MECHANICAL COMPATIBILITY OF TI COATINGS DEPOSITED BY HVOF THERMAL SPRAYING

Elena Simona CUTEAN, Ion MITELEA, Viorel – Aurel ŞERBAN, Florin Marian CORNEA

Politehnica University of Timişoara, Faculty of Mechanical Engineering, Bd. Mihai Viteazu Nr.1, 300222 Timişoara, Romania,

cuteansimona@yahoo.com, ion.mitelea@mec.upt.ro

Abstract

During the last decade, high velocity oxy-fuel (HVOF) thermal sprayed coatings play an important role in industrial applications where exceptional friction, wear and corrosion resistance are required. The properties of HVOF coatings are highly dependent on a number of parameters including the preparation of the part surface, composition, morphology, size distribution and feed rate, the precise control of gas flow, stand-off angle of deposition and part temperature.

Ensuring appropriate functional properties of HVOF coatings requires a good compatibility with the substrate material. The optimal selection of the coating material takes into consideration the metallurgical, mechanical and process technology compatibility. The mechanical properties of coatings must match the substrate. From this point of view, maintaining a high corrosion resistance is mainly conditioned by achieving a good adhesion and a microstructure free of internal cracks or other defects. This paper aims to characterize the adhesion and scratch resistance using Millennium200 - Technical Tribo equipment of Ti layer deposited on C45 steel by means of HVOF technique.

Keywords: titanium, coatings, microstructure, corrosion tests.

1. INTRODUCTION

Thermal spraying processes are used in many industrial areas due to the wide range of materials which can be used and to the properties provided to the components, especially high wear and corrosion resistance [1]. Adhesion is one of the most important factors that determine the coatings application, durability and exploitation properties. The adhesion of coatings depends on the spraying method and parameters, materials, residual stresses of the coatings and the roughness of the substrate. If adhesion of the coatings is not sufficient, the coatings may exfoliate during exploitation, which can lead to the pieces failure. It is important that thermally sprayed coatings should be hard, resistant to wear or corrosive environment [5], [6].

In order to evaluate the adhesion of thermal spray coatings and to determine the influence of substrate roughness upon adhesion, different methods have been proposed in the literature [5]. Scratch test is one of widely used, fast, and effective methods to obtain the critical loads that are related to adhesion properties of coatings. This test is performed by applying either a progressive (linearly increasing) or constant load [2]. A stylus is moved over a specimen surface with a linearly increasing load until failure occurs at critical loads (Lci). The normal force (Fz) and tangential force (Fx) are recorded also during the tests. The failure mechanisms are examined by an optical microscope. Acoustic Emission (AE) is also measured during the test. Lci is a function of coating-substrate adhesion, stylus-tip radius, loading rate, mechanical properties of substrate and coating, coating thickness, internal stress in coating, flaw size distribution at substrate-coating interface, and friction between stylus-tip and coating. The critical load Lci is defined as the load at which the failure of the coating occurs. This load is related to the practical adhesion strength and the damage resistance of the coating/substrate system [4].
The scratch test procedures are described in the national/international standards, which are usually enforced also in the European, American, Japanese or other national standards [2]. The standards are designed for a wide range of different coating materials.

2. EXPERIMENTAL PROCEDURE

1.1. Preparation of samples

For the experimental program, α-Ti commercial pure titanium powder was used with the dimension of the particles ranging between 15 and 25 μm, and as substrate it was used C45 non-alloyed steel. The deposition of α-Ti coatings was realized using HVOF thermal spraying equipment together with ID CoolFlow thermal spray gun from endowment of Politehnica University of Timisoara. Prior to the deposition, the samples were degreased and blasted with electrocorindum with the dimension of the particles of 1 mm, at a pressure of 5 bars and a blasting distance of 50-60 mm. After blasting, the samples were cleaned with alcohol. The deposition parameters of the HVOF process are presented in Table 1 [1].

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>70</td>
<td>2.6</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

For combustion was used kerosene, at a rate of 2.6 l/h, and as powder carrier gas nitrogen with a flow of 15 l/min. The spraying distance was kept constant at the value of 85 mm perpendicularly to the samples surface. The thickness of deposited layers are 60 μm and 120 μm respectively [1].

Figure 1 presents the scanning electron microscope analysis of the titanium layers deposited by HVOF thermal spraying method.

![SEM analysis of titanium coating (cross-section)](image)

After the scanning electron microscopy analysis it can be observed that the deposited layers by HVOF method does not present defects such as cracks or microcracks. Due to relatively low temperatures of HVOF method (∼ 2800°C), the particles reaches in plastic state and due to high speeds of the gas stream during the spraying process the coatings are dense and compact, without cracks.

1.2. Scratch test investigation

The process of scratching was realized in a controlled and monitored manner to observe adhesive or cohesive failures. In this study, the Millennium200 - Tribo Technic Rockwell C equipment was used to determine the load which causes the failure of Ti coatings. A 0.2 mm spherical diamond stylus was used at
progressive load ranging from 0 N to 125 N and from 0 to 200 N respectively. The points where the coating fails by cracking represents the critical failure loads. Figure 2 presents the principle of scratch testing [5].

