Available online at www.sciencedirect.com

ScienceDirect

Ceramics International 41 (2015) 10349–10379

CERAMICS INTERNATIONAL

www.elsevier.com/locate/ceramint

Review paper

# Wear resistance investigation of titanium nitride-based coatings

Eleonora Santecchia[a], A.M.S. Hamouda[a], Farayi Musharavati[a], Erfan Zalnezhad[b,*], Marcello Cabibbo[c], Stefano Spigarelli[c]

[a]Mechanical and Industrial Engineering Department, College of Engineering, Qatar University, 2713, Doha, Qatar
[b]Department of Mechanical Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Korea
[c]Dipartimento di Ingegneria Industriale e Scienze Matematiche (DIISM), Università Politecnica delle Marche, I-60131, Ancona, Italy

Received 28 January 2015; received in revised form 14 April 2015; accepted 27 April 2015
Available online 6 May 2015

**Abstract**

The wear of components while they are in service is a predominant factor controlling the life of machine components. Metal parts are often damaged because of wear-driven failures causing the loss of dimensions and functionality.

In order to reduce wear, researchers follow two paths: (i) use new, wear resistant materials or (ii) improve the wear resistance of materials by adding alloying elements or performing surface treatments. Thin film hard nitride coatings are seen as a viable way to enhance the wear resistance of metallic materials, thus extending the lifespan of products. This paper reviews the wear resistance of titanium nitride-based coatings obtained using physical vapor deposition (PVD), chemical vapor deposition (CVD), and thermal spraying techniques. The results of thin film coatings deposition on the wear performance and on the coefficient of friction are investigated. The advantages and disadvantages of coating methods are discussed. Finally, recent developments and new possibilities for coating manufacturers to produce films with enhanced wear performance are briefly discussed.


*Keywords:* A. Films; C. Wear resistance; C. Friction; E. Wear parts

**Contents**



*Corresponding author. Tel.: +82 2 2220 0431; fax: +82 2 2292 3406.
*E-mail addresses:* e.santecchia@qu.edu.qa (E. Santecchia), erfan@hanyang.ac.kr (E. Zalnezhad).

http://dx.doi.org/10.1016/j.ceramint.2015.04.152
0272-8842/

## 1. Introduction

The scientific research on advanced materials is unstoppable. Many research groups from all over the world have pushed the performances of materials beyond their theoretical limits, in order to achieve the best results possible [1]. When manipulating raw materials becomes too challenging, surface coating is the best way to improve the performance and the durability of materials, especially those exposed to aggressive environments or extreme working conditions.

For several years, thin hard coatings were considered to be crucial in the production of mechanical parts and tools, owing to their hardness and wear resistance properties [2–5]. Nitride coatings are the most frequently used because they combine features such as high bond strength to the substrate [6,7] and excellent resistance to wear, erosion, and corrosion [6,7]. In particular, transition metal nitrides are widely used because of their excellent intrinsic properties such as (i) good conductivity, (ii) hardness, (iii) high melting point, (iv) chemical stability, and (v) wear resistance. For these reasons, transition metal nitrides have been used as diffusion barriers and in hard, wear resistant, and anti-corrosion coatings [8–23]. Titanium nitride (TiN) is a hard and versatile ceramic material, known to crystallize in the B1 NaCl structure. It exists as a solid solution with a nitrogen concentration in the range of 37.5–50% [24,25]. TiN has good wear and corrosion resistant properties [26,27], and it is widely applied on cutting tools in order to increase their lifespan [28]. Titanium nitride has biocompatible properties [29–31] as well as a combination of high ductility and hardness, leading to its use on medical implants such as orthopedic and dental prosthesis [32–36].

The application of titanium nitride based coatings on machining tools is essential because there are limitations related to the use of lubricating oils to minimize the environmental impact of industrial machining operations [37–39]. Moreover, recycling cleansing agents and disposal of waste remain critical safety and pollution issues [40–43]. Dry machining represents a viable alternative to wet machining [44] but it requires surface engineering techniques that provide low friction and wear resistant surfaces, in order to get the same advantages provided by cutting fluids, acting as transfer mediums for chip removal, coolants, and lubricants [39]. From a technological point of view, high speed machining [45] is another industrial process that is attracting more and more attention. Consequently, combining these two cutting methods was inevitable and has resulted in the evolution of dry high-speed cutting systems [46,47]. The major issue related to dry cutting and high speed machining is local heat generation, implying the use of tools with high heat resistance, and having heat insulating coatings on tool surfaces [48]. During dry cutting procedures, high temperatures cause hardness changes, metallurgical transformations, and even chemical composition variations caused by deforming materials and the steps taken to overcome sliding friction between tools, work pieces, and chips. This behavior has a dramatic influence on tool life and on the finished product, in terms of surface integrity and the accuracy of the dimensions and shape [49–51].

The goal of this paper is to provide a broad overview of the wear resistance of titanium nitride based coatings obtained using different preparation techniques including physical vapor deposition (PVD), chemical vapor deposition (CVD), and spraying techniques.

Physical vapor deposition (PVD) techniques are used extensively to deposit a wide range of materials on a number of substrates. The general classification of PVD techniques is made according to the methods used to evaporate the target (material to be deposited) [52]. Titanium nitride-based coatings are mostly deposited by magnetron sputtering, cathodic-arc and pulsed laser deposition techniques [52]. The wide diffusion of PVD techniques for industrial applications is due to the resulting coatings, hard and durables that can be deposited on organic or inorganic substrates. The high temperatures involved in the deposition process and the high vacuum required, are the major drawbacks of these methods [52].

Chemical vapor deposition (CVD) techniques are based on the use of chemical precursors to form a thin film on a substrate by reacting in an isolated chamber. CVD techniques can be divided in groups according to the method used to activate the chemical precursors [52]. Plasma enhanced and plasma assisted chemical vapor depositions (PECVD, PACVD), as well as thermal chemical vapor deposition, are the most used techniques to obtain TiN-based thin film coatings. CVD techniques allow the synthesis of very pure and dense thin films enabling high deposition rates on objects with complex geometries and shapes. However, the complexity of some chemical processes, as well as the toxicity of exhausted gases represent the main drawbacks associated with these techniques.

PVD and CVD both suffer from the greatest film thickness achievable, which is usually around 10 μm [53]. This issue can be overcome using spraying techniques. Thermal spraying and reactive spraying are used to obtain titanium nitride based films [52].

## 2. Deposition techniques

### *2.1. Physical vapor deposition (PVD) techniques*

Physical vapor deposition (PVD) is a group of techniques widely used to obtain thin films. Generally, during a PVD process the material to be deposited is evaporated from a solid or liquid source (target) and is carried in the form of plasma to the substrate, where it condenses. According to the method applied