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# MODIFICATION OF TIN COATINGS BY ION IMPLANTATION

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**Abstract:** The high-speed steel HS 6-5-2 cutting inserts coated with TiN were subjected to ion implantation with both silicon (dose $2x10^{17}Si^{+}/cm^{2}$) and silicon with nitrogen ions (dose $(1+1)x10^{17}(Si^{+} + N^{+})/cm^{2}$) on the subsurface layer of the rake face. Microhardness was examined before and after ion implantation. The composition and structural properties of the subsurface layer were examined by Glow Discharge Optical Emission Spectroscopy (GD-OES). The turning tests of 40H construction steel with the use of the cutting inserts implanted and non-implanted were performed. During the tests the two components of the net cutting force (the main cutting force $F_c$ and feed force $F_f$) as well as the wear parameters VB on the major flankalong with the surface roughness (Ra) were measured. The implanted inserts exhibited higher durability compared to non-implanted ones.

**Keywords:** Ion Implantation, TiN, Silicon, HSS, Turning

## 1. INTRODUCTION

Good resistance to impact loads of HSS tools means that they are still used during various types of machining. The limiting factor in their application is faster loss of cutting properties during processing at higher cutting speeds. Improving the wear resistance of these steels can be achieved using several methods, egz.: by powder metallurgy for the manufacturing (Lindskog, 1993), by the PVD processes for coatings (Keenan et al., 1998) or the use of the ion technology to modify the properties of the steels' surface layer or coatings (Hensel et al., 1989; Narojczyk et al., 2005; Zhang et al., 2004; 2007). Ion implantation into the working surfaces of cutting tools allows to change certain of their characteristics (depending on the choice of dopant elements and the parameters of the process) (Liu et al., 1995; Perez et al., 1999; Shalnov et al., 2011; Mikula et al., 2011; Baojian et al., 2014). Implanted ions change the structure and chemical composition of the surface layer (Sun et al., 2010). The consequence of these changes is an increase of the wear resistance. The research done by other authors (Gerth et al., 2008; Kieckow et al., 2006; Martev et al., 2008; Mikula et al., 2011; Musil, 2012) show that the method of ion implantation can create transition layer with specified composition which enhances the adhesion of the TiN layer into the substrate and thereby improves its utility properties.

Good example of this technology may be the modification of TiN coatings with aluminum, boron or silicon ions, which stabilize the coating at higher temperatures (Zhang et al., 2004; 2007; Yang et al., 2007; Grančič et al., 2014). The purpose of this study was to evaluate the effect of ion implantation of silicon or silicon and nitrogen into the TiN subsurface layer on the properties of the rake face of HS 6-5-2 inserts.

## 2. EXPERIMENTAL PROCEDURE

For the purpose of the study, the samples from HS 6 – 5 – 2 (SW7M) high speed steel have been prepared in the form of SPUN 1203 04 (Fig. 1) standard inserts, and in the form of 3 mm cylinders with the diameter of 28 mm. The samples were coated with TiN (process: BALINIT®A by Balzers Sp. z o.o. Polkowice). The subsurface layer of the rake faces of all samples were subjected to ion implantation with silicon ($Si^{+}$) or silicon with nitrogen ($Si^{+} + N^{+}$) ions. Parameters of the process have been presented in Tab. 1.

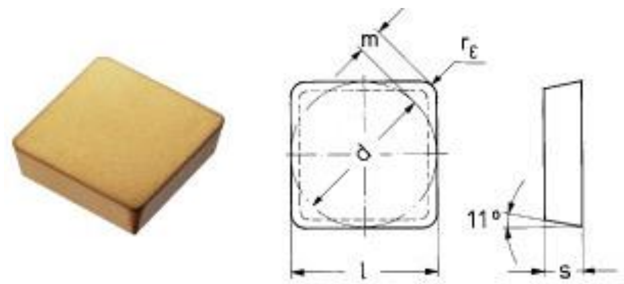


**Fig. 1.** The SPUN 1203 04 insert from HS 6 – 5 – 2 with TiN

**Tab. 1.** Parameters of high speed steel HS 6-5-2 inserts implantation.

| HS 6-5-2 Inserts | Ion | Energy |
|---|---|---|
| Non implanted | - | - |
| Implanted with $Si^{+}$ | $2x10^{17}$ $Si^{+}/cm^{2}$ | 80 keV |
| Implanted with $Si^{+} + N^{+}$ | $(1+1)x10^{17}$ $(Si^{+} + N^{+})/cm^{2}$ | 80 keV |

The implantation was carried in TITAN direct beam ion implanter with MEVVA type ion source (fig. 2). Vacuum in the

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implanter working chamber was at a level of 2÷4·$10^{-4}$ Pa and the sample temperature did not exceed 200°C.

