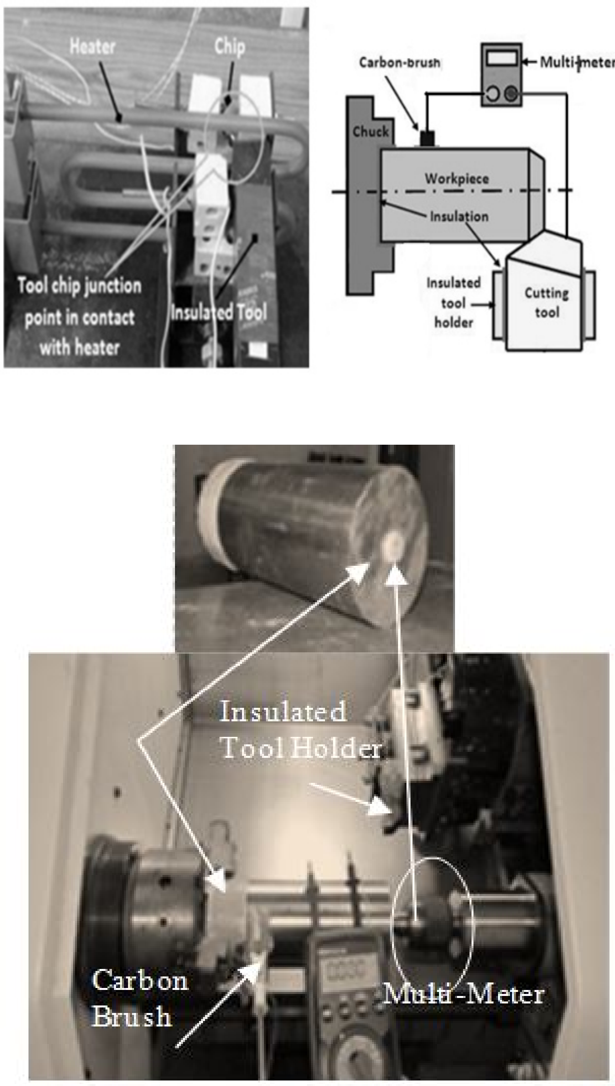

Fig. 2. (a) Calibration Set-up (b) Schematic Experimental Set-up (c) Experimental Set-up

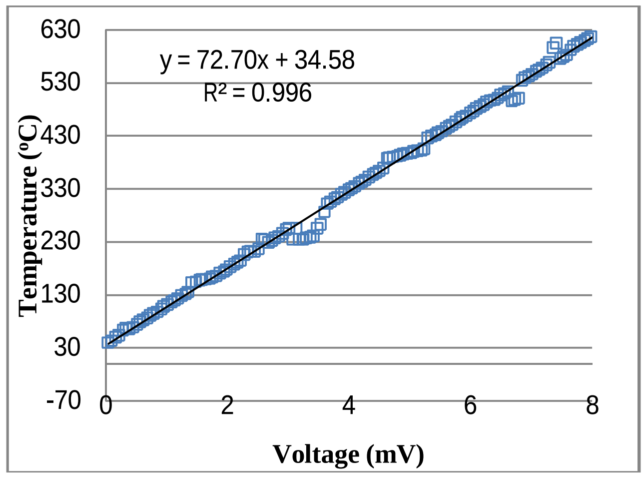

Fig. 3. Calibration Curve for TiN/TiAlN Coated Carbide Insert and AISI 304 Workpiece

A tool-chip interface temperature model considering the effect of cutting speed and feed at constant depth of cut (1 mm) was developed based on experimental data. The average interface temperature results were analyzed using the least error square method using DataFit software. A chip-tool interface temperature model is expressed as below.

$$\mathbf{T = 296 * V^{0.26} * f^{0.11}}$$

where ,

T- Average chip-tool interface temperature (°C)

V- Cutting speed (m/min)

F - Feed (mm/rev)

The R-squared values of model are 0.99 ,which indicates that the developed model is reliable and could be used effectively for predicting the average chip-tool interface temperature during turning for the given tool and work material pair and within the domain of the cutting parameters.

Curves showing the interface temperature by varying one of the input parameters and keeping other parameters constant are plotted using developed models. Figs. 4(a) and (b) depict the variation of chip-tool interface temperature with cutting speed, feed at constant depth of cut(1mm), respectively. It can be seen that the interface temperature increases with increase in cutting parameters and is higher because of poor thermal conductivity of the coating as well as AISI 304 work material. However, cutting speed has more prominant effect than feed on the chip-tool interface temperature.

3.2 Cutting Force

In turning operation three force components exists viz cutting force, feed force and radial force. The cutting force acts along the direction of cutting speed (tangential to turned surface). The cutting force plays major role in determining the machinability of AISI 304 work material. A cutting force model considering the effect of cutting speed and feed at constant depth of cut (1 mm) was developed based on experimental data.

