Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room Grand Exhibit Hall - Session EP

Symposium E Poster Session

EP-2 Clarification of the Relationship between Friction Behavior and Tribo-electrical Performance of Triboelectric Nanogenerator*, W Zhang,* Key Laboratory of Education Ministry for Modern Design and Rotor-Bearing System, Xi'an Jiaotong University, China*; **Pengfei Wang**, D Diao,* Institute of Nanosurface Science and Engineering, Shenzhen University, China

Ever since the concept of triboelectric nanogenerator (TENG) was proposed in 2012, the TENG attracted much attention from researchers for its unprecedented advantages of simple fabrication, low weight, low cost and abundant choices of materials and so on. When the in-plane sliding mode TENG working, one of the friction pair sliding on the other one, sliding friction is introduced to the sliding surface and the friction behavior between two surfaces have great influence on the tribo-electrical performance (including output current, voltage and power) of TENG. However, until now the law between friction behavior and tribo-electrical performance is unclear and it limits the journey of TENG's widely practical utilization. Moreover, the research about the relationship between friction behavior and tribo-electrical performance of TENG isn't receiving enough attention . The target of this research is to clarify the relationship between friction behavior and tribo-electrical performance of TENG.

In this work, graphene sheets embedded carbon (GSEC) films were fabricated by mirror confinement electron cyclotron resonance (MCECR) plasma sputtering method under low-energy electron irradiation and Polydimethylsiloxane (PDMS) are selected as the friction pair materials of in-plane sliding mode TENG. The electrometer and independently designed reciprocating tribometer was used to obtain the output current, voltage and the friction behavior of GSEC film based TENG, respectively. Moreover, the dependence of the short-circuit current and open-circuit voltage on the external loading resistance and the output power as a function of variety resistance of the GSEC film based TENG was obtained with connecting different resistance during measurements. It believed that with the friction coefficient increasing, so did the output current and voltage of GSEC film based TENG, but the energy conversion efficiency decrease. On the contrary, when the friction coefficient decreases, the tribo-electrical performance of GSEC film based TENG decrease slightly but the energy conversion efficiency increase dramatically. The clarification of the relationship between the friction behavior and tribo-electrical performance of TENG is beneficial to improve the tribo-electrical performance as well as optimize the design of TENG.

EP-4 Effect of Cr Content and Various Interlayers on Mechanical Properties of CrAlN Coatings Synthesized by UBMS*, **HoeKun Kim**, J La, M Song, S Lee, Y Hong,* Korea Aerospace University, Republic of Korea

Transition metal nitride coatings are very attractive materials because of their excellent mechanical properties. Especially, the CrAlN coatings have been paid much attention to cutting tool's film due to their high hardness, low surface roughness and excellent thermal stability.In this work the influence of Cr content and various interlayers on mechanical properties of CrAlN coating was investigated. In order to control the Cr content the pulsed DC current was adjusted between 0.4 and 2.0 A, and various interlayers such as CrN, CrZrN, CrN/CrZrSiN were synthesized between the CrAlN coating and the WC substrate. The microstructure, residual stress, hardness and elastic modulus, and friction coefficient were evaluated by field-emission scanning electron microscopy (FE-SEM), laser reflectance system, nano-indentation, and ball-on-disc type wear tester, respectively.

When the Cr content in the CrAlN coatings increased from 0.11 to 0.24 at.%, the hardness and compressive residual stress were measured to be in a range from 31 to 41 GPa, and from 4.3 to 5.7 GPa, respectively. Hardness enhancement could be attributed to the solid solution hardening, in that with Cr insertion. The lattice distortion in the coating developed, and this leads a compressive residual stress enhancement. Therefore, the dislocations became more and more difficult to move, and the hardness of coatings gradually increased. After the scratch test, the critical load of the CrAlN coatings gradually decreased from 48 to 41 N. Generally, the high residual stress causes the low adhesion, and the compressive residual stress could be considered as a factor on the adhesion decreasement. During the wear test, the friction coefficient of the CrAlN coatings with the CrN and CrN/CrZrN interlayer exhibited improved values of 0.34 compared to that of the CrAlN coating with the CrZrN interlayer (COF 0.41). These improved friction coefficient could be attributed to the H/E ratio of the interlayer between the CrAlN coating and the WC substrate. In view of the coating structure, there exists a gradual increase in the H/E ratio from the WC substrate (H/E, 0.040), to the CrN interlayer (H/E, 0.076), and CrZrSiN interlayer (H/E, 0.083), and the CrAlN coating (H/E, 0.089). The CrN and CrZrSiN interlayers induced a smooth transition of the stress effectively under loading conditions, and wear properties could be improved significantly by structuring the coating with an optimal gradient of the H/E ratio of the coating/interlayer/substrate.

