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FINITE ELEMENT ANALYSIS OF NANO INDENTATION OF CHROMIUM NITRIDE COATING ON A HSS SUBSTRATE

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ABSTRACT

Coating is a controlled process at the nano level to significantly enhance the ability of surface properties of substrate like hardness and elastic modulus. Surface coatings like Chromium nitrite (CrN) coating films provide excellent surface properties on substrate. By using technique like finite element simulation, the coating performance under load can be estimated and thus provided valuable information, for the design and the use of coatings for different applications. Aim of present study was to model and simulate nano indentation process on chromium nitrite coated high speed steel (HSS) by finite element method and to compare its results with experimental nanoindentation results. A two-dimensional (2D) and three-dimensional (3D) axisymmetric model was modeled/meshed and analyzed in ANSYS software. The indenter was modeled as rigid body of diamond material. The models have the ability to simulate the loading-unloading curves and the development of plastic deformation during indentation.

Keywords— CrN coating, finite element analysis, Nanoindentation.

I. INTRODUCTION

A coating is a covering that is applied to the surface of an object, usually referred to as the substrate. The purpose of applying the coating may be decorative, functional, or both. Functional coatings may be applied to change the surface properties of the substrate, such as adhesion, wettability, corrosion resistance, or wear resistance. CrN (chromium nitride) is an excellent coating that provides lubricity and superior wear and corrosion resistance. CrN has a very low residual stress, which provides for the best adhesion and ductility of any of the PVD coatings. High hardness, low coefficient of friction and the low residual stress of CrN combine to resist abrasive, metal-on-metal wear, and galling. CrN is an excellent coating for applications such as automotive parts, molds and dies, pump parts, shafts, dry deep drawing and works especially well when used against copper. CrN was developed to solve wear problems in special application areas where titanium based coatings were not successful.

V. S. Jatti et al. stated that finite element method is a powerful device to simulate the indentation process at the nanoscale. This study presents 2-D and 3-D axisymmetric FE model to predict the nanoindentation procedures [1].

Zahid Hussain et al. concluded that nanoindentation is a versatile technique to characterize bulk materials and nanostructured coating layers. Finite element simulation allows better understanding of deformation phenomenon at small scales and is also useful to examine the elastic-plastic transition regime. Finite element simulation of nanoindentation is also successfully used in measuring the elastic-plastic properties of thin films on substrates like work hardening coefficient, yield strength and residual stress [3].

P.Wiecinski et al. presented that the results obtained from their study provide a new insight into the behaviour of Cr/CrN multilayer coatings, in particular the ones deposited on Ti6Al4V alloy. This new insight among others concerns the reaction of such coatings to a localized load in the form of an indentation test[4].

M.R. Ayatollahi et al. stated that the nano-indentation and the uniaxial tensile experiments were performed on aluminum 1100. Very good agreement was found between the values of Young’s modulus measured from the two test methods. Then, an axisymmetric finite element model was used to simulate the nano-indentation process [6].

X Chen et al. stated that the method for determining material properties from indentation tests, whilst accounting for the indentation size effect has been proposed that utilizes IFEM and a novel indentation elastoplastic constitutive relation [12].

1.1 Process

CrN is applied using lateral rotating cathode technology in a PVD (physical vapor deposition) process. Material is vaporized from a solid source in the form of atoms/molecules and then transported in the form of a vapor through a vacuum, low pressure gas/plasma to the substrate where it condenses. The standard process temperature is 425°C/750°F and provides the toughest coating. Low deposition temperature possible (220°C/420°F) [26].

1.2 Cathodic Arc Deposition

Cathodic arc deposition or Arc-PVD is a physical vapor deposition technique in which an electric arc is used to vaporize material from a cathode target. The vaporized material then condenses on a substrate, forming a thin film. The technique can be used to deposit metallic, ceramic, and composite films. The arc evaporation process begins with the striking of a high current, low voltage arc on the surface of a cathode (known as the target) that gives rise to a small (usually a few micrometers wide), highly energetic emitting area known as a cathode spot. The localized temperature at the cathode spot is extremely high (around 15000 °C), which results in a high velocity (10 km/s) jet of vaporized cathode material, leaving a crater behind on the cathode surface. The cathode spot is only active for a short period of time, and then it self-extinguishes and re-ignites in a new area close to the previous crater. This behaviour causes the apparent motion of the arc [13].

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II. MODELLING

2.1 Nano indentation Process

Nano indentation is a powerful technique where the indenter tip of known geometry is projected into the specific site in the material to be tested, increasing load is applied and when it reaches the designated maximum value, partial unloading is performed until desired depth is attained. The holding segment is introduced which allows the material to relax before unloading. The process is repeated many times and position of the indenter tip and the surface is monitored with differential transformer [25].

