www.ierjournal.org International Engineering Research Journal (IERJ) Special Issue 2 Page 2383-2386, 2015, ISSN 2395-1621

ISSN 2395-1621

Modelling and Analysis of Nano-indentation Process by Finite Element Approach and Experimental Validation

[#1]Priti A.Tembhurnikar, [#2]Ashwin D. Patil

[1]prititembhurnikar77@gmail.com
[2]ashwinpatil16@gmail.com

[1,2]Department of Mechanical Engineering,
MET's BKC IOE,
SPPU, Nashik-422003, India

ABSTRACT

Surface coating provides excellent surface properties to base materials. Thus, the aim of present study was to develop a model to simulate nano-indentation process. In order to simulate this process three dimensional model was developed. Nano-indentation process was simulated using ANSYS software and the indenter was modelled as rigid body of diamond material. The results of nano-indentation process showed that the models have the ability to simulate the loading-unloading curves and showed the development of plastic deformation during indentation process.

Keywords— Nano-indentation, ANSYS software, Surface coatings, Three dimensional process.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

The mechanical properties of bulk materials have limitation with respect to wear resistance, hardness, scratch resistance, elastic modulus etc. Such properties can be improved by depositing appropriate coating on bulk materials. Coating is a controlled process at the nano level to significantly enhance the ability surface properties of substrate and improve the tribological performance of the products.

In engineering application, the ability of coating to perform without catastrophic failure is major concern. The failure of coated substrate can be related to the failure of coating itself or deformation of the substrate. Several different mechanisms of failure have been observed in coated surface, such as elastic, plastic and fracture deformation. It has been observed that coated surface very often fail due to tensile fracture. Tensile fracture mainly occurs at the contact edge of a contact due to the high tensile stresses experienced there. So, it is important to analyse the properties of coated surfaces.

Nano-indentation is one of the techniques which is used to measure mechanical properties of bulk materials and coated surface which are mentioned above. Different numerical techniques have been developed to use in many field of engineering that can be used in nano-indentation problems. One of the simple methods is indentation technique which has advantage over conventional techniques of easy use and excellent accuracy using minimum amount of materials. This technique is useful for welded parts with continuous property variation, brittle materials with unstable crack growing. But the test results are difficult to analyse because of the complicated triaxial stress state under the indenter.

However such a drawback can be eliminated by finite element analysis. Material deformations and the influence of coating thickness and elastic modulus can be analysed by three-dimensional finite element method (FEM) modeling on microlevel, by stress, strain, and displacement computer simulations. Thus, finite element method provides numerical solution to the complex problems.

Chicot et al. (2011) experimental and theoretical data from literature was used to study the mechanical properties of goethite, hematite and magnetite. Using indentation and molecular dynamic analysis hardness and elastic properties of materials were obtained [1].

Ziskind et al. (2011) showed nano-indentation test on peritubular and intertubular human dentin to find out Young's modulus. Two step experiments were carried out firstly on the intertubular dentin areas & highly mineralized peritubular dentin sections and secondly test nano-indentation experiment was done on the face of polyhedron specimen [2].

Ajaja et al. (2011) studied the Ti coatings which were deposited on Ti surface. Nano-hardness test and micro hardness test were performed on coated surface and bulk surface. For each sample true hardness values and nano-indentation measurements, plasticity of strain gradient were used [3].

Hyun et al. (2011) studied a FE simulation of dual conical ball indenter method. The analysis of indentation parameter and load-depth curves was done. The diameter of projected contact is explained as a function of material properties; tip-radius, indenter angle and modulus of elasticity were found [4].

Passeri et al. (2011) used the atomic force microscopy in order to study polyaniline thin film and indentation modulus. The atomic microscopy instrument is used to calculate indentation experiment at micro level. In order to get maximum indentation depth, polymeric references materials, hardness values were calibrated [5].

Ananth and Ramesh (2012) studied behaviour of non-conformal surfaces of ball on flat surface subjected to normal and the substrate shear stress. The substrate material chosen for the analysis is ultra high strength steel, titanium alloy, magnesium alloy, aluminium alloy and the stainless steel material are considered for the rigid ball material. Before imposing sliding the FE model is validated through the Hertz solution for different contacting material pair under normal load. The analysis facilitated in evaluating the surface phenomena variables. The results are obtained for the combining effect of normal load and shear friction and same were normalized with the corresponding yield strength to determine the failure mode of the material surface. The results obtained from the analysis are exploited in the understanding of the tribological behaviour of the contact pairs [6].