EP-5 Effect of Boride Coating on Hydrogen Embrittlement of AISI 8620 Steels*, **MarcoAntonio Doñu Ruiz**, N Lopez Perrusquia,* Universidad Politecnica Del Valle De Mexico, Mexico*; V Cortes Suarez, J Romero Serrano,* Univerisdad Autónoma Metropolitana, Mexico*; M Reyes Cortes,* Universidad Politecnica Del Valle De Mexico, Mexico

The present work studied the effect of boriding coatings on hydrogen embrittlement on AISI 8620 by means the mechanical behavior. The formation of boride were carry out at three different temperatures (1173, 1223, and 1273K) for 6 hours of exposure time by dehydrated paste pack method. After boronizing, the presence of the boride coatings were observed scanning electron microscopy (SEM), X-ray diffractometer and energy dispersive spectroscopy (EDS) analysis.

Hydrogen was introduce into samples with boride coating through cathodic charging applying a current density of 50 mA/cm^2 by 0.5 M sulphuric acid solution kept at a room temperature.

The mechanical behavior of boride coating with hydrogen diffusion were used the following experimental techniques: Vickers micro-hardness, Daimler-Benz Rockwell-C indentation and three-point bend test. As a result of the hydrogen diffusion on sample boride, the borided layer thickness decrease and microhardness tests showed a significant increase in the surface hardness caused by the increased boronizing temperature, moreover the adhesion strength in all condition obtained sufficient cohesion. Finally, three point bend tested show a drastic reduction in ductility and increase the fracture stress value.

EP-6 Characterization and Wear of Co-Cr-Mo-Si Alloy Coatings at High Temperatures*, L Amaral,* Universidade Federal do Paraná, Brazil*; E Nascimento,* Universidade Técnológica Federal do Paraná, Brazil*; **AnaSofia D'Oliveira**,* Universidade Federal do Paraná, Brazil

CoCrMoSi alloys were developed for high temperature applications particularly to resist liquid metal corrosion, due to the distribution of the Laves phase. However, the range of properties of this alloy system allows for uses well beyond the original scope. The metallurgical stability of CoCrMoSi coatings exposed to temperature has been shown to be associated with the stability of Laves phase. The successful use of coatings for high temperature applications requires the understanding of oxidation behavior and influence of the oxide layer on wear. This research focuses on the study of the abrasive wear behavior of CoCrMoSi coatings exposed at 450C and 750C for 6h in an air furnace. The aim is to characterize the oxides formed at the surface of coatings and their role on wear. The CoCrMoSi alloy was deposited by Plasma Transferred arc on AISI304 stainless steel plates (120mmx100mmx12mm). Abrasive wear tests were carried out on a rotating ball apparatus with applied loads ranging from 0.2N to 0,45N. The low loads intended to magnify the impact of surface oxides on wear behavior. For each surface a set of wear tests was carried out with small increments on the applied load until the oxide film was broken and the CoCrMoSi coating started to worn. Raman spectroscopy and X-ray diffraction identified oxides at the surface. Confocal microscopy and scanning electron microscopy analysis characterized the wear scar. At the oxidation temperature used of 450ºC Co and Fe oxides form. The kinects of Co_3O_4, Fe_3O_4 and Fe_2O_3 allow for the fast oxidation of Co and Fe even at low temperatures. Under these conditions scratches were identified on the wear scar associated with the removal of oxide particles, suggesting a low adherence to the coating surface. Exposure at 750ºC resulted on a continuous oxide film of Cr_2O_3 , analysis of the wear scar reveals rolling to be the predominant mechanism. Correlation with non-oxidized CoCrMoSi coatings shows that oxides formed at 450ºC do not impact on the wear performance of coatings. Oxidation at 750ºC resulted on a reduction of friction coefficient, leading to an increase on wear resistance.

