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X38CrMoV5-1 steel, PVD technology,
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PROPERTIES OF PVD COATINGS MANUFACTURED ON X38CrMoV5-1 STEEL FOR PLASTIC MOULDING APPLICATIONS

In plastics moulding industry a lot of parts sustain in relative movement: ejectors, slides, dies, etc. Some seizing or micro-welding may appear, especially when lubrication is not used. In this paper, PVD coatings have been obtained thanks to hybrid Cathodic Arc Evaporation system. Several properties of the coatings have been investigated such as chemical composition, microstructure, friction coefficient at ambient and high temperature conditions, nanohardness and their modulus of elasticity.

1. INTRODUCTION

Injection moulding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection moulding, which vary greatly in their size, complexity, and application. The injection moulding process requires the use of an injection molding machine, raw plastic material, and a mold. X38CrMoV5-1 is a typical tool steel commonly used in forging and plastic moulding industry for production of ejectors, slides and dies - Fig. 1. This steel is characterized by very good mechanical properties: high tensile strength, hardness, high abrasion resistance, high yield stress 2200MPa. The chemical composition in wt % of investigated X38CrMoV5-1 steel is: 0.42% C, 0.5% Mn, 1.2% Si, 5.5% Cr, 1.4% Mo, 0.3% V, Fe balance. There are a lot of tribological problems encountered in plastics moulding tools concerning different kind of wear i.e.: adhesive, abrasive, corrosive, etc [1-3]. For to solve these problems, most of the retained solutions concern hard coatings such as carbon and nitride manufactured by different CVD or PVD methods [2-4].

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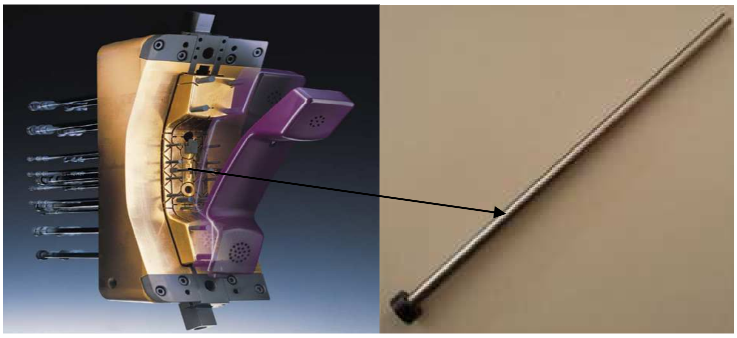
a)  b) 

Fig. 1. Ejection process of plastic part (handset) at the end of injection cycle with using ejector pins (a); picture of different nitrided stepped ejector pins (b)

In the paper two kinds of hard PVD coatings: TiC+a-C:H and MoS_2TiW have been manufactured on X38CrMoV5-1 steel samples with using hybrid Cathodic Arc Evaporation system and compared. After a brief description of the process, identification and properties of appropriate coatings such as microstructure, friction coefficients, nanohardness and modulus of elasticity were taken into consideration. Tribological tests were conducted at ambient conditions 25°C but also at the high temperature 200°C because in some cases, moulds are heated in this range of temperature.

2. STAND FOR DEPOSITION OF PVD PROTECTIVE COATINGS

For deposition of TiC+a-C:H and MoS_2TiW coatings on X38CrMoV5-1 circular steel samples of ø 30mm the modified hybrid PVD Cathodic Arc Evaporation - PVD CAE system has been used. The process of manufacturing of these coatings has been realized using multisource, hybrid factory-scale equipment type URM 079, which allows for deposition of coatings by physical method in the Institute of Materials Science at Technical University of Lodz [5-7]. This device is equipped with two independent continuous arc power supplies with magnetic filtration of microdrop for production of metallic plasma - maximum discharge current 180V, two pulsating carbon plasma power supplies -average pulse power 1kW and magnetron source - power 10kW with flat circular target of 100mm of dimension. It allows for plasma cleaning of the surface by four independent ionic guns - 4 kW/100mA in argon atmosphere. Polarization voltage of substrate in range of high voltages is controlled from 800-2500V, however in range of low voltages from 0-200V. Nominal vacuum is below $1{,}0x10^{-4}$ Pa.

