Fracture toughness improvement on hard metal surfaces by ion implantation

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INTRODUCTION

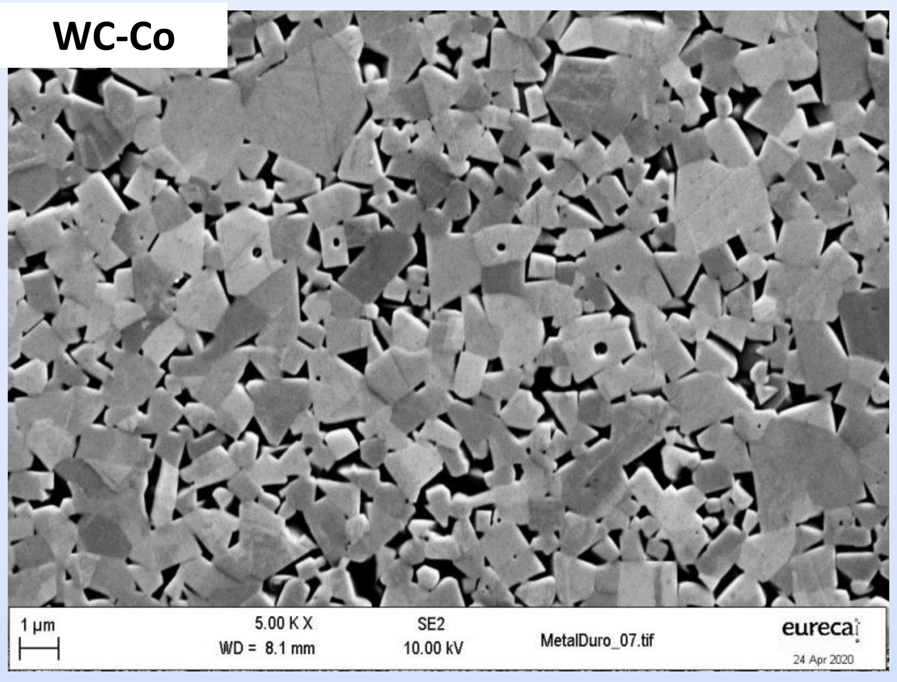
Adhesion strength is an important property required for coated cutting tools to work efficiently. Ion implantation pre-treatment of the substrate has been reported to improve adhesion strength of the coating due to a synergic improvement on fracture toughness and compressive residual stress generation. In this work Ti, Cr and N implanted WC-Co substrates have been mechanically tested and microstructurally characterized. Residual stress of the samples was evaluated using FIB-DIC technique. Implanted titanium and chromium samples show the highest value of fracture toughness. In addition, the implantation of these ions decreases the hardness and elastic modulus.