EP-7 Influence of Nitrogen Content on the Properties of CNx Coatings Deposited onto AISI H13 Steel by DC Magnetron Sputtering*, **Elbert Contreras**, F Bolívar, M Gómez,* Universidad de Antioquia, Colombia

The increasing interest for new coatings with higher properties, opened the doors to research of carbon nitrides (CNx); these coatings are attractive for industrial applications due to their its high recovery rates, low friction coefficients and wear rates, in addition to their self-lubricating properties. In this research, CNx coatings were deposited by DC magnetron sputtering, using a Graphite target and a power density of 2,4W/cm^2, deposition temperature was 250°C, working pressure of 6-7x10^{-3} mbar and a BIAS voltage of -70V, prior to the deposition an ionic cleaning was carried out to clean the surface of the substrates, the percentage of nitrogen was varied between 10% and 50% ($N_2/(Ar+N_2)$) in the gas mixture, in order to evaluate the effect of nitrogen incorporation on microstructure, composition, mechanical and tribological properties. The thicknesses around 2.0 µm were obtained for all coatings; SEM images revealed homogeneous, compact and columnar coatings; the XRD analysis showed that all coatings are completely amorphous. The micro-Raman spectra are characteristic of carbon-rich sample; these clearly show D band (*disordered aromatic rings)* and G band *(graphite).* It was also possible to identify the band associated to C-N triple bonds. The mechanical and tribological properties are affected by the incorporation of nitrogen, by increasing the nitrogen in the gas mixture, increasing the compressive residual stress and hardness; all coatings show similar tribological behavior, with smooth friction records, their low friction coefficients and wear rates are significantly low compared to others self-lubricating coatings like, VN, VSiN, CrVN, etc.

EP-9 Modelling of IN 738 LC Alloy Mechanical Properties based on Microstructural Evolution Simulations for Different Heat Treatment Conditions*, M Boyraz,* ***Bilge Imer,*** Middle East Technical University, Turkey

Conventionally cast nickel-based super alloys, such as commercial alloy IN 738 LC, are widely used in manufacturing of industrial gas turbine blades. With carefully designed microstructure and the existence of alloying elements, the blades show improved mechanical properties at high operating temperatures and corrosive environment. The aim of this work is to model and estimate these mechanical properties of IN 738 LC alloy solely based on simulations for projected heat treatment conditions or service conditions. The microstructure (size, fraction and frequency of gamma prime- γ′ and carbide phases in gamma- γ matrix, and grain size) of IN 738 LC needs to be optimized to improve the high temperature mechanical properties by heat treatment process. This process can be performed at different soaking temperature, time and cooling rates. In this work, micro-structural evolution studies were performed experimentally at various heat treatment process conditions, and these findings were used as input for further simulation studies. The operation time, soaking temperature and cooling rate provided by experimental heat treatment procedures were used as micro-structural simulation input. The results of this simulation were compared with the size, fraction and frequency of γ′ and carbide phases, and grain size provided by SEM (EDS module and mapping), EPMA (WDS module) and optical microscope for before and after heat treatment. After iterative comparison of experimental findings and simulations, an offset was determined to fit the real time and theoretical findings. Thereby, it was possible to estimate the final micro-structure without any necessity to carry out the heat treatment experiment. The output of this microstructure simulation based on heat treatment was used as input to estimate yield stress and creep properties. Yield stress was calculated mainly as a function of precipitation, solid solution and grain boundary strengthening contributors in microstructure. Creep rate was calculated as a function of stress, temperature and microstructural factors such as dislocation density, precipitate size, inter-particle spacing of precipitates. The estimated yield stress values were compared with the corresponding experimental hardness and tensile test values. The ability to determine best heat treatment conditions that achieve the desired microstructural and mechanical properties was developed for IN 738 LC based completely on simulations.