3. SURFACE PREPARATION OF X38CrMoV5-1 STEEL SAMPLES

Polishing process of samples made of X38CrMoV5-1 steel has been carried out using Phoenix Beta 2, Buehler-Germany dual platen grinder-polisher machine equipped with

Vector power head - Fig. 2. This stand is on equipment of Department of Production Engineering of Technical University of Lodz. The technological conditions of realized operations of grinding and polishing have been shown in Table 1. Elaborated technological process has ensured suitable preparation of samples, in range of required roughness parameters and their proper purity (including removal of machining products). The surface of polished samples has had silver, glossy colour and no visible tool marks.

Fig. 2. The overall view of the Beta 2 dual platen grinder-polisher machine equipped with Vector power head and specimens holder

Table 1. Conditions of technological process of X38CrMoV5-1 steel samples preparation

Process stages	**Abrasive surface**	**Type of abrasive material**	**Lubricant type**	**Process time [min]**	**Feed force [N/cm^2]**	**Rotation speed of platen V [m/s]**
Grinding	BuehlerMet silicon carbide abrasive paper	Silicon carbide SiC P 600 (grits size ø 26µm)	Water	5	20	6
	BuehlerMet silicon carbide abrasive paper	Silicon carbide SiC P 1200 (grits size ø 15µm)	Water	3	10	3
Lapping	Medium hard woven silk cloth VerduTex	Monocrystalline diamond suspension MetaDi -oil based (grains size ø 3µm)	Oil-based polishing extander Buehler AutoMet Lapping Oil	2	5	2
Polishing	Soft synthetic pad ChemoMet	Aluminium oxide (Al_2O_3) final polishing suspension MasterPrep (grains size ø 0,05µm)	-	2	5	1

4. MORPHOLOGY OF SURFACE LAYER OF PVD COATINGS

The morphology of TiC+a-C:H and MoS_2TiW coatings has been assessed basing on scanning electron microscope - SEM images. For investigations scanning electron microscope Philips XL 30 has been used. Presented investigation results concern comparison of morphology of X38CrMoV5-1 steel samples after polishing process and with manufactured TiC+a-C:H and MoS_2TiW coatings - Fig. 3.

a) b) c)

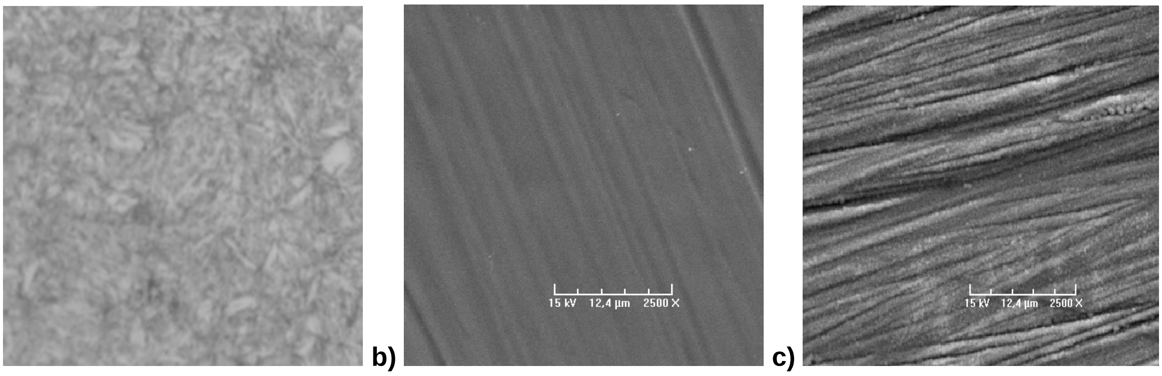


Fig. 3. Images of X38CrMoV5-1 steel samples obtained by scanning electron microscope - SEM: a) without PVD coating (magnification x 1000), b) surface with TiC+a-C:H coating (mag. x 2500), c) surface with MoS_2TiW coating (mag. x 2500)

These images have revealed significant changes in morphology of surface layer. SEM images of X38CrMoV5-1 steel samples without PVD coating - Fig. 3a have shown no visible scratches or impurities, what means that their surface layers have been correctly prepared.

X38CrMoV5-1 steel samples with manufactured TiC+a-C:H coatings - Fig. 3b have been characterized by smooth structure however with manufactured MoS_2TiW coatings - Fig. 3c have been characterized by irregular structure imaging probably different forms in manufactured coatings.