MATERIALS

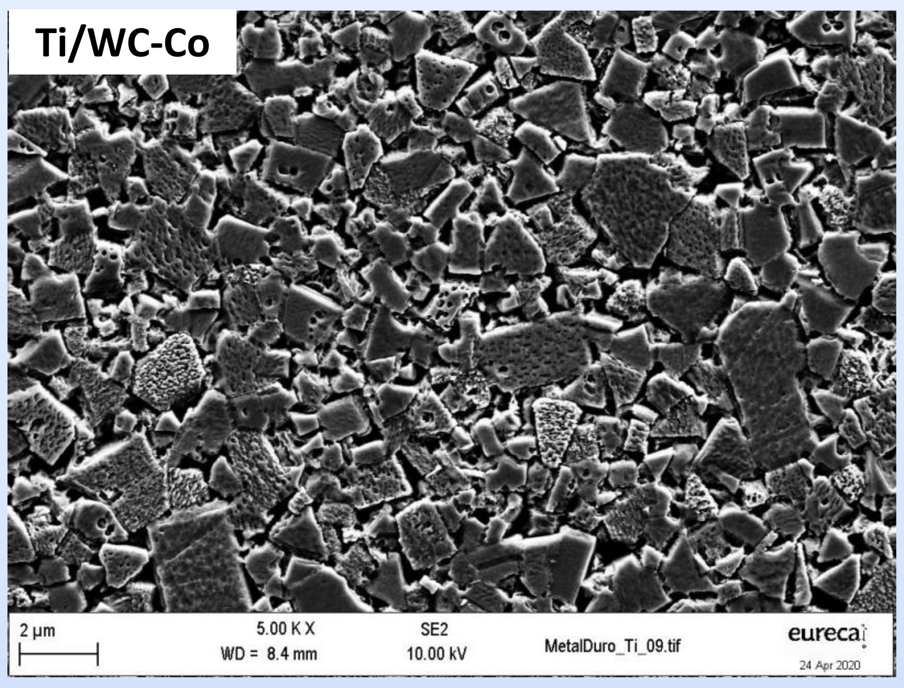
Ti and Cr were implanted via filtered cathodic arc using a pulsed high voltage source and N_2 was implanted via End-Hall ions source. The conditions for ion implantation are 60 minutes, 25kV, 45mA for titanium and chromium and 40mA for nitrogen. The ion dose was estimated to be $1.1\cdot10^{18}$, $1.1\cdot10^{18}$ and $2.5\cdot10^{18}$ ions/cm^2 for titanium, chromium and nitrogen, respectively.

Cathodic arc evaporation was used to deposit the coating. The process was carried out using the industrial equipment Platit p80, in a vacuum chamber with an argon atmosphere at 0.8-2 Pa and a negative bias voltage of -65 V. Cr and Al+Si cathodes were used as material source.

