International Journal of Engineering & Technology, 7 (3.17) (2018) 183-185

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Simulation of Nanoindentation of Single and Multiple Coating Layers for Automotive Bearings

Wan Fathul Hakim W.Zamri[1]*, Intan Fadhlina Mohamed[1], Khairunas Bakri[1], Muhamad Faiz Md Din[2]

[1] Centre for Materials Engineering and Smart Manufacturing (MERCU),
Faculty of Engineering & Built Environment,
Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor, Malaysia
[2]Faculty of Engineering,
National Defense University of Malaysia (UPNM),
Kem Sungai Besi,
57000 Kuala Lumpur, Malaysia
**Corresponding author E-mail: wfathul.hakim@ukm.edu.my*

Abstract

A coating is capable of changing the resistance to wear. This study focused on the simulation of the nanoindentation of AISI440C steel coated with single and multiple layers of TiN and TiSiN. TiN and TiSiN coatings are often used for tools and equipment, especially for the automotive bearing. The main objective of this study was to identify the mechanical properties for single coating layers of TiN and TiSiN by means of a nanoindentation simulation using ANSYS Mechanical APDL software. Most mechanical failures are due to stress factors, as defined by the mechanical properties of the material concerned. Nevertheless, information on the mechanical properties of coating materials is still limited, especially for TiN and TiSiN. Therefore, this study analysed the response of the materials under pressure from an indenter tip to obtain their mechanical properties. The lack of information about researches into the mechanical properties and response of coating materials, when subjected to a load, makes it necessary to conduct a study of the techniques of the layered coating. Among the mechanical properties that were considered were the elastic modulus, Poisson's ratio, yield strength, and hardness of the material.

Keywords: *Coating layers, Nanoindentation, Single coating, TiN, TiSiN*

1. Introduction

A coating is a deposition of a material or a layer to cover or protect the original material for a specific use [1]. In the field of mechanical engineering, the advantages of a coating are that it is capable of providing protection to the base material by means of wear resistance, hardness, resistance to corrosion, and so on [2]. However, coating technology has evolved with the emergence of layered coating techniques that can provide even more benefits [3]. TiN and TiSiN coatings are often used for tools and equipment, especially for the automotive bearing. These coatings are known for their hardness and durability. Therefore, they are expected to provide greater resistance against damage caused by surface contact through their energy absorption efficiency [4]. Information on the mechanical properties of coating materials is still limited, especially for TiN and TiSiN layers. In addition, the analysis of the stress distribution in the coating layer is an important basis because it is related to crack initiation. The effect of the coating is also a major contributor to the reduction of wear in materials [5]. Thus, this study conducted a more thorough investigation into the mechanical properties and surface performance of the materials when subjected to a nanoindentation test for single and multiple coating layers of TiN and TiSiN. This study was carried out by modelling a nanoindentation simulation using the finite element method with the ANSYS Classic Mechanical APDL.

2. Methodology

This nanoindentation simulation was modelled based on the working principle of a nanoindentation machine, where a sample of the coating material was subjected to an indentation test by exerting a load on the surface of the coating through an indenter tip. This nanoindentation process generated a load versus indentation depth curve, which was divided into two phases, namely, the loading and unloading phases. An analysis of this curve provided data on the behaviour and mechanical properties of the coating material.
This simulation model was developed by preparing codes for the commands to be fed into the ANSYS software. The simulation was conducted by using the indentation depth as a reference for the implementation of the simulation. To reach the prescribed depth, the loading was carried out according to the requirements of the simulation. Figure 1 shows the nanoindentation simulation model for the single coating layers of TiN and TiSiN. There were three important parts to this simulation, namely:

- AISI440C material substrate
- Single TiN and TiSiN coatings, and multiple TiN/TiSiN coating layers
- Diamond conical indenter tip

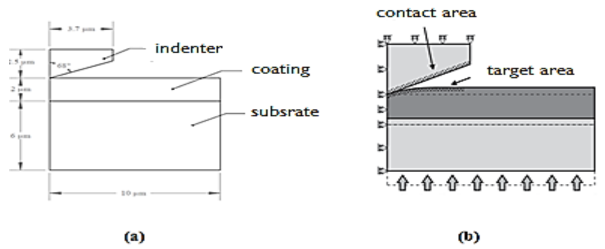

Fig 1: Nanoindentation model (a) the sketch of the model (b) the boundary condition