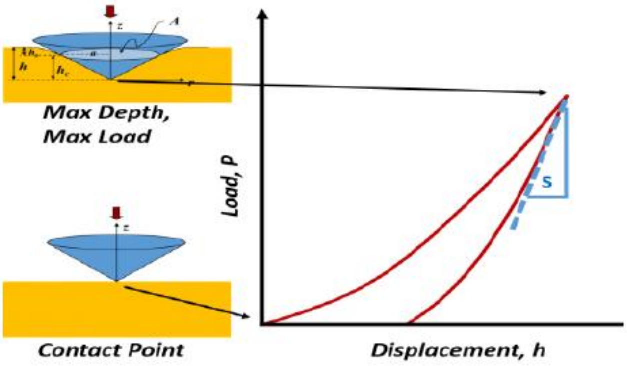

Fig. 1. Nano indentation process [24]

2.2 P-h Curve

An indenter load and displacement during loading and unloading are recorded onto region of interest (in a continuous or stepwise mode). The depth varies between several tens of nanometer and several micrometers. The principle mechanical property determined in indentation tests is hardness H, which is defined as load P divided by the projected area of the contact surface A.

2.2.1 Information Derived From P-H Curve

E and H is determined by Oliver Pharr Method [3]

$$h_c = h + \quad (1)$$

$$A = f(\quad) \quad (2)$$

$$H = \quad (3)$$

$$E = \frac{\sqrt{\pi}}{2} \quad (4)$$

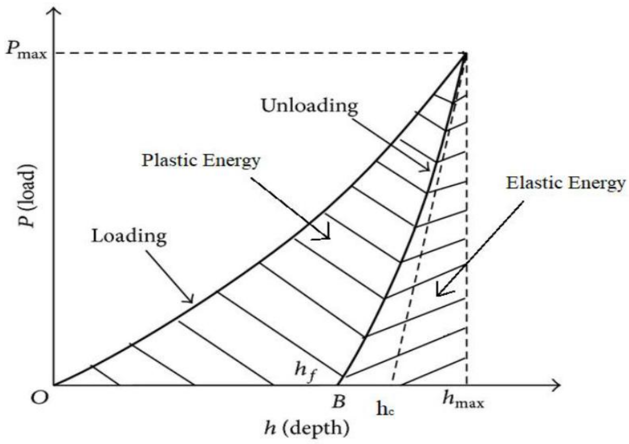

Fig. 2. p-h Curve [25]

where,

h = Maximum Depth

hc = Contact Depth

S = Slope of Curve

Ɛ = Strain

2.2.2 Berkovich Vs. Vickers Indenter

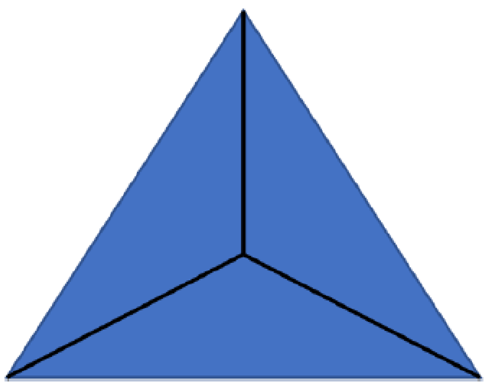

Fig. 3. Berkovich Indenter

$A_{proj} = 3\sqrt{3}\ h^2 \tan^2 63.5$

A_{proj} = 24.56

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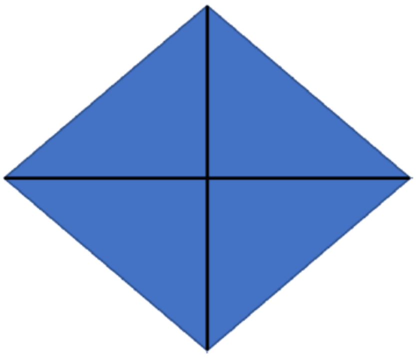

Fig. 4. Vickers indenter

$A_{proj} = 4\,h^2\,tan^2\,68$

$A_{proj} = 24.504$

2.3 Experimental Details

• CrN films were deposited by using Lateral Rotating Cathode Technology in a Physical Vapour Deposition method.

• Thickness – 5 to 10 microns.

• Temperature – 425^0C.

2.4 Process

CrN is applied using lateral rotating cathode technology in a PVD process. Material is vaporized from a solid source in the form of atoms/molecules and then transported in the form of a vapour through a vacuum, low pressure gas/plasma to the substrate where it condenses. The standard process temperature is 425°C and provides the toughest coating. Low deposition temperature possible (220°C) [26].