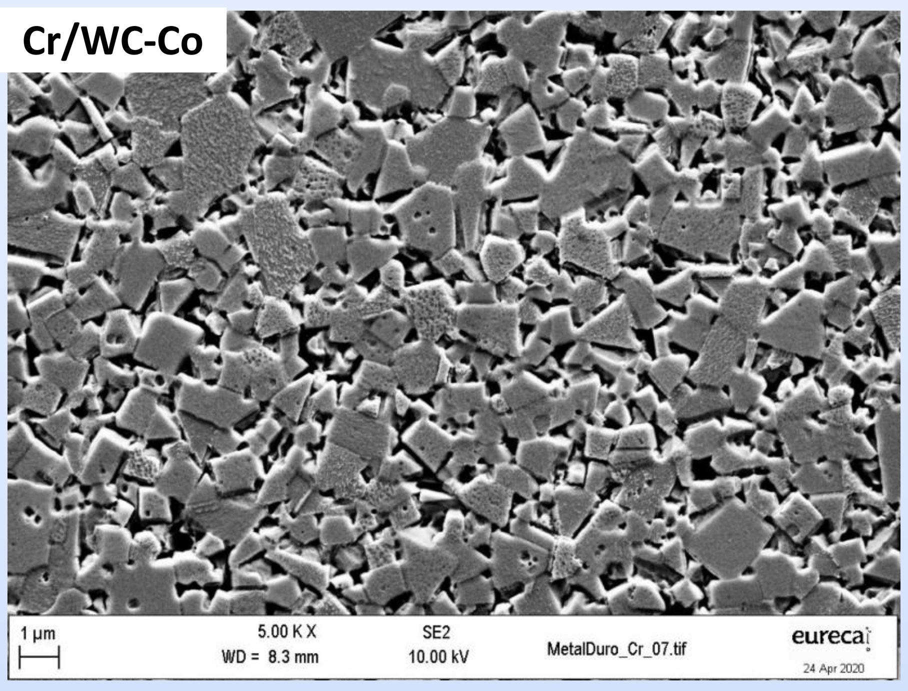
WC-Co



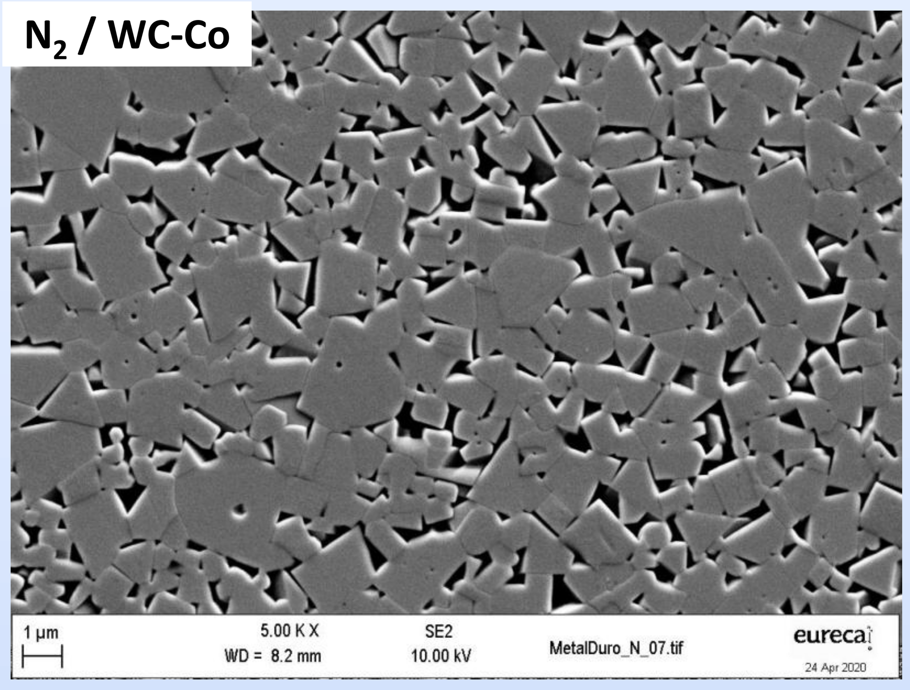
Ti/WC-Co



Cr/WC-Co



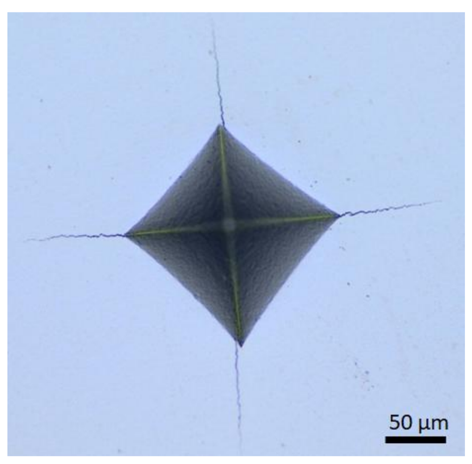
N_2 / WC-Co



METHODS AND RESULTS

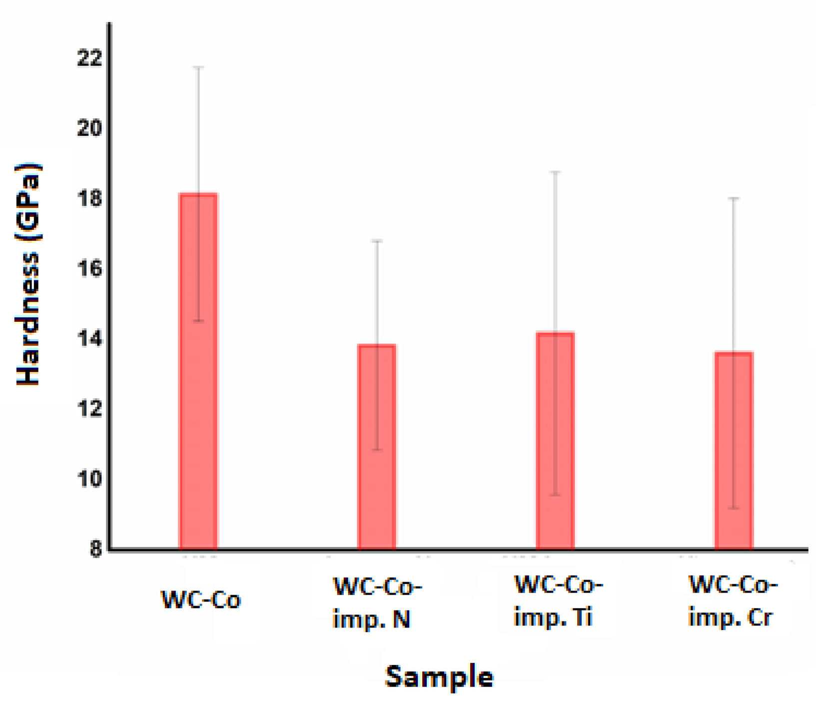
FRACTURE TOUGHNESS

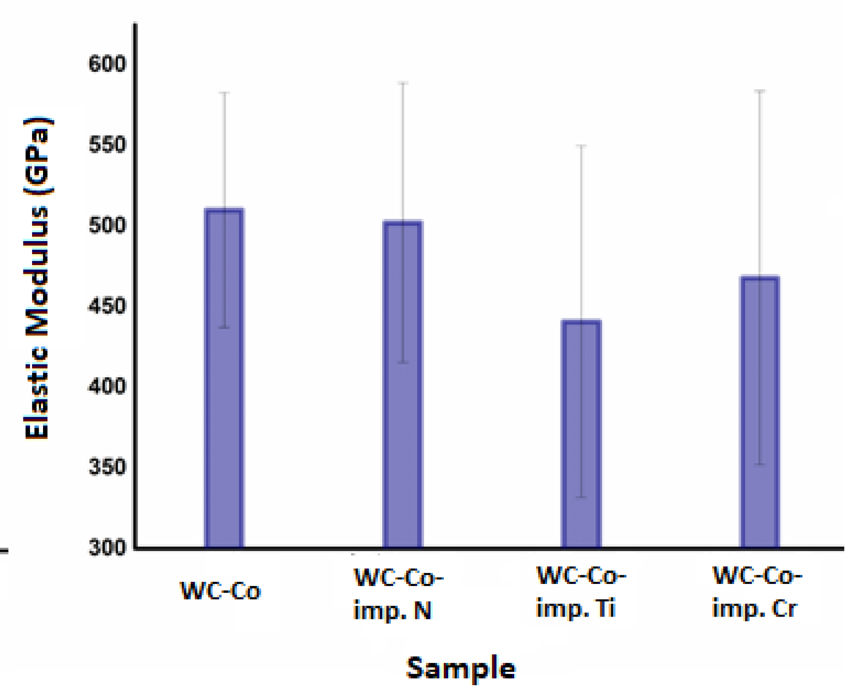
K_{IC} was determined by the indentation method (Niihara) using vickers indenter at 30kg.



Sample	Hardness (GPa)	K_{IC} (MPa·m$^{1/2}$)
Substrate	15.6 ± 0.1	12.7 ± 0.1
Imp. Cr	15.7 ± 0.2	17.1 ± 2.4
Imp. Ti	15.7 ± 0.2	15.4 ± 1.4
Imp. N	15.6 ± 0.1	12.5 ± 0.9