The machining parameters were gathered in the Tab. 2. The turning tests were performed without cooling liquid. The geometry of the inserts used during machining were the following: tool clearance $\alpha_o$ = $6^0$, tool rake angle $\gamma_o$ = $5^0$, tool cutting edge angle $\kappa_r$ = $75^0$, corner radius $r_\varepsilon$ = 0.4 mm (Fig. 3).

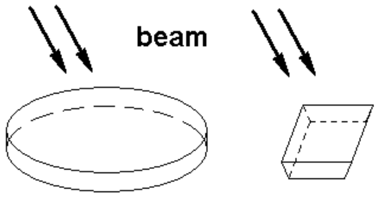


**Fig. 2.** The samples used for the tests

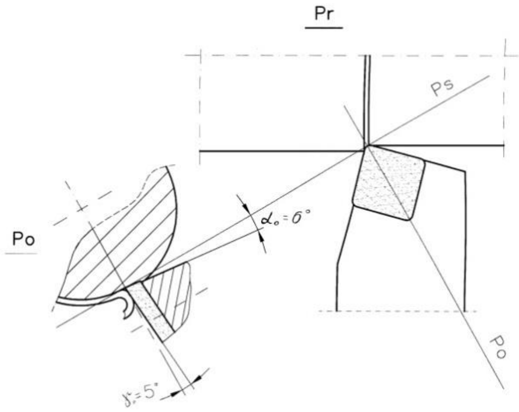


**Fig. 3.** The geometry of the insert used during turning

**Tab. 2.** Cutting conditions for the turning tests

| Cutting speed $v_c$ [m/min] | Feed rate f [mm/rev] | Cutting depth $a_p$ [mm] |
|---|---|---|
| 50 | 0.1 | 1 |

In order to determine the changes in the subsurface layer of the TiN coatings caused by implantation, the element composition analysis was performed on cylindrical samples. The Glow Discharge Optical Emission Spectrometry (GD-OES) was performed on JY 10000 RF spectroscope by Jobinn Yvon. This is a known method used for analyzing the chemical composition of the surface layers (Barbaszewski et al., 1989; Seidel et al, 1997). Atoms are sputtered from the sample surface in an argon (Ar) glow discharge. The sputtered atoms recombine with electrons in the plasma discharge. The light emitted from this recombination is analyzed using an optical emission spectrometer in order to obtain a depth profile of chemical composition (Fig. 4) (Toshiba, 2015).

The following elements were found in the surface layer: titanium (Ti), chromium (Cr), nitrogen (N), silicon (Si), tungsten (W), molybdenum (Mo), vanadium (V), and iron (Fe). Results have been presented in the Fig. 5.

Hardness measurements of layers prior and post implantation were done with the Vickers 402 MVD hardness meter by Wilson Wolpert.

Turning tests on annealed 40H steel of hardness 180 HB were performed on prepared samples. Tests were performed on AVIA Turn 30 turning machine. The wear of the samples was determined by periodic measurements of the wear parameters VB on the major flank (Fig. 6) using microscope. The measurements of the surface roughness of the machined surfaces (Ra) were performed on SJ301 by Mitutoyo after each turning (Fig. 7).

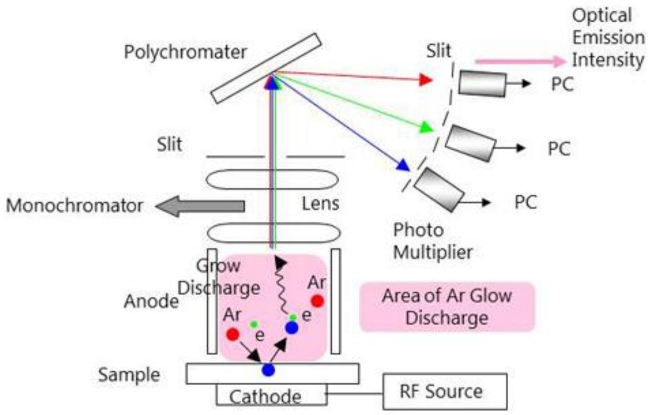


**Fig. 4.** Principle of operation RF GD-OES (Toshiba, 2015)

The forces during machining were measured with load cell dynamometer capable of measuring cutting force $F_c$ and feed force $F_f$ components. The average values were presented in the Fig. 8.