The nanoindentation simulation was developed as a three-dimensional model with the symmetry of 1/8. The substrate had a thickness of 6 µm and the thickness of the coating was 2 µm. The selected thickness used in this simulation based on the studies by [6] and [7], which mentioned the range of the coating thickness is around 2-5 µm. The conical-shaped indenter tip was set at an angle of 68º from the centre of rotation. The target element used in this model along the upper surface of the coating was TARGE170, while CONTA174 was used on the surface below the indenter tip. The forces and displacements in this simulation acted along the direction of the Y-axis. As shown in Figure 1(b), a fixed constraint was applied to the bottom of the sample to prevent it from moving horizontally and vertically. Although the material was able to move along the axis of symmetry and to change its shape vertically, there was no movement in the horizontal direction. The development of the mesh was initiated by the command, AMESH, which means "area mesh", in a 2-dimensional model. Then, a 3-dimensional mesh was developed by giving the command, VROTAT, which means "volume rotate". Figure 2 shows a sketch of the mesh for the nanoindentation simulation.

At the pre-simulation stage, the development of a single coating began with the selection of the type of elements to be used, namely, the PLANE182 as the two-dimensional element, SOLID186 as the three-dimensional element, TARGE170 along the upper surface of the coating sample, and CONTA174 for the part below the indenter tip. Then, the development of the geometry continued with the development of points at the corners of the two-dimensional sketches of the elements. These points were connected by a line, which was then made wider in two dimensions. The development of a two-dimensional mesh was carried out after the process of encoding with LESIZE, which was capable of dividing the area with lines that formed small nets. The development of the three-dimensional element was performed using the VROTAT code, which means the volume rotation, with a rotation angle of 45°. After this command code, a cylinder with the symmetry of 1/8 was formed. Next, the same process was used to develop the indenter tip.

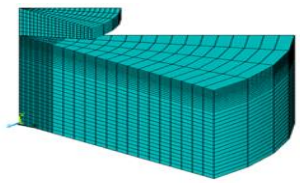

Fig 2: The meshing condition of the model

3. Results and discussion

3.1 Validation of nanoindentation simulation model

To ensure the development of a good model, the results of the load versus indentation depth curve were compared with the findings of [8], who used TiN as a coating on HSS steel material. The results of that study were used as a benchmark to validate the nanoindentation simulation in this study. Figure 3 shows the curve of the load versus the indentation depth for the simulation in this study, which was compared with the experimental curve obtained in the study by [8]. This simulation was modelled with a maximum indentation depth of 0.3 µm. Therefore, it was concluded that the nanoindentation simulation model that was developed in this paper is valid and can be adopted for further simulations of coating layers. The mechanical properties of TiN can be determined through this model.

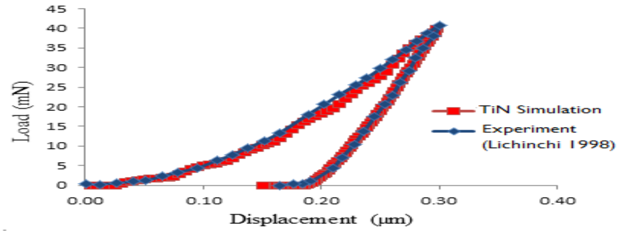

Fig 3: Load-displacement curve

3.2 Mechanical properties of single TiN coating

A single TiN coating had a modulus of elasticity of 427 GPa, Poisson's ratio of 0.25, and yield strength of 13.5 GPa. There were many factors that influenced the indentation results in the load versus indentation depth curve, including the mesh size, modulus of elasticity, Poisson's ratio, yield strength, tangent modulus and indentation depth. All aspects were taken into consideration in producing the results on the mechanical properties of the single TiN coating. The hardness of the single TiN coating obtained from this simulation was 23.42 GPa. Compared to the findings of previous studies, this hardness value was acceptable because it is within the range of the hardness values obtained from previous studies. Table 1 shows the mechanical properties of the single TiN coating compared to the results of previous studies.