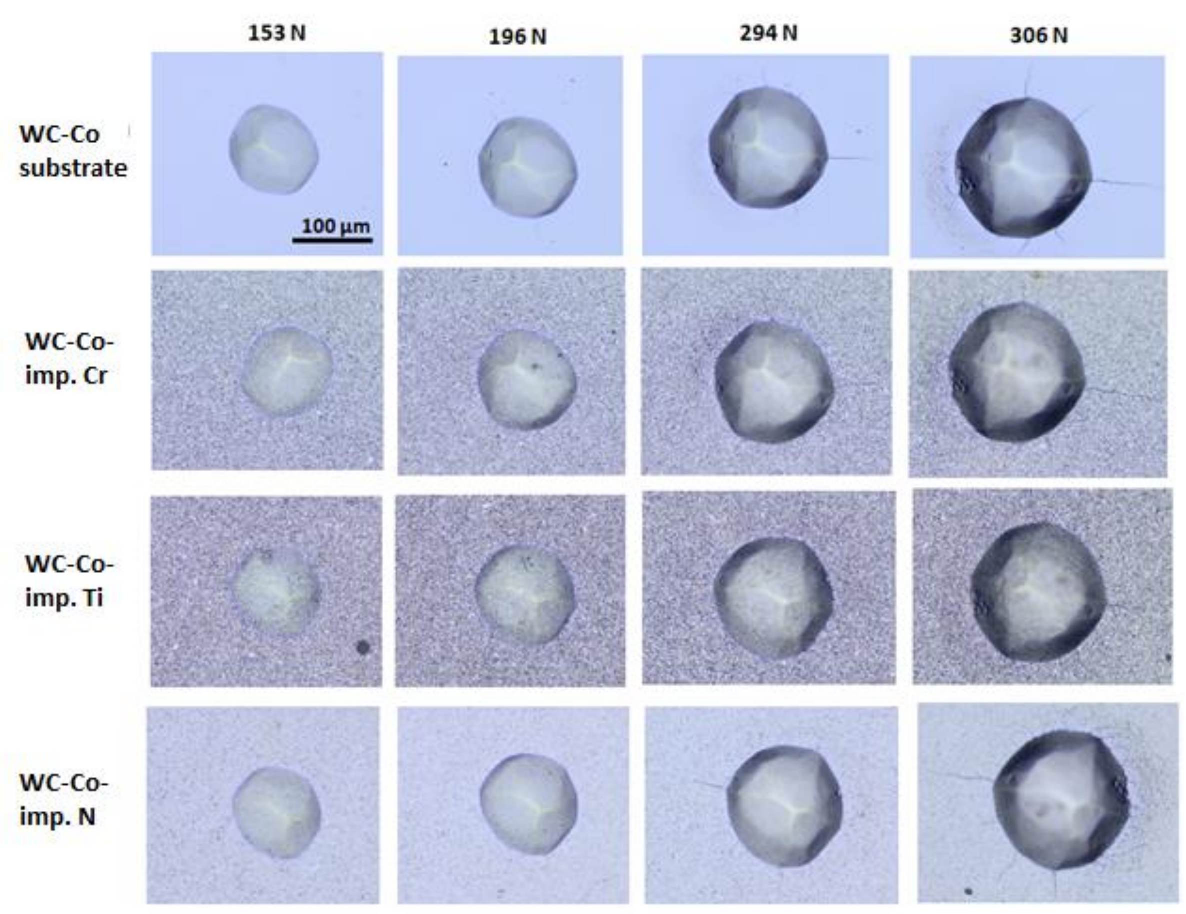
NANOINDENTATION TEST





Nanoindentation maps have been made with a Berkovich tip. With a load of 10mN, 30x30 indentations and in a space of 100x100 microns. As can be seen, the implantation of the ions decreases the hardness of the samples. Elastic modulus decreases slightly in the case of chromium and nitrogen, and notably in the case of titanium.