2.5 Hysitron Inc Minneapolis USA, TI-900

Fig. 5. Hysitron Inc Minneapolis [24]

2.6 Specifications

Load control and displacement control capabilities.

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• TI 900- Load range up to 11500 µN.

• TI Premier- Load range up to 9500 µN.

• The sample should be able to focus in 50x(TI 900) and 10x, 20x (TI Premier).

• Can be used for testing thin films and small structures

• High-resolution in-situ SPM imaging that enables precise test positioning accuracy (±10 nm) and observation of post test deformation behaviour.

• Dynamic measurement mode and modulus/hardness mapping available [24].

2.7 Technical Specifiction

• Load Range : Low load - upto 9.5 mN, High load - upto 500 mN

• Displacement Range Low load: Maximum Indentation displacement (Z)- 5µm, Maximum lateral displacement - 16µm

• High load: Max indentation displacement- 80µm

• Low Load Resolution : Indentation 75nN, Lateral axis 3µN

• Displacement resolution : Indentation axis up to 0.04nm, Lateral axis up to 4nm

• Heating/Cooling stage : Temperature range 250C to 6000C.

• Frequency range: 1Hz to 300Hz (Below 10Hz, the test can take a very long time).

• Load range : Maximum force - 10000 µN (10 mN) [24].

III. FE MODELLING

The model was modelled and meshed in ANSYS software.