Kaimin and Yue (2012) studied nano-indentation test on the influence of acid and alkaline on the spinal surface and nickel aluminates spinal. For evaluation of Young's modulus and hardness the products were tested in order to incorporating the waste materials [7].

Pardo et al. (2013) studied properties of hard nano-composite coatings and self-organized a-C: Cu the effect of concentration of metal on mechanical tribological properties, mechanical and structural. In this experiment, 20-25 nm thick copper metal layers and alternating carbon are used for developing multi layer self-organised structure. The nano-hardness and young's modulus is found out [8].

Chen et al. (2013) studied scratch damage resistance of silica-based on polymeric substrates coated with sol-gel coatings. By using the ISO 15184 standard scratch test were done [9].

Huang et al. (2014) studied the nano-indentation creep study on an ion beam irradiated oxide dispersion strengthened alloy and found out that Oxide dispersion strengthened (ODS) alloy is considered advanced materials for nuclear application due to their radiation tolerance and creep resistance. Ion beam irradiation is used to study the property changes due to displacement damage [10].

Tillmann and Momeni (2014) studied the deposition of layered composite thin films made of NiTi and TiCN films deposited Si (100) substrate by DC magnetron sputtering. The mechanical properties, microstructures, and shape memory behaviour of these bilayers were investigated using nano-indentation technique, differential scanning calorimetry, scanning electron microscopy and X-ray diffraction. The results of this research show that the presence of TiCN layer on NiTi thin film modifies its mechanical properties while maintaining the shape memory effects [11].

Xiao et al. (2014) studied the four-ball test to find out tribological performance of WC/C, DLC and TiN coatings using and evaluated the tribological performance of coatings for high-speed and heavy-duty power-transmitting gears [12].

Aim of present study is to develop three dimensional models in order to simulate nano-indentation process on a TiN coated high speed steel substrate. ANSYS software was used to simulate the nano-indentation process.

II. MATERIAL AND METHODS

The models were designated as master and slave surfaces. In these models, ball indenter was considered as rigid of diamond material having tip radius of 200 µm. The indentation is very small as compared to size of the sample. The volume of substrate was taken in to consideration as $12\times4\times2$ mm^3 (length, width, and thickness). Input material properties required for modelling is shown in table 1. Figure 1 shows the substrate and TiN coating after meshing. The substrate was meshed by Hexa (Brick) mesh and the ball indenter was meshed by shell mesh with spider rigid. A fine mesh was used around the contact area and near the tip of indenter. The developed model has an order 2 and the number of nodes are 109500 and number of element are 36194.

TABLE I

MECHANICAL PROPERTIES

Sr. No.	**Modelling parts**	**Properties**
1	Ball indenter	Material=Diamond Poisson's ratio= 0.07 Young's modulus= 1140GPa
2	Coatings	**TiN Coating** Material = Titanium Nitride Poisson's ratio = 0.22 Young's modulus = 300 GPa

3	Substrate	Material = High Speed Steel Poisson's ratio = 0.29 Young's modulus = 200 GPa Yield strength = 4100 MPa Strain hardening coefficient = 20

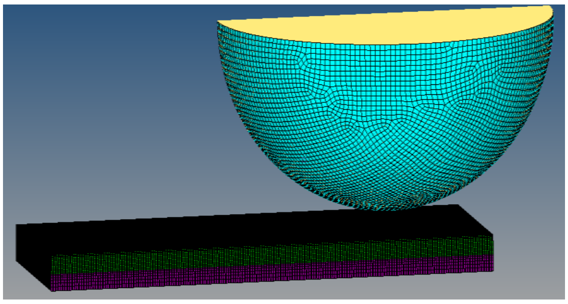

Fig.1 Meshed assembly for nano-identation

The following are the assumptions made to simulate and model nano-indentation process:

i. Materials is homogeneous and continuum.
ii. During modelling surface are considered as smooth and residual stresses are neglected.
iii. Coating/substrate interference is perfectly bonded.

III.RESULT AND DISCUSSION

In order to find out the mechanical properties of very thin films or bulk materials one of the simple way is nano-indentaion, in particular elastic modulus and hardness values. For indentation problems in many fields of engineering and science lots of numerical technique are used. Finite element method if one of the promising methods in order to study the complex stress-strain field of bulk materials or thin films in nano-indentaion problems. The loading-unloading behaviour of nano-indentation process can be reproducing by finite element approach. Nano-indentation is the application of controlled load with concurrent measurement of depth through use of a hard indenter tip. A typical load-displacement curve for a ductile metal is shown in Fig.2.