EP-10 Influence of EP Additive Containing Lubricants on the in-situ Formation of Low Friction Tribofilms on Tungsten Based Coatings*, **Bernhard Kohlhauser**, H Riedl,* Institute of Materials Science and Technology, TU Wien, Austria*; M Ripoll,* AC2T Research GmbH, Austria*; P Mayrhofer,* Institute of Materials Science and Technology, TU Wien, Austria

The reduction of the coefficient of friction combined with reduced wear rates is a major topic in many different industrial applications. Extreme-pressure (EP) and anti-wear (AW) additives as well as low friction coatings have been intensively investigated for several years to achieve this behavior. Lately, the addition of WS_2 or MoS_2 nanoparticles has been proven to be beneficial to the reduction of friction in various tribological contacts. Investigations into the application of sulphur containing lubricants in combination with tungsten functionalized or doped surfaces like W-DLC coatings revealed an additional decrease in the coefficient of friction and wear rates compared to base oils. This effect was proposed to be related to the in-situ formation of a WS_2 carrying low friction tribofilm.

To obtain more information about the suggested formation of WS_2, tungsten based carbide coatings have been deposited applying physical vapour deposition (PVD) and were tested in a linear oscillation SRV testing system. The influence of the applied normal load and EP additive concentration was investigated. Energy dispersive X-ray spectroscopy (EDXS), X-ray photoelectron spectroscopy (XPS), X-ray diffraction (XRD) and transmission electron microscopy (TEM) analyses were carried out to investigate the interface near regions within the tribocontact. An emphasis was placed on the distinction whether the reduction of friction and wear is contributed by the in-situ formation of WS_2 rather than by the generation of Magnéli phase oxides.

EP-13 Laser Cladding Ni-based Alloy/nano-Ni Encapsulated h-BN Self-lubricating Composite Coatings*, **Hua Yan**, P Zhang, Q Gao, Y Qin,* Shanghai University of Engineering Science, China*; R Li,* Central South University, China

Nano-Ni encapsulated h-BN/Ni-based alloy (Ni60A) self-lubricating composite coatings on a medium carbon steel were fabricated by laser cladding using two types of lasers: a 5kW continuous wave (CW) CO_2 laser and a 400W pulsed Nd:YAG laser, respectively. A high-energy ball milling method was adopted to clad nano-Ni onto nano-h-BN with an aim to enhance the compatibility between the h-BN and the metal matrix during laser cladding process. The microstructure, phase structure and wear properties of the the self-lubricating composite coatings were investigated by means of scanning electron microscopy (SEM) and X-ray diffraction (XRD), as well as dry sliding wear testing. The research indicated that laser cladding of the self-lubricating composite coatings demonstrates sound cladding layers free of cracks and porosities. It was found that a reaction between h-BN and Ni-based alloy was occurred, which generated hard phase CrB and Ni_3B leading to the increasing of the microhardness of the coatings by CO_2 laser cladding, and laser molten pool suppressed h-BN floating up to upper regions of coating for lower temperature and quickly solidification by YAG laser cladding.The high energy ball milling of nano-Ni onto nano-h-BN significantly improved the interfacial compatibility between h-BN and Ni60A matrix. The friction coefficient of the laser-clad Ni60A/nano-Ni encapsulated h-BN coating was reduced obviously.

EP-14 Leather Treated with Ag/TiO_2 Nanoparticles for Footwear Industry: Tribological and Antimicrobial Activity*, I Carvalho,* University of Coimbra, Portugal*; S Ferdov,* ***CristianaFilipa Almeida Alves,*** University of Minho, Portugal*; M Cerqueira,* INL-International Iberian Nanotechnology Laboratory, Portugal*; R Franz,* Montanuniversität Leoben, Austria*; C Gaidau,* INCDTP-Leather and Footwear Research Institute Division, Romania*; S Carvalho,* University of Minho, Portugal

The proposed work aims to functionalize leathers for footwear industry with antimicrobial properties based on Ag-TiO_2 nanoparticles. The synthesis of nanoparticles was carried out through an innovative and optimized method. The structural characteristics were evaluated by X-ray powder diffraction and the results showed that the TiO_2 nanoparticles are in the anatase phase, with dimensions below 10 nm.

Leather samples were functionalized with TiO_2 and Ag-TiO_2 NP's; these nanomaterials did not change the surface chemical composition of the leathers. Fourier transform infrared spectroscopy showed that the characteristic chemical bands of leathers (-CH_3 stretching vibration) were maintained.