Table 1: Mechanical Properties of single TiN coating

Modulus of elasticity (GPa)	Poisson's ratio	Yield strength (GPa)	Tangent modulus (GPa)	Hardness (GPa)	References
427	0.25	13.5	8	23.42	Simulation
427-450	0.25	13.5-14.5	-	27	[8]
430	-	-	-	22	[9]
-	-	13	-	25	[10]
440	-	-	-	25	[11]

3.3 Mechanical properties of single TiSiN coating

The second coating in this study was that of. The simulation of the TiSiN coating gave a modulus of elasticity of 600 GPa, Poisson's ratio of 0.2, and yield strength of 15.5GPa. The indentation depth was given as 0.2µm. When compared with the curve for the simulation of the TiN coating, the TiSiN curve had a higher maximum load at an indentation depth of 0.2 µm. The hardness of the single TiSiN coating obtained by the simulation was 28.56 GPa. It was concluded that the TiSiN coating was harder than the TiN coating. Table 2 shows the mechanical properties of the TiSiN coating obtained by the simulation compared to those obtained by previous studies.

Table 2: Mechanical Properties of single TiSiN coating

Modulus of elasticity (GPa)	Poisson's ratio	Yield strength (GPa)	Tangent modulus (GPa)	Hardness (GPa)	References
600	0.2	15.5	8.5	28.56	Simulation
406-449	-	-	-	35	[12]
-	-	-	-	20-42	[13]
600	-	-	-	50	[14]
560	-	-	-	26.8	[4]

3.4 Overall comparison of the mechanical properties of single and multiple coating layers

To determine the effects of coating layers on the mechanical properties, TiN/TiSiN coating layers were simulated using ANSYS

software. The purpose of this simulation was to study the effect of the thickness of TiSiN on TiN. Seven combinations of thicknesses of coating layers were simulated, as shown in Figure 4.
The results also included sketches of the load versus indentation depth curves for single and multiple coating layers of TiN and TiSiN so as to compare the changes in the curves. The coating layers in Figure 5 showed that the single coating of TiN had the lowest value. Then, the maximum value of the curve increased with the addition of the first layer of TiSiN (uppermost) with a thickness of 0.25 µm and 0.5µm. However, with increasing thicknesses of 0.75µm, 1µm, 1.25µm, 1.5µm and 1.75µm, the increase in the maximum load was not very significant.

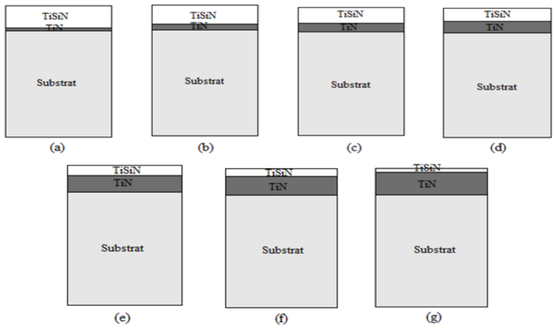

Fig 4: Seven combinations of thicknesses of coating layers

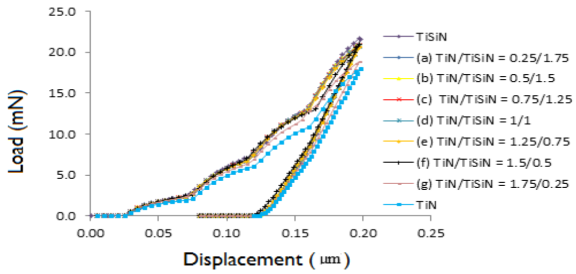

Fig 5: Load-displacement curve for single and multiple layers

Table 3: Mechanical Properties of Single and Multiple Coating Layers

Coating	Modulus of elasticity (GPa)	Poisson's ratio (v)	Yield strength (GPa)	Tangent modulus (GPa)	Hardness (GPa)
TiN	427	0.25	13.5	8	23.42
TiSiN	600	0.2	15.5	8.5	28.56
(a) TiN/TiSiN = 0.25/1.75	NIL	NIL	NIL	NIL	27.30
(b) TiN/TiSiN = 0.50/1.50	NIL	NIL	NIL	NIL	27.20
(c) TiN/TiSiN = 0.75/1.25	NIL	NIL	NIL	NIL	27.09
(d) TiN/TiSiN = 1.00/1.00	NIL	NIL	NIL	NIL	26.94
(e) TiN/TiSiN = 1.25/0.75	NIL	NIL	NIL	NIL	26.63
(f) TiN/TiSiN = 1.50/0.50	NIL	NIL	NIL	NIL	25.90
(g) TiN/TiSiN = 1.75/0.25	NIL	NIL	NIL	NIL	24.46