5. IDENTIFICATION OF PVD COATINGS

Identification of TiC+a-C:H and MoS_2TiW coatings manufactured on X38CrMoV5-1 steel samples has been done using Energy Dispersive X-ray Spectroscopy - EDS. This is an analytical technique commonly used for the elemental analysis or chemical characterization of the samples.

The measurements have been carried out using SEM microscope - Philips XL 30 equipped with electron microprobe X-ray analyser EDAX in Materials Department of École Catholique d’Arts et Métiers - ECAM in France. The X-ray spectrums have been presented in Fig. 4.

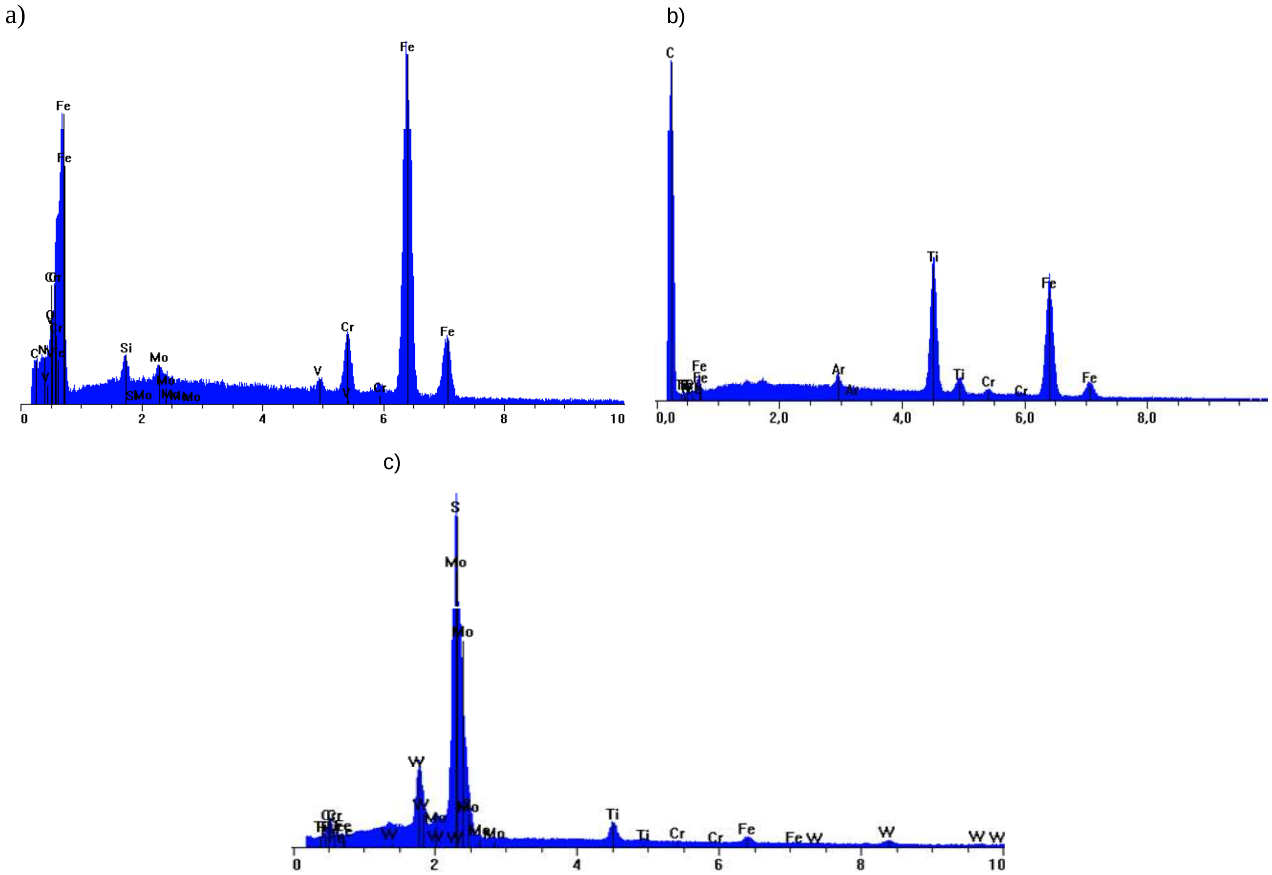


Fig. 4. EDS investigation results of X38CrMoV 5-1 steel samples: a) without PVD coating, b) with TiC+a-C:H coating, c) with MoS_2TiW coating

The obtained results have shown that predominant components in chemical composition of X38CrMoV 5-1 steel samples have been Fe, Cr, Mo, Si and V - Fig. 4a, with manufactured TiC+a-C:H coating: C, Ti, Fe, Cr - Fig. 4b and with manufactured MoS_2TiW coating: S, Mo, W and Ti - Fig. 4c.