The loading portion of the curve incorporates convoluted response of the material to strain including elastic and plastic deformation mechanisms. However, the unloading portion of the curve, for most materials, consists mainly of elastic recovery. After the unloading process the unloading curve shows the plastic deformation.

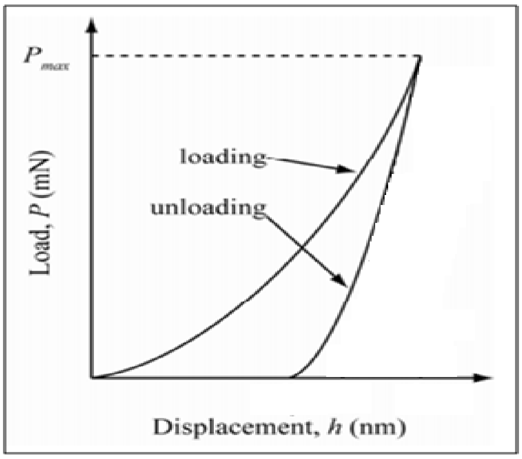

Fig.2 Load-Displacement curve

By using three dimensional models the development of plastic deformation in TiN coated substrate was investigated with increase in depth of penetration. The increase in plastic deformation region in TiN coated HSS substrate material is shown in Fig.3. The plastic deformation in the specimen at the interface i.e. between the ball indenter and substrate is initiated at the beginning and then propagated. At the beginning at preload is small so the indentation depths are developed in lateral and vertical direction. When the normal load is increases large indentation depth are observed with the propagation of stresses in both directions i.e., lateral and vertical direction (fig.3).

With the help of finite element analysis, the nano-indentation loading-unloading process of TiN coated HSS substrate was simulated. Fig.4 shows the load-displacement curve for TiN coated HSS substrate. The loading and unloading rate was same with a value of 1 mN/sec.

A maximum load of 40 mN for a dual time of 60 seconds was kept and the maximum depth of 248 nm indentation was observed. Out of the total displacement 248 nm, the 162 nm is the residual displacement.

The contact constraint is defined by master (ball indenter) and slave (substrate) surfaces. The ball indenter can penetrate the substrate. The indentation process is simulated both during loading and unloading step. The values of applied load by the ball indenter on coated substrate are in the range of minimum of zero 0 mN and maximum of 40 mN. During loading process the simulation is performed to a depth, which is 75% of thickness of TiN coating in the y-direction, i.e. the indenter tip penetrates only into the coating; while during unloading process the indenter tip returns to the initial position (0, 0, 0). When the ball indenter comes in contact with coated substrate the value of load is 0 mN. During loading the velocity of indenter is 1 mN/sec and the maximum value of load will get up to 40 mN. The boundary conditions are applied along the original point, centerline and bottom of specimen by fixing the sample at horizontal axis.

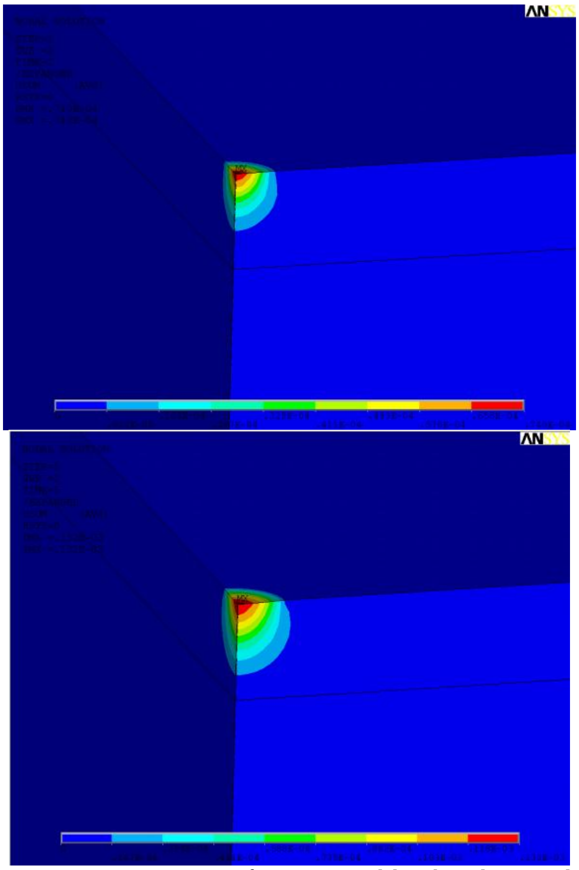

Fig.3 Von Mises stress contours for 3-D FE model as the indentation depth is increased