## 3. RESULTS AND DISCUSSION

The results of hardness measurements for both, implanted and non implanted TiN layers indicate a slight increase of silicon implanted layer, whereas in the case of silicon plus nitrogen implantation, the hardness decreased (Tab. 3).

**Tab. 3.** Hardness of the TiN coatings

| HS 6-5-2 Inserts | Hardness [HV0.1] |
|---|---|
| Non implanted | $940^{\pm 27}$ |
| Implanted with $Si^+$ | $965^{\pm 32}$ |
| Implanted with $Si^+$ + $N^+$ | $870^{\pm 22}$ |

The former case is the effect of introduction of the silicon ions into the crystal lattice, the latter is probably due to nitrogen ions knocking out previously implanted silicon ions from the TiN surface layer.

The results of chemical analysis of the HS 6-5-2 inserts' TiN surface layers are presented in the Fig. 5.

Implanted layers indicate the presence of silicon with maximum at a certain depth from the surface (which is innate to this kind of processes).

Measurements of HS 6-5-2 steel inserts with implanted and non-implanted coatings, conducted after machining, indicate significant wear decrease on the major flank (VB parameter), especially in the case of silicon plus nitrogen implantation (Fig.6).

Similar tendency was observed in the case of roughness measurements (Ra) (Fig. 7) of the machined surfaces, especially when silicon plus nitrogen implanted inserts were used, where Ra

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decreased by 50%.

The values of cutting forces ($F_c$) during machining with implanted samples, were observed to be smaller compared with non-implanted case. This is especially clear for the feed force ($F_f$) in fig. 8. This is probably due to the change in the conditions of friction on the rake face of the cutting insert as a result of ion implantation. Similar results were also observed by other researchers (Shalnov et al, 2011; Yang et al., 2007).