The antimicrobial activity was evaluated by agar diffusion tests against two bacteria species – a Gram negative and a Gram positive, Pseudomonas aeruginosa and Staphylococcus aureus, respectively, and a fungus specie – Candida albicans. The results revealed that the leathers covered with Ag-TiO_2 nanoparticles have antimicrobial activity. The cytotoxicity of nanoparticles was also assessed by MTS test using fibroblast 3T3 which shows the cell's viability. This test was performed to test if these nanoparticles easily penetrated inside the human body. The results showed that the nanoparticles are non-cytotoxic. In order to test the adhesion of the deposited Ag/TiO_2 nanoparticles to the leather substrates, a series of tribological tests in ball-on-disc configuration has been performed using different counterpart materials ranging from rubber (e.g. nitrile rubber) to polymers (e.g. PTFE, PUR or POM). The analysis of the coating wear by light optical and scanning electron microscopy, as well as Raman spectroscopy, revealed details regarding the adhesion of the Ag/TiO_2 nanoparticles depending on the deposition method and parameters applied. The conducted experiments represent a first step towards a systematic study of the mechanical performance of leathers treated with nanoparticles in order to evaluate their suitability for future applications in the footwear industry.

EP-17 An Oliver&Pharr Method for Lateral-Force Nanoindenters*, Norbert Schwarzer,* SIO, Germany

It will be shown how the classical Oliver and Pharr method [1] has to be extended in order to make it fit for the performance and analysis of mixed loading nanoindentation tests. While the classical Oliver and Pharr method can only deal with pure normal loads and allows the extraction of hardness and Young's modulus for a given Poisson's ratio [1, 2, 3], the extended method principally allows for the simultaneous parameter identification of hardness, yields strength in two directions, Young's modulus and Poisson's ration. Under proper experimental conditions, also the extraction of intrinsic stresses seems to be possible. The author will present the method, the theoretical background and a few experimental examples (data from T. Chudoba, ASMEC GmbH, with thanks).

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EP-18 Investigation of Tribological Properties of Aluminium-Titanium Diboride (Al/TiB_2) MMC under Dry Sliding Condition*, A Sheelwant, S Narala,* BITS Pilani Hyderabad Campus, India***; Palaparty Shailesh,*** Methodist College of Engineering and Technology, India

Aluminium Metal Matrix Composites are a special class of metal matrix composites with immense potential which open up countless possibilities to enhance properties of materials that are needed in aerospace, military and automotive applications. The potential of these materials lies into their ability to be tailored to fulfil the expectations of the designer. In this study, microstructure and wear properties of aluminium metal matrix composite (AMMC) reinforced with titanium diboride (TiB_2)were investigated. The composite was fabricated through liquid state processing by incorporating 3, 6, 9, 12 and 15 wt% of titanium diboride into aluminium matrix. Uniform distribution of the reinforcement particles into the metal matrix was observed by the microscopic examination of the composite. To determine the friction and wear properties of the composite, experiments were conducted on a pin-on-disc tribometer, under dry condition, by varying applied load and sliding velocity while keeping the sliding distance constant. Loads of 10N, 30N, 50N and velocities of 100 m/min, 200 m/min, 300 m/min were employed over a constant sliding distance. Results obtained from the test revealed that the friction coefficient and overall wear rate increase with the increasing load and sliding velocity. However, the Al/TiB_2 composite shows lower wear rate in contrast to the unreinforced aluminium. Analysis of the worn out surface of the composite under scanning electronic microscope reveals the domination of abrasive wear. The details presented in the current paper form a basis for materials engineers to switch over to AMMCs from monolithic metals and alloys which offer superior wear properties.

Keywords: Aluminium metal matrix composite, Al-TiB_2, Friction, Wear, Dry sliding

EP-20 Tribological Characterization of Thin Films based on Residual Stress, Volume of Wear, Micro-abrasive Wear Modes and Coefficient of Friction*, Ronaldo Cozza***, *J Wilcken, S Delijaicov, G Donato,* University Center of FEI – Educational Foundation of Ignatius "Padre Sabóia de Medeiros", Brazil