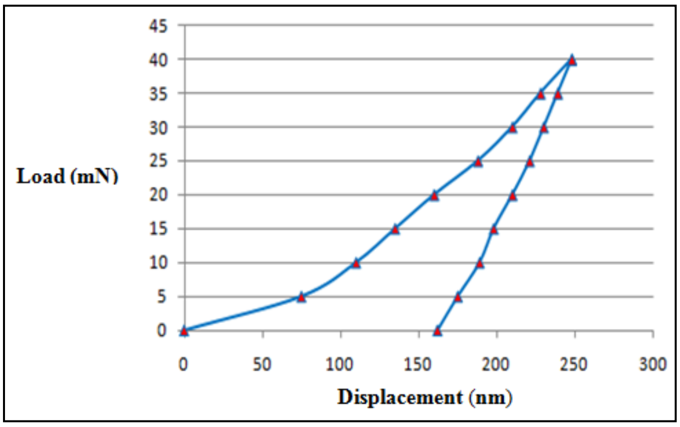

Fig.4 Load-Displacement curve by FE simulation for TiN

During indentation process purely elastic deformation takes place only during the beginning of the indentation process. In order to calculate occurrence of plastic deformation, Von-Mises yield criterion is applied. The equation of Von-Mises stress is given by the expression 1,

$$\sigma_{Mises} = \sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \tag{1}$$

Where σ_1, σ_2 and σ_3 are the three principal stresses. Whenever σ_{Mises} reaches the yield strength σ_0, the material begins to deform plastically.

IV. Conclusions

This study presents 3-D FE modeling and simulation to predict the nano-indentation process. The FE model has been developed to simulate the nano-indentation response of TiN coated HSS substrate. The model is capable of simulating the loading and unloading stages of the plastic deformation behaviour during the indentation process. Thus, it can be concluded that finite element method is a powerful tool to simulate the indentation process at the nanoscale.

REFERENCES

[1] Chicot D., Mendoza J., Zaoui A., Louis G.; Mechanical properties of magnetite (Fe_3O_4), hematite (α-Fe_2O_3) and goethite (α-FeO.OH) by instrumented indentation and molecular dynamic analysis, Journal of the European Ceramic Society. 28, 2653-2573, 2011.

[2] Ziskind D., Hasday M., Cohen S., Wagner H.; Young's modulus of peritubular and intertubular human dentin by nanoindentation test, Structural Biology. 174, 23-30, 2011.

[3] Ajaja J., Golddbaum D., and Chromik R.; Characterization of Ti cold spray coatings by indentation methods , Acta Astronautica, 69, 923-928,2011.

[4] Hyun H., Kim M., Haeng J., Lee H.; A dual conical indentation technique based on FEA solutions for property evaluation, Mechanics of Materials, 43, 313-333, 2011.

[5] Passeri D., Alippi A., Rossi M., Bettucci A.; Indentation modulus and polyaniline thin film by atomic force microscopy, Synthetic materials, 161, 7-12, 2011.

[6] Ananth M., and Ramesh R.; Analysis of sliding behaviour of non-conformal surfaces subjected to shear traction, International Conference on Modelling Optimization and Computing. 38, 2645-2656, 2012.

[7] Kaimin S. and Yue H.; Nano-indentaion on nickel aluminate spinal and the influence of acid and alkaline on the spinal surface, Ceramics International. 38, 3121-3128, 2012.

[8] Pardo A., Buijnsters J., and Endrino J.; Effect of the metal concentration on the structural, mechanical and tribological properties of self-organized a-C:Cu hard nano-composite coatings, Applied Surface Sciences, 280, 791-798,2013.

[9] Chen Z., Linda Y., and Wu A.; Scratch damage resistance of silica-based sol-gel coatings on polymeric substrates, Tribology of Polymeric Nanocomposites, 2, 467-511, 2013.

[10] Zijing Huang, Nanoindentation creep study on an ion beam irradiated oxide dispersion strengthened alloy, Journal of Nuclear Materials, 451, 162–167, 2014.

[11] Wolfgang Tillmann and Soroush Momeni, Deposition of superelastic composite NiTi based films, Vacuum, 104, 41–46, 2014.

[12] Yangyi Xiao, Wankai Shi, Jing Luo, Yijian Liao., Tribological performance of TiN, WC/C and DLC coatings measured by the four-ball test, Ceramics International, 40(5), 6919–6925, 2014.