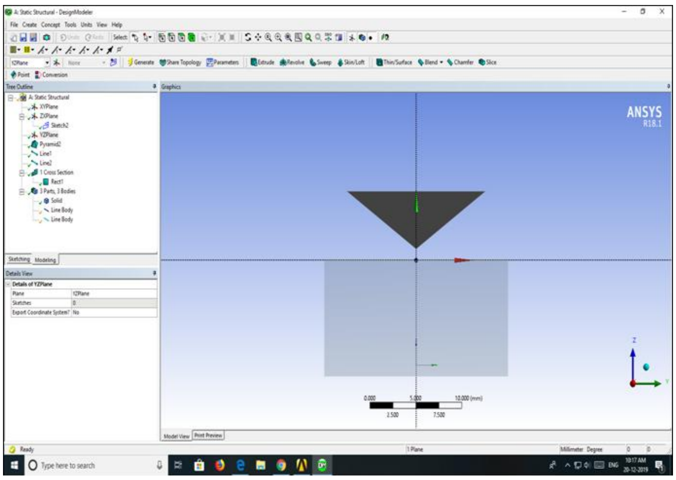

Fig. 6. Front View

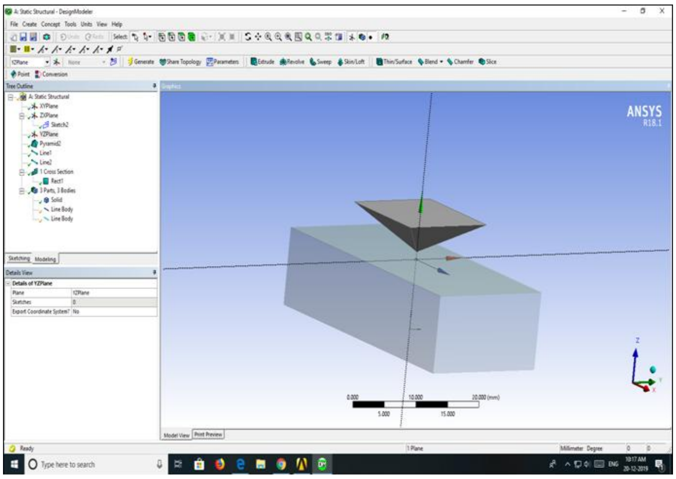

Fig. 7. Isometric view of model

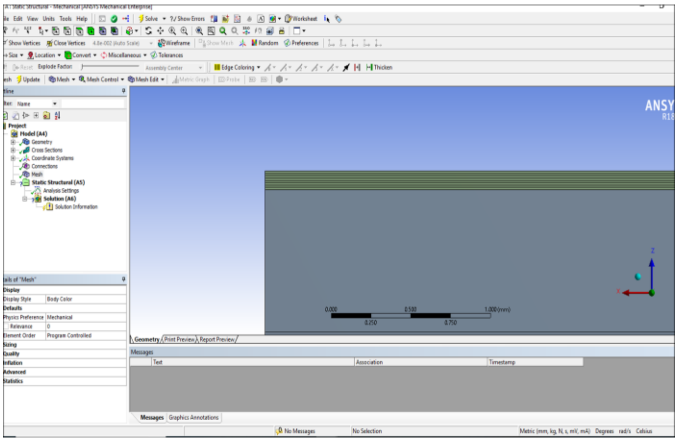

Fig. 8. Coating layer meshing

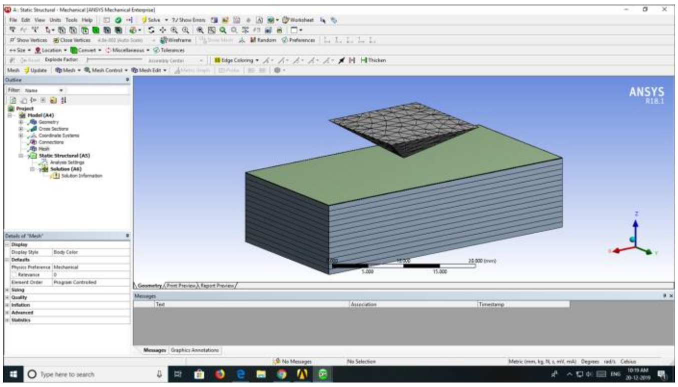

Fig. 9. Meshing of Indenter

IV. RESULTS AND DISCUSSIONS

The load-displacement curve obtained for CrN film is shown in fig.10, four indentations (a, b, c and d) curves are obtained on one sample. The loading and unloading rate was same with a value of 0.5 mN/sec. A maximum load of 5 mN and the maximum depth of indentation of 110 nm were applied over 90 seconds. The residual displacement was 45 nm for a total displacement of 120 nm. Thus, the film underwent 65% elastic deformation and 35% plastic deformation.

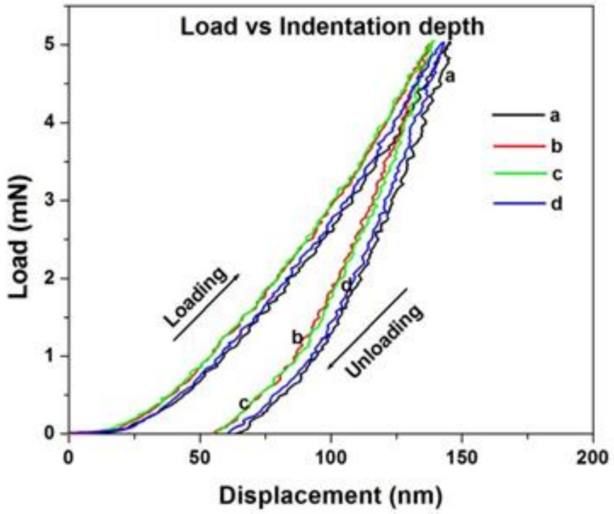

Fig.10. Load-displacement curve of CrN film

With the help of finite element analysis, the nanoindentation loading-unloading process of CrN coated HSS substrate was simulated. The comparison of load-displacement curves between experimental results and FE calculation is shown in fig.11.

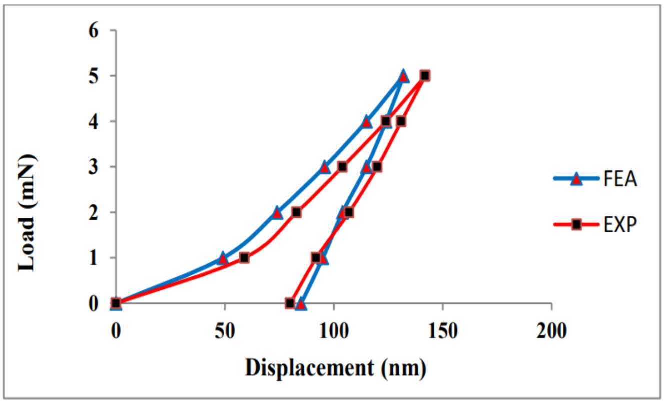

Fig.11. Comparison of simulated results with experimental data

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V. CONCLUSIONS

Nano indentation is a standard method to investigate mechanical properties like hardness, elasticity etc. Many report shows that CrN coating could exhibit excellent corrosion properties and even better oxidation resistance, as well as better adhesion on tool steel when compared to other coating. The FE model has been developed to simulate the nanoindentation response of CrN coated HSS substrate. Chromium nitride coating is applied by lateral rotating cathode technology in a physical vapour deposition process. The FE model has been developed to simulate the nanoindentation response of CrN coated HSS substrate. The model is capable of simulating the loading and unloading stages of the plastic deformation behaviour during the indentation process. The simulation result is in good agreement with the experimental results.It was found that finite element method is a powerful method to simulate the indentation process at the nanoscale.

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