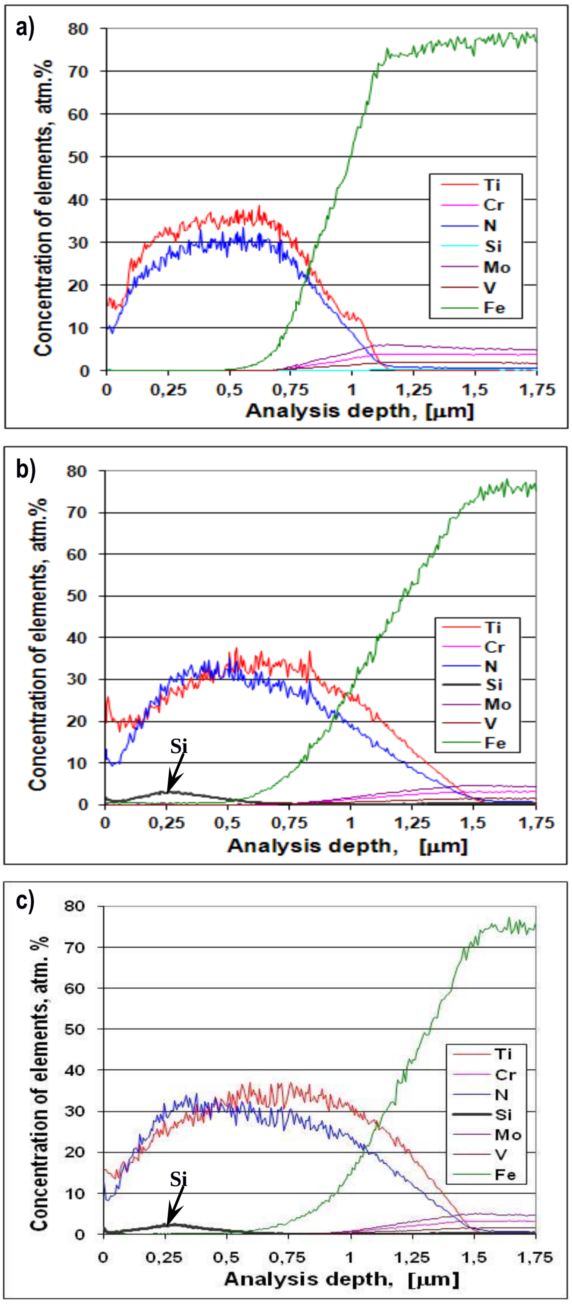


**Fig. 5.** The chemical composition of the TiN layer on high speed steel HS 6-5-2: a) non implanted, b) implanted with Si, c) implanted with Si+N

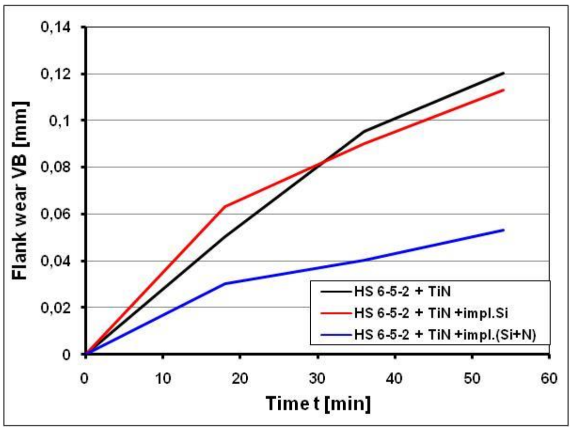


**Fig. 6.** The mean values flank wear during the turning of steel 40H with the use inserts HS 6-5-2 with TiN

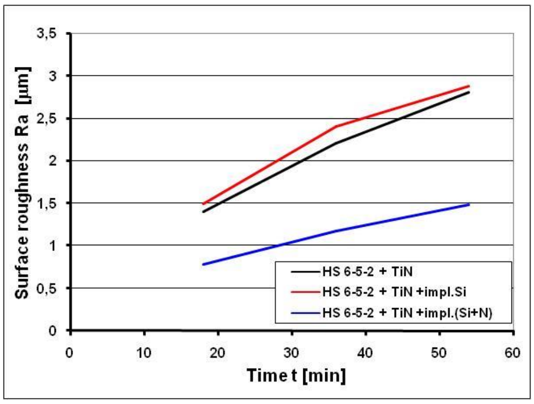


**Fig. 7.** Average workpiece surface roughness, Ra, during the turning of steel 40H with the use inserts HS 6-5-2 with TiN

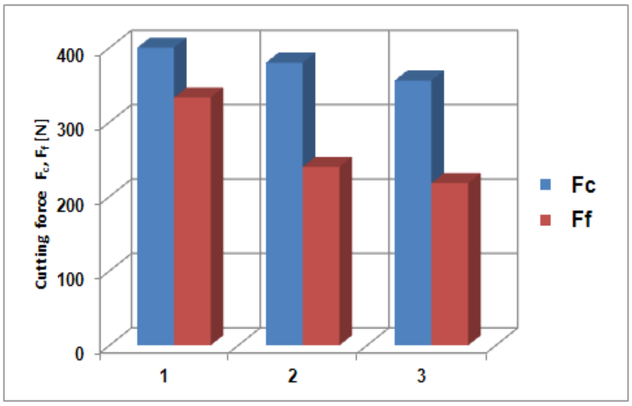


**Fig. 8.** The mean values cutting forces during the turning of steel 40H with the use inserts HS 6-5-2: 1 – TiN, 2 – TiN implanted Si, 3 – TiN implanted Si + N

## 4. CONCLUSION

Presented laboratory measurements and machining tests of the inserts made from high speed steel HS 6-5-2 with TiN coating further subjected to ion implantation with silicon and silicon plus nitrogen revealed that:

– significant decrease of the feed force Ff after the silicon and silicon plus nitrogen implantation,

- improved wear resistance on the major flank (VB) especially after the silicon plus nitrogen implantation,
- improved quality of the machined surface (Ra decrease the value to 50% after the implantation of silicon and nitrogen),
- the process of implantation of TiN coating did cause not case a significant change in the hardness of the layer.

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