6. MEASUREMENTS OF FRICTION COEFFICIENT OF PVD COATINGS

Tribological investigations of TiC+a-C:H and MoS_2TiW coatings manufactured on X38CrMoV5-1 steel samples have been done with using computer-controlled high temperature tribometer (CSM Instruments SA-Switzerland) with using steel (100Cr6) balls as a counter-samples. Tribological tests have been conducted at ambient conditions 25°C and at the high temperature 200°C. Results have been elaborated with using TriboX Software. Parameters of the friction coefficient test have been as follows: load - 5N, ball radius - 6mm, average velocity - 10 cm/s, distance 200-800m. The results of friction coefficient measurements of uncoated X38CrMoV5-1 steel samples have been presented in Fig. 5.

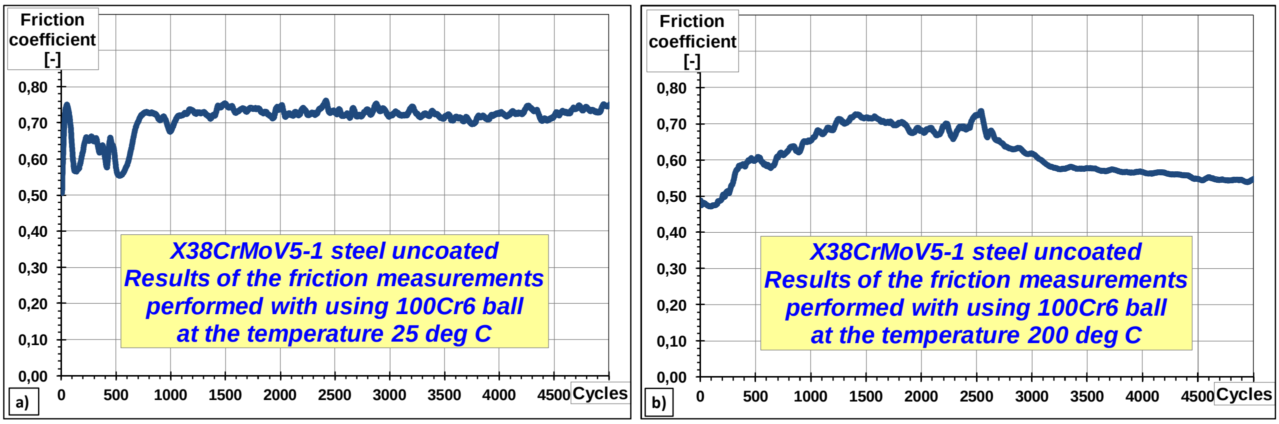


Fig. 5. Friction measurements of X38CrMoV5-1 steel uncoated: a) at the temperature 25ºC; b) at the temperature 200ºC

Investigation results have shown that friction coefficient of uncoated X38CrMoV5-1 steel samples with using steel (100Cr6) balls as a counter-samples has been high in ambient conditions 25ºC and has been equal after 200 meter test to 0,7. However in high temperature 200ºC the friction coefficient decreased after 200 meter test to value 0,55.

The results of friction coefficient measurements of X38CrMoV5-1 steel samples with manufactured TiC+a-C:H and MoS_2TiW coatings have been depicted in Figs. 6-7.