MERCEDES TEST



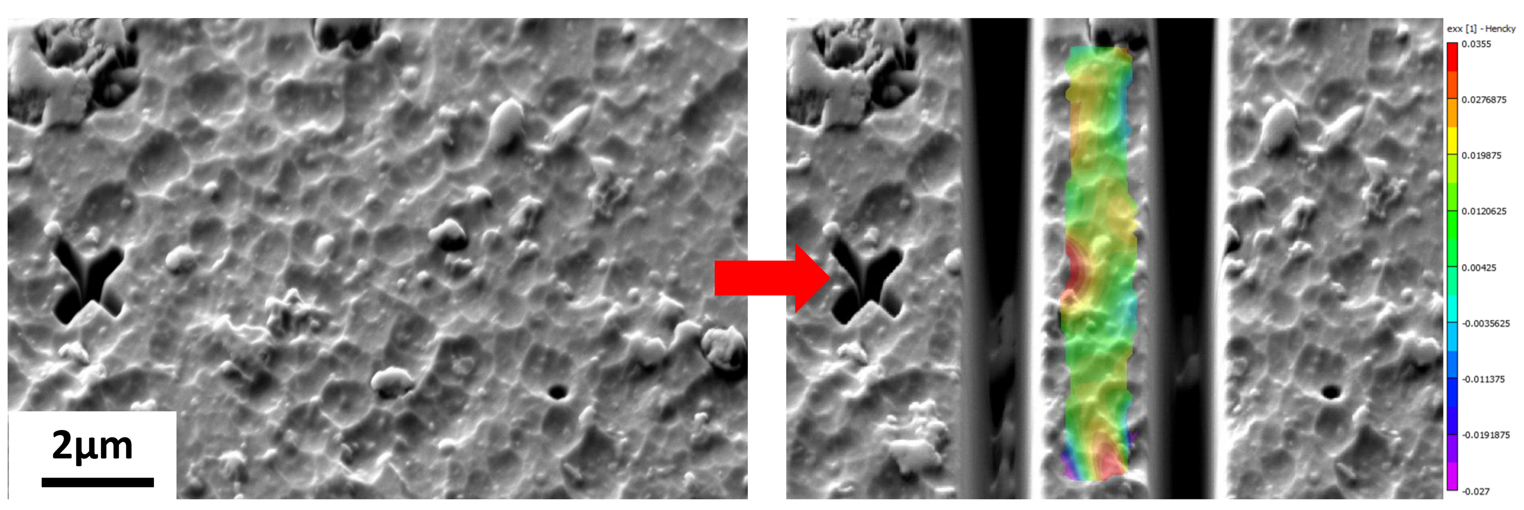
At 294N, cracks appear in the substrate and in the sample implanted with N. At 306N, all samples show cracks, with much less cracks in the samples implanted with chromium and titanium. These results are in agreement with the toughness values obtained.

RESIDUAL STRESSES

FIB-DIC technique it is based on producing strain relieve in a surface by means of focused ion beam (FIB) milled geometries and its subsequent measurement by digital image correlation (DIC). The basis is the relationship between the stress state originally present within the gauge volume of interest, which depends on the material structure and the geometry milled, and the resulting strain relaxation measured by DIC after the material has been removed by FIB milling. To calculate strain, VIC-2D-software for digital image correlation was used. Real strain field in the x direction was obtained. An average strain among the area between the slots was calculated, this average strain in x-direction was defined as ΔƐxx and was used to calculate residual stresses in *Equation 1.*

Equation 1:

$$\sigma_R = \sigma_{xx}^0 = -\Delta\varepsilon_{xx}^I \frac{E}{1-\nu^2}$$



Sample	ΔƐxx	Poisson's Ratio	Elastic Modulus (GPa)	Residual Stress (GPa)
Cr/WC-Co*	0.008 ± 0.001	0.25	468	-4.7 ± 0.3
WC-Co	It is assumed that there are no residual stresses in the substrate, moreover with the FIB-DIC technique they could not be measured because there was not enough variation in the pixels before and after milling.			

**This technique has been used only on the sample with the best properties (chromium-implanted) to compare it with the substrate.*

CONCLUSIONS

- **Fracture toughness increases in samples implanted with chromium and titanium.**
- **Implanted samples have lower hardness and elastic modulus.**
- **Compressive residual stresses have been calculated on the chromium-implanted sample.**