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Mechanical and tribological characterization of tools coatings for dry tapping

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Abstract: In the past years several efforts have been done to develop techniques for dry machining, at present limited to soft materials, especially in difficult machining operations like tapping. Hard materials like High Speed Steels requires the development of suitable tools surfaces. On the other hand, for reducing time and costs, a reliable forecast over the machining behaviour of the coatings would be desirable. For these purposes, a new developed nanocomposite coating, consisting of nanocrystalline TiN and amorphous Si_3N_4, was deposited on high speed steel (HSS) taps via Plasma Activated CVD and its performance tested in tapping of HSS workpieces under dry condition. Such behaviour was compared to that of TiN and TiCN coatings, traditionally employed in this field. Mechanical and tribological properties of the coatings were studied and related to machining behaviour. The nanocomposite coated tool showed higher tool life in tapping; this behaviour was explained in terms of good wear resistance and good adhesion between coating and substrate. Analysis of the results indicated characterization tests able to give a reliable forecast over the machining performance of the coatings.

Keywords: Mechanical characterization, Coating, Nanocomposite, Dry machining.

1. INTRODUCTION

Dry machining of hard materials like High Speed Steels requires the development of appropriated tools surfaces having good wear resistance, high hardness, high strength and toughness.

Previous work [1] reported the good performance in milling of HSS AISI M2 using a nanocomposite coating consisting of nanocrystalline TiN and amorphous Si_3N_4 (named Marwin®) deposited onto HM substrate. Further research work is needed to assess the effectiveness of this high performance coating with application to a more delicate cutting operation such as tapping under dry condition of the same workpiece.

For this application HM is not widely employed as substrate because of its fragility, so the nanocomposite coating was deposited onto HSS. The tapping performance was compared to that of TiN and modified TiCN, used as references.

The second goal of this paper is the research of a reliable correlation between the results of the most common laboratory tests and the cutting performances of the coatings. In fact, this is of great interest for the cutting tool makers and for the end users, since this could lead to the formulation of a test protocol for the purpose of forecasting cutting tool life. Under this framework properties like hardness, adhesion and wear resistance of the proposed coatings have been studied with the aim to correlate them with the machining behaviour.

In the following, it will be shown how the tests allow for a forecasts of the cutting performance of the taps.

2. EXPERIMENTAL

2.1. Materials

Nano-structured coating was a monolayer obtained via Plasma Activated Chemical Vapour Deposition (PACVD), consisting of nanocrystalline TiN and amorphous Si3N4 (named Marwin in the following). The other two coatings were TiN and a modification of TiCN, both obtained via PVD techniques. HSS M2 was selected as substrate

2.2. Mechanical characterization

Nanoindentation tests were performed using a nanoindenter MTS mod. XP with a berkovich indenter under a maximum load of 400 mN, with an indentation time of 90 s. The calculation of the Young's modulus and hardness was performed by the nanoindenter software TestWorks^{TM} ver. 4.06A considering a Poisson ratio of 0.22.

The coating's adhesion has been evaluated by scratch test. The corresponding critical load is taken as a coating adhesion parameter.

2.3. Tribological characterization

Friction tests and wear tests were done with a High speed and High temperature CSM tribometer. For friction tests a Pin-on disk configuration was chosen, using as pin material AISI 52100 with diameter of 1.5 mm, under dry conditions, and applying a load of 7N.

For wear tests an alumina ball with 6 mm of diameter was used under 150°C (same temperature of machining tests), applying a load of 7 N and a linear speed of 50 cm s^{-1}. The end test criterion was coating consumption.

Track depth on the samples was measured by a profilometer Form Talisurf 120. Three measurements in different points were made in each sample and the average value was calculated.

The track morphology was observed by scanning electron microscopy (SEM - Leica Stereoscan). Qualitative surface analysis was performed by energy dispersion spectroscopy (EDS).

2.4. Cutting tests

Tapping tests has been conducted using a CNC Olivetti with a peak power of 40 kW. Machined material was a HSS AISI M2 under cutting speed of 25-30 m min^{-1}, tapping length of 20 mm through, dry conditions. The end test criterion was the reduction of initial pitch diameter of 20 μm.

3. RESULTS AND DISCUSSION

3.1. Mechanical characterization

The results of nanoindentation tests are shown in Table 1. Scratch test results are shown in Figure 1, where a clear prevalence of Marwin can be observed, indicating a stronger adhesion towards the substrate.