![Figure 2 Principle of scratch testing [5]](image)

The scratch test gives very reproducible data that can be used to compare the behavior of various coatings. The critical loads depend on the mechanical strength (adhesion, cohesion) of the coating-substrate composite but also on several other parameters; some of them are directly related to the test itself, while others are related to the coating-substrate system. At high load regimes, the damages usually appear from coating detachment from the substrate either by spalling, buckling or chipping, as presented in Figure 3 [3]. Ti coatings adhesion was investigated also by optical microscopy.

![Figure 3 Surface failures generated in scratch tests: 1 - angular cracks; 2- parallel cracks; 3- transverse semi-circular cracks, coating chipping, coating spalling; 4 - coating breakthrough [3].](image)

2. **RESULTS AND DISCUSSION**

The coating failure is detected by examination the scratch tracks using an optical microscope. The scratch stylus is usually a Rockwell C diamond with 120° tip radius, and the scratch test method is described in the (prospective) European Standard EN 1071-3.

The scratch tests were performed on two sets of samples, namely Ti coatings with a thickness of 60 μm and 120 μm deposited by HVOF technique on C45 medium carbon steel. The main parameters of the scratch test are presented in Table 2.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Coatings thickness [μm]</th>
<th>Initial force [N]</th>
<th>Final force [N]</th>
<th>Loading rate [N/min]</th>
<th>Length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-C45Ti</td>
<td>60</td>
<td>0</td>
<td>125</td>
<td>125</td>
<td>8</td>
</tr>
<tr>
<td>2-C45Ti</td>
<td>60</td>
<td>0</td>
<td>200</td>
<td>200</td>
<td>5.4</td>
</tr>
<tr>
<td>3-C45Ti</td>
<td>120</td>
<td>0</td>
<td>125</td>
<td>125</td>
<td>8</td>
</tr>
<tr>
<td>4-C45Ti</td>
<td>120</td>
<td>0</td>
<td>200</td>
<td>200</td>
<td>5.4</td>
</tr>
</tbody>
</table>
For each set of samples, the adhesion of the Ti deposited layers was realized by determining the critical load points based on acoustic emission. It was determined also the maximum force at which the Ti coating resists and the length of the diamond displacement until the coating exfoliated. The results of the scratch tests are presented in the following figures.

**Fig. 4** Scratch test results of sample 1-C45Ti

From Figure 4 it can be observed the critical loads and the microscopic images of the track resulted after the scratch test of Ti coating with the thickness of 60 μm, at a loading rate of 125N/min. The first crack in the coating appears at a load of 30.51 N, while at 78.46 N the coating is completely removed.

**Fig. 5** Scratch test results of sample 2-C45Ti
When the loading rate is increased up to 200N/min, it can be observed that the values of the critical loads are lower than the values obtained at the loading rate of 125N/min. In this case, the coating is completely removed at the load of 71.62 N and a displacement less than 4.15 mm, as it can be observed from Figure 5.

**Fig. 6** Scratch test results of sample 3-C45Ti

**Fig. 7** Scratch test results of sample 4-C45Ti
Figures 6 and 7 illustrate the scratch test results for the Ti coatings with the thickness of 120 μm at two different loading rates, namely 125 N/min (Figure 6) and 200 N/min (Figure 7). In this case also the coatings present the same behaviour. It can be noticed a minor difference between the critical loads (approx. 2N) at the two loading rates applied. A notable difference can be observed in the displacement of the stylus at the loading rate of 125N/min, which is higher with 2 mm compared to the stylus displacement for the loading rate of 200 N/min.

3. CONCLUSIONS

The results of the investigation show that:

1. The deposited layers by HVOF method does not present defects such as cracks or microcracks.

2. Scratch tests allow the determination of the critical loads that characterize the coating-substrate adhesion. In this study, the coating-substrate adhesion of Ti coatings decreases when the coating thickness increases.

3. In the case of Ti coatings with the thickness of 60 μm, the first crack occurs at a force of 30.61 N, and a displacement of 2.68 mm. The coating exfoliates after a shift of 6.60 mm and a force of 78.46 N at the loading rate of 125 N/min. The first crack of the coating with a thickness of 120 μm appears at 29.44 N force and a displacement of 2.47 mm. At 72.53 N and displacement of 6.22 mm the titanium layer is removed at the same loading rate.

4. If the loading rate increases to 200 N / min the resistance of the deposited layer decreases. The first crack appears at a lower load of 24.09 N and a displacement of 1.47 mm. When applying a load of 71.62 N the coating with a thickness of 60 μm is exfoliated. In the case of Ti coating with a thickness of 120 μm both force and displacement values decrease. The first crack occurs at an applied load of 25.77 N and displacement of 1.53 mm and when a load of 74.52 N is applied, the deposited layer is removed from the substrate.

5. Scratch testing can detect adhesion problems in coating process before parts are actually put to use. By applying loads in a controlled and closely monitored fashion, the tool allows to identify quantitative and reproducible critical load failures.

ACKNOWLEDGEMENTS

Learning agreement number 26/11.2011 Politehnica University of Timișoara, Faculty of Mechanical Engineering.

REFERENCES