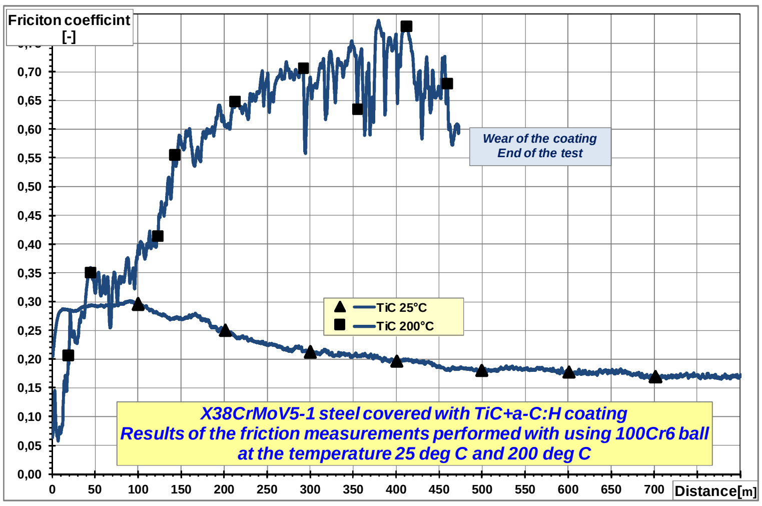


Fig. 6. Comparison of results of friction coefficient measurements of X38CrMoV5-1 steel with TiC+a-C:H coating at the temperature 25 and 200ºC performed with using 100Cr6 ball

Investigation results has shown that measured friction coefficient of X38CrMoV5-1 steel samples with TiC+a-C:H coating performed with using 100Cr6 ball after 800 meter test has decreased from 0,3 to 0,18 at the temperature 25°C, however at the temperature 200°C the friction coefficient has increased rapidly from 0,1 to 0,7 after 400 meters - Fig. 6. In case of X38CrMoV5-1 steel samples with MoS_2TiW coating the measured friction coefficient after 800 meter test has increased only from 0,12 to 0,16 at the temperature

25°C, however at the temperature 200°C the friction coefficient has increased from 0,04 to 0,08 - Fig. 7. It means that both PVD coatings significantly improved tribological properties of X38CrMoV5-1 steel, which friction coefficient is equal to 0,55-0,7 - Fig. 5, however in high temperatures better results have been observed for MoS_2TiW coating.

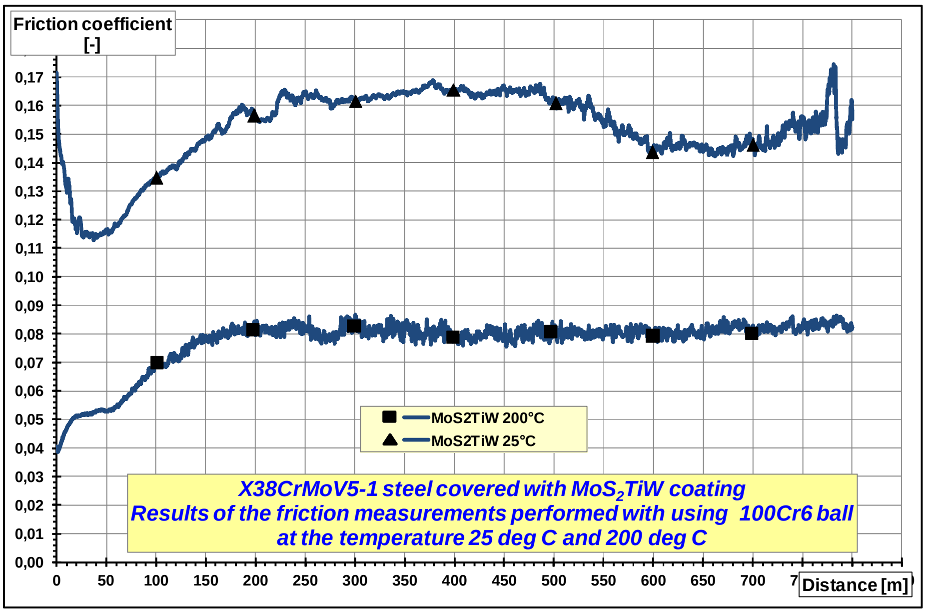


Fig. 7. Comparison of results of friction coefficient measurements of X38CrMoV5-1 steel with MoS_2TiW coating at the temperature 25 and 200°C performed with using 100Cr6 ball

7. NANOHARDNESS AND MODULUS OF ELASTICITY INVESTIGATIONS OF PVD COATINGS

Nanohardness and longitudinal modulus of elasticity of PVD coatings has been measured using Nano Intender® G200 equipment, MTS Nano Instruments-USA, equipped with a Berkovich diamond pyramidal penetrator. The measurements of nanohardness have been conducted with using Continuous Stiffness Measurement - CSM method This method is perfect for measurements of thin coatings, where their properties are changing with increasing of the depth [8]. Results have been recorded and elaborated with using TestWorksPro 4 software. Representative results of nanohardness measurements of the examined TiC+a-C:H and MoS_2TiW coatings manufactured on X38CrMoV5-1 steel samples have been shown in Fig. 8.