The purpose of this work is to conduct a tribological characterization of thin films based on residual stresses, micro-abrasive wear modes, volume of wear (V) and coefficient of friction (μ). Initially, the residual stresses of thin films of TiN, CrN, TiAlN, ZrN, TiZrN, TiHfC and TiHfCN were analysed by X-ray diffraction; after ball-cratering wear experiments were performed using a ball of AISI 52100 steel and abrasive slurries prepared with black silicon carbide (SiC) particles and glycerine. The normal force (N) and the tangential force (T) were monitored throughout the tests and the coefficient of friction was calculated as $\mu = T/N$. The results showed that the abrasive slurry concentration affected the volume of wear, the occurrence of micro-abrasive wear modes (grooving abrasion or rolling abrasion) and, consequently, the magnitude of the coefficient of friction: *i*) a low abrasive slurry concentration was related with low volume of wear, action of grooving abrasion and a relatively high coefficient of friction; *ii*) a high abrasive slurry concentration was related with high volume of wear, action of rolling abrasion and a relatively low coefficient of friction. In general, the compressive residual stresses measured were relatively low (< 1 GPa).

Keywords: Micro-scale abrasion, residual stress, two-body abrasion, three-body abrasion, PVD coatings.

EP-22 Frictional Behavior of Bismuth-based Soft Coatings*, B Pilotti, G Prieto,* Universidad Nacional del Sur, Argentina***; Esteban Broitman,*** Esteban Broitman Engineering Consulting, Sweden*; W Tuckart,* Universidad Naciona del Sur, Argentina

The aim of this study was to analyze the frictional behavior of a bismuth-based soft coating, developed using a novel, eco-friendly and economically competitive synthesis. Bismuth has a non-toxic nature, making it attractive for the development of new tribological applications such as coatings or as oil additives.

Bismuth sulfide (Bi_2S_3) nanoparticles were synthesized in-house by means of an eco-friendly reaction in an aqueous medium under mild reaction conditions, in presence of a surfactant. The obtained particles were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The Bi_2S_3 nanoparticles were mixed with a commercial organic varnish in order to generate a soft coating. The coating had a weight fraction of nanoparticles of 17.4 wt% and was manually applied on a SAE 4140 steel disk . The frictional response of the soft coating was evaluated using a pin on disc test (v_l=0.02 m/s; p_0=1100 MPa; 6 m of sliding speed), using an AISI 52100 steel ball with a diameter of 6 mm as the counterpart. The same test procedure was employed using a commercially available molybdenum disulfide varnish to serve as a reference.

Both coatings exhibited similar friction coefficients during the test, with an initial low value (<0.1) that increased slightly towards the end of the test. The bismuth based soft coating showed an average friction coefficient ~30% higher than the molybdenum disulfide coating used as reference.

Note: B. Pilotti, G. Prieto, and W. R. Tuckart are also affiliated to CONICET, Argentina.

EP-24 Compositional and Mechanical Characterization of Ti-Ta Coatings Prepared by Confocal Dual Magnetron Co-Sputtering*, A Bahrami,* Universidad Nacional Autónoma de México, Universidad Nacional Autónoma de México, Mexico*; J Pérez Alvarez, R Mirabal-Rojas,* Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Mexico***; Osmary Depablos-Rivera,*** Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Ciudad Universitaria, Mexico*; A Ruiz-Ramirez, A Valencia-Velazco,* Universidad Nacional Autónoma de México, Ciudad Universitaria, Mexico*; S Rodil,* Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Mexico

Toughness and hardness are two important characteristics for coating applications in manufacturing industry. In this study, Titanium-Tantalum coating were deposited by magnetron co-sputtering technique, using titanium and tantalum as targets, on steel and silicon substrate. The power applied to the Ti target was fixed at 200 W, while the Ta power was varied from 10 to 60 W. The effects of the Ti- to- Ta ratio on the chemical composition, mechanical and wear properties of Ti-Ta films were investigated. X-ray photoelectron spectroscopy (XPS), Scanning electron microscopy and X-ray diffraction (XRD) were used to evaluate the composition and oxidation state of the films, morphology and structure of obtained thin films, respectively. The hardness was evaluated by nano-indentation test. The XPS results showed that the Ti in the films without Ta is presented only in the metallic state. Also it was found that the percentage of the added Ta varies from 2 to 14 at% by increasing the applied power to the Ta target. The XRD results showed that the coatings were crystalline, and there is no evidence of the formation of intermetallic phases. The results show that increasing the Ta content cause a significant improvement in scratch resistance of the coatings. The crack propagation analysis was evaluated using the data obtained from micro-indentation and the residual stress from XRD and hardness results.

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