Table 1.
Nanoindentation test

Coating		E (GPa)	Hardness (GPa)
TiN	*Mean*	542.67 ± 30.97	22.52 ± 1.00
TiCN	*Mean*	333.04 ± 57.83	26.25 ± 6.41
Marwin	*Mean*	564.14 ± 133.49	31.34 ± 7.80

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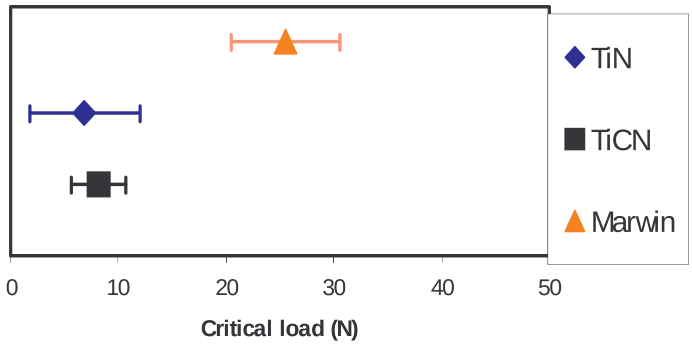

Figure 1. Scratch test results

3.2.Tribological characterization

Pin and ball on disk tests allow to gather information about friction coefficient, under the Coulomb's hypothesis, and wear behaviour of the materials [2]. The values of the friction coefficients at 150°C are shown in Table 2:

Table 2.
Friction coefficient average

Tool material	Friction coefficient av. (150C°)
TiCN	0.42
TiN	0.40
Marwin SI	0.54

Tests indicated a higher value for Marwin coating in friction coefficient.

To define wear resistance of the coatings, track depth on the sample was measured and, according to the literature, as an indicator of the ball wear, the section area of the lost volume of the ball was considered [2,3]. The test end criterion was the complete consumption of the coating, based on thickness assessed by Calotest (data omitted for sake of brevity). Results are shown in Figure 2. Combined analysis of track depth and wear area on the ball suggests Marwin coating to have the highest wear resistance. In fact, even if TiCN has similar depth, Marwin causes higher wear on the ball, indicating higher wear resistance.

SEM-EDS analysis of the tracks indicates the complete coating consumption at the end of the ball on disk test for all the samples and the presence of alumina coming from the ball. This fact indicates the wear behaviour of samples and ball in the performed ball-on- disk test was a typical third-body wear mechanism [4].

3.3. Cutting tests

Tapping tests results under 25 and 30 m min^{-1} are shown in Figure 3. It can be observed that Marwin coating shows the highest performances in this application.

Characterization tests allow to easily understand this behaviour. In fact, such new developed nanocomposite coating exhibited a slightly higher wear resistance. Furthermore, it has higher adhesion towards the substrate. It has to be noticed that, for this application, adhesion between coating and substrate is very important, especially in dry condition, when chips are not quickly evacuated and adhere on rake face, causing delamination or modifying coating composition and, in turn, its features.

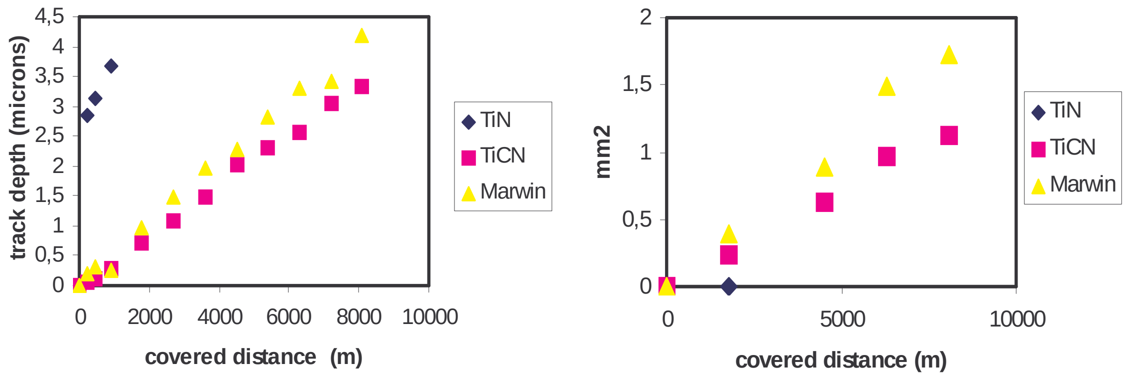

Figure 2. a) Sample track depth vs. path length; b) area on the ball vs. path length

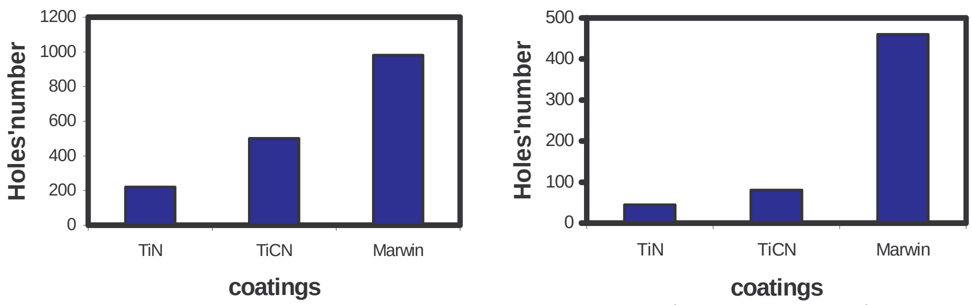

Figure 3. Results of the tapping tests under a) 25 m min^{-1}, b) 30 m min^{-1}.

4. CONCLUSION

Mechanical, tribological properties and machining behaviour of a new developed coating were analysed with the twofold aim to define its possible exploitation in tapping machining and to understand how much characterization tests can predict the cutting ability of the coatings. Marwin has been shown to have good performance also in tapping and a good correlation between laboratory and cutting tests was found.

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