The mechanical properties of the single coating of TiN and TiSiN were obtained through this simulation. The single coatings of TiN and TiSiN each had their own modulus of elasticity, Poisson's ratio, yield stress, tangent modulus and hardness. However, with the coating layers, the mechanical properties of the materials were maintained and caused changes to the hardness of the coating material in response to each coating layer. Table 3 shows the mechanical properties of the single and multiple TiN and TiSiN coating layers, where for the multiple coating layers, there was only a change in the hardness value.

4. Conclusion

Nanoindentation simulations were successfully carried out on single and multiple coating layers of TiN and TiSiN. The load versus indentation depth curves were obtained from these simulations and were confirmed by the findings of previous studies. These simulations were successful in obtaining the mechanical properties of the single and multiple TiN and TiSiN coating layers. For the TiN/TiSiN coating layers, the thickness of each layer of TiN and TiSiN had an effect on each other. When the thickness of the TiSiN layer was increased, the maximum load also increased accordingly.

Acknowledgements

The authors would like to thank the Malaysia research foundation: Skim Geran Penyelidikan Fundamental: FRGS/1/2017/TK05/UKM/02/3 for funding this work within the project "Mechanical and Tribological Properties of Multilayer Coatings with a Hierarchical Architecture for the Metal Forming Industry".

References

[1] Bunshah, "Handbook of Deposition Technologies For Films and Coatings," Lost Angelest, California: Noyes publication, 1993.
[2] L. Dobranski, A. Sliwa, L. Zukowska, J. Mikula and K. Golombek, "Structure and mechanical properties of PVD coatins for tool materials," Journal of Achievements in Materials amd Manufacturing Engineering, 33-41 (2010).
[3] Kasim, "Galas SMJ3533," In Kasim Sukudai, Johor, Universiti Teknologi Malaysia, 2011.
[4] X. Zhoa, Z. Xie and P. Munroe,"Nanoindentation of Hard Multilayer Coatings: Finite Element modelling," Materials Science and Engineering: A (528), 1111-1116 (2010).
[5] K. Holmberg, A. Laukkanen, E. Turunen, and T. Laitinen, "Wear Resistance Optimisation of Composite Coatings by Computational Microstucture Modelling," Surface Coatings and Technology (247), 1-13 (2014).
[6] A. Savan, H. Boving, F. Fluehmann, and H. Hintermann, "Increased performance of bearings using TiC-coated balls," Journal de Physique IV (Proceedings), 943-948 (1993).
[7] M. Stoibera, E. Badischa, C. Lugmairc and C. Mittererb, "Low-friction TiN coatings deposited by PACVD," Surface and Coatings Technology (163-164), 451–456 (2003).
[8] M. Lichinchi, C. Lenardi, J. Haupt and R. Vitali, "Simulation of berkovich nanoindentation experiment on thin film using finite element method," Thin solid film (312), 240-248 (1998).
[9] S. Zhang and W. Zhu, "TiN coating of tool steel : a review," Journal of material processing technology (39)," 165-177 (1993).
[10] P. Steyer, A. Mege, D. Pech, C. Mendibide and J. Fontaine, "Influence of the nanostructuration of PVD hard TiN-based films," Surface and Coatings Technology (202), 2268-2277 (2008).
[11] P. Woa, P. Munroea, Z. Zhoub, K. Li and Z. Xiec, "Effects of TiN sublayers on the response of TiSiN nanocomposite coatings," Materials Science and Engineering A (527), 4447–4457 (2010).
[12] Y. Cheng, T. Browne, B. Heckerman, C. Bowman, V. Gorokhovsky and E. Meletis, "Mechanical and tribological properties of TiN/Ti multilayer coating," Surface and Coatings Technology (205), 146–151 (2010).
[13] C. Guo, D. Lee and P. Chen, "Deposition of TiSiN coatings by arc ion plating process," Applied Surface Science (254), 3130–3136 (2008).
[14] W. Henderer and F. Xu, "Hybrid TiSiN, CrC/C PVD coatings applied to cutting tools," Surface and Coatings Technology (215), 381–385 (2013).