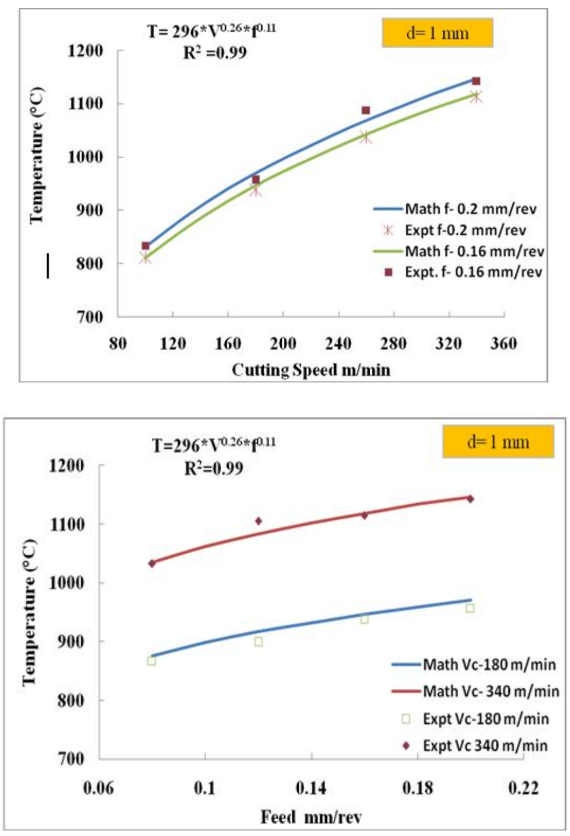

Fig.4. Variation of Interface Temperature with (A) Cutting Speed (B) Feed

The cutting force results were analyzed using the least error square method using DataFit software. A cutting force model is expressed as below.

$$Fc=3169 * V^{-0.09} * f^{0.84}$$

where ,
Fc- Cutting force (N)
V- Cutting speed (m/min)
f - Feed (mm/rev

The R-squared values of model are 0.98 ,which indicates that the developed model is reliable and could be used effectively for predicting the cutting force during turning for the given tool and work material pair and within the domain of the cutting parameters.

Curves showing the cutting force by varying one of the input parameters and keeping other parameters constant are plotted using developed models. Figs.5 (a) and (b) shows the variation of cutting force with various cutting speed and feed. It can be seen that cutting force magnitude is higher for low cutting speed and high feed rate, for a constant depth of cut (1 mm). It is because of the higher coefficient of friction between the tool and the work material compared to higher cutting speed and lower feed rates. Also, at higher cutting speed and higher feed rates the temperature generation rate is higher which makes the material soft at cutting zone. This helps in removing the material at lower cutting forces. However, feed has more prominant effect than cutting speed on the cutting force.

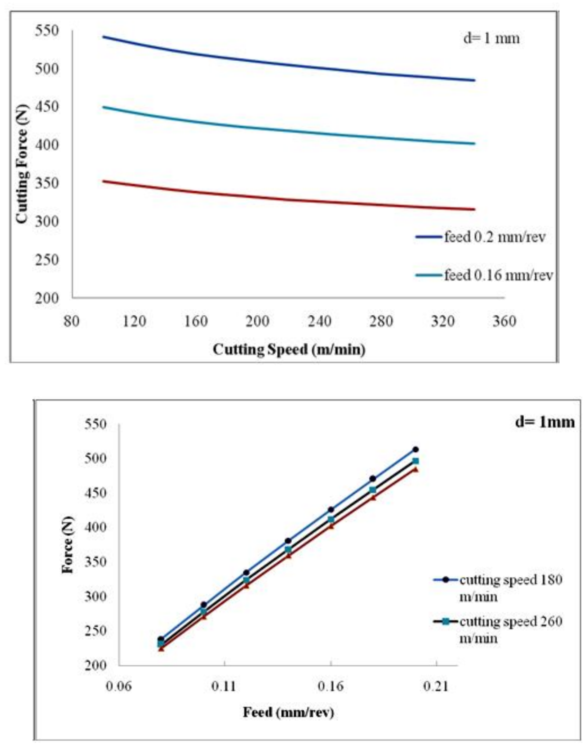

Fig. 5. Influence of (a) cutting speed and (b) feed on cutting force at constant depth of cut of 1 mm

4. Conclusions

Turning experiments on AISI 304 austenitic stainless steel were performed with multi-layered TiN/TiAlN coated carbide tool. The coating was deposited on K-grade insert using Cathodic arc evaporation technique. A chip-tool interface temperature model was developed considering the effect of cutting speed and feed at cnstant depth of cut of 1 mm. The classical tool-work thermocouple method was used to to deterine the thermal E.M.F. signals generated at a hot junction produced by the top layer of the coating and the chip. In order to establish the relationship between the e.m.f. generated and the corresponding temperature, a calibration set-up was developed. The developed regression model for interface temperature as well as cutting force shows excellent fit and predicted results are very close to the experimental results. It also showed that the developed model is reliable and could be used effectively for predicting the interface temperature and cutting force for the given tool and work material pair and within the domain of the cutting parameters. Experimental observations indicate that the interface temperature increases with increase in cutting speed where as feed is the dominant parameter for the cutting force. The interface temperature 938°C was observed at 180 m/min cutting speed and 0.16 mm/rev feed.

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