Investigation results has shown that X38CrMoV5-1 steel samples with TiC+a-C:H coatings have had been characterized by very high nanohardness equal to 18GPa. X38CrMoV5-1 steel samples with MoS_2TiW coatings have had nanohardness equal to about 7GPa.

The results modulus of elasticity of TiC+a-C:H and MoS_2TiW coatings manufactured on X38CrMoV5-1 steel samples have been shown in Fig. 9.

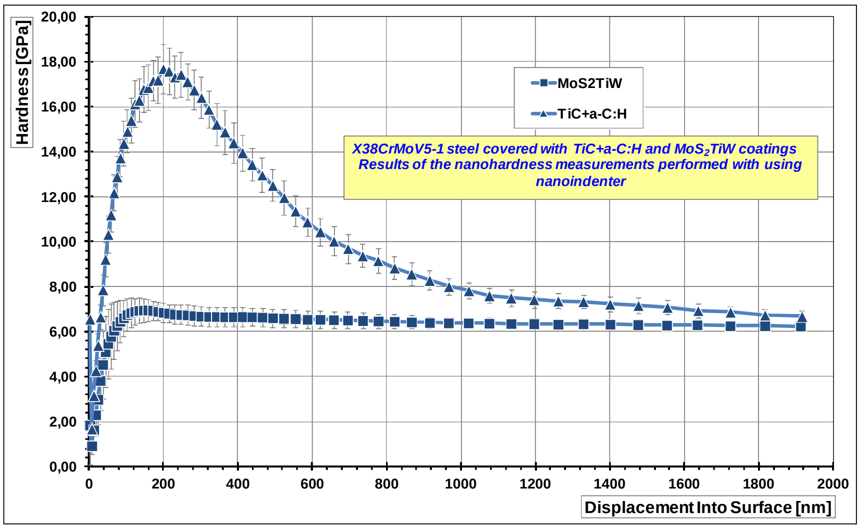


Fig. 8. A comparison of nanohardness measurements of X38CrMoV5-1 steel with TiC+a-C:H and MoS_2TiW coatings

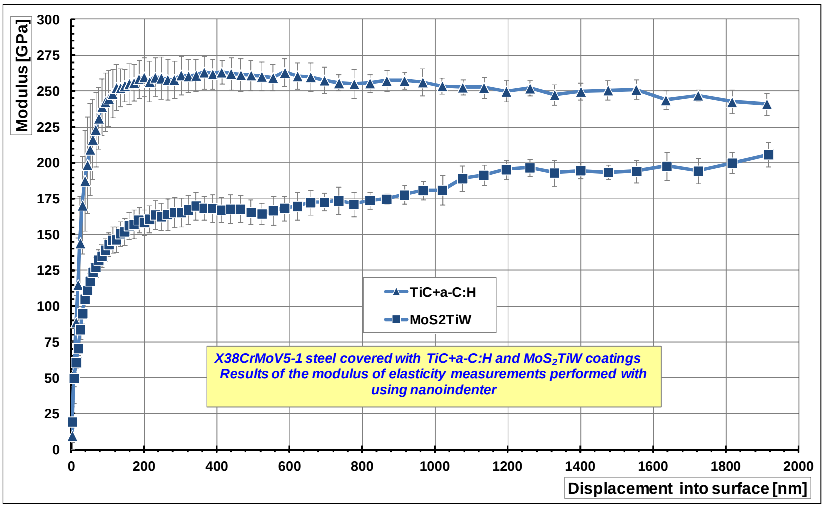


Fig. 9. A comparison of longitudinal modulus of elasticity measurements of X38CrMoV5-1 steel with TiC+a-C:H and MoS_2TiW coatings

Investigation results has shown that X38CrMoV5-1 steel samples with TiC+a-C:H coatings have had very high modulus of elasticity equal to 270GPa, however with MoS_2TiW coatings 170GPa.

8. CONCLUSIONS

Protective TiC+a-C:H and MoS_2TiW coatings manufactured on X38CrMoV5-1 steel samples have considerably improved their tribological properties. They have been characterized by low friction coefficient even in high temperatures, high wear resistance, relatively high nanohardness and longitudinal modulus of elasticity. These predispose them especially for plastic moulding applications i.e. in production of ejector pins.

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