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Procedia Engineering 2 (2010) 1617–1623

Procedia
Engineering

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Fatigue 2010

Fatigue in AISI 4340 steel thermal spray coating by HVOF for aeronautic application

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Received 28 February 2010; revised 9 March 2010; accepted 15 March 2010

Abstract

Currently, high-strength materials, particularly AISI 4340 steel, are used in several landing gear components. Due to the high resistance to wear and corrosion required, the components are usually coating by hard chromium. This treatment produces waste, such as Cr+6 (hexavalent chromium), generally after applying the coating of hard chromium which is harmful to health and the environment. The process HVOF (High-velocity-oxygen-fuel) is considered a promising technique for deposition of hard chromium alternative coatings, for example, coatings based on tungsten carbide. This technique provides high hardness and good wear strength and more resistance to fatigue when compared to AISI 4340 hard chromium coated. To minimize loss fatigue due to the process of deposition, shot peening is used to obtain a compressive residual stress. The aim of this study was to analyze the effects of the tungsten carbide thermal spray coating applied by the HVOF, in comparison to the conventional hard chromium electroplating on the AISI 4340 high strength steel behavior in fatigue. Optical microscopy and scanning electron microscopy were used to observe crack origin sites, thickness and adhesion of the coating.

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Keywords: Fatigue; AISI 4340 steel; Shot peening; HVOF process

1. Introduction

The process of fatigue is one of the most responsible for fractures in mechanical components. In the design of structures subjected to cyclic loads, a study should be considered accurate aiming greater reliability and security [1].

In the prediction of fatigue life of these components are studied three design philosophies: safe life, fail safe and damage tolerance. In secure life, it is the service life based on an acceptable probability of failure at a specific voltage. In cases where the presence of a crack is found before the estimated life, imminent failure is indicated, the replacement of much of a structure that has not yet reached its useful life is done, since it specifies that the life of the material ends at the stage of crack initiation [2]. Fail safe philosophy ensures that a component or structure can still be used even in the presence of a crack, provided that it has a size smaller than the critical planning and has a regular inspection [3]. The concept of damage tolerance, structures are designed so that they have linked their use to provide a secure life, which resembles a Philosophy of Life Safe, but with a difference. In the forecast are considered concepts of Fracture Mechanics, causing the average life of the structure (or material) has a stage where there may

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be defects (eg cracks), but with proper planning so that fractures do not occur [4]. An important consideration in this study is the selection of materials with high fracture toughness [5].

In recent years, materials of high resistance of automotive, aviation and oil have been used with coatings deposited in order to match the mechanical strength with resistance to corrosion and wear. The electrodeposited chromium has been the most frequently used process due to features such as high hardness (850 to 1050 HV), wear resistance and corrosion and low coefficient of friction. The hard chrome plating reduces resistance to fatigue due to their high tensile residual stresses in the coating-substrate interface. The process of electrodeposition of hard chromium ions produced as a waste of hexavalent chromium in the state, and harmful to the environment and human health [6].

Recent surveys show that after the deposition of semi-melted high-speed process by HVOF (High-Velocity-Oxygen-Fuel) has shown properties of resistance to fatigue and corrosion better than chromium electrodeposited [7]. Dust particles are rendered semi-accelerated by the driving gas at high speed out of the nozzle of the gun with a speed of about 900 m/s collide with the workpiece surface to be coated. The fuel mixture in the combustion chamber in addition to oxygen, are: propylene, acetylene, propane, hydrogen and kerosene, ignition and combustion gas control is clearly targeted [7].

One technique that has been used to minimize the loss of fatigue life due to the deposition process of coating, both for hard chrome and for the thermal spray is the shot peening. This technique introduces compressive residual stresses on the surface of the material that hinder the nucleation and propagation of fatigue crack growth [8].

2. Experimental Procedure

2.1. Materials and mechanical properties

The steel of AISI 4340 aeronautical use, is a low alloy steel which has the following chemical composition: 0,41C - 0,73Mn - 0,25Si - 0,80Cr - 1,74Ni and 0,25Mo wt%. The mechanical properties were obtained by a hardening heat treatment to 815 ° C for 45 minutes with cooling in oil between 20 and 60 ° C, followed by double tempering at 220 ° C for 2 h with cooling in air. The mechanical properties obtained were: 50 - 53 HRc, yield strength of 1500 MPa and tensile strength of 2000 MPa.

The coating used was the WC-CrC-Ni deposited by HVOF, chemical composition: 20% Cr, 6% Ni, 5.8% C, W rest. Its features high corrosion resistance, high chemical resistance, excellent wear properties and are employable to 760 ° C.

2.2. Thermal spray coating (HVOF)

The coating WC-CrC-Ni system was applied by the HVOF thermal spray, where its thickness varies between 100 and 150µm. The fuel mixture in the combustion chamber in addition to oxygen are: propylene, acetylene, propane, hydrogen and kerosene, with ignition and combustion gas control is clearly targeted. The equipment to be used in this project is installed in Praxair Surface Technologies, in Curitiba, Parana, Brazil. The powder was deposited with the model JP 5000, TAFA1310VM Technologies, at a density of 4.8 g/cm³ according to ASTM B-212, with a deposition rate of 900m / s, and rate of 50µm per minute.

2.3. Axial fatigue test

The specimens for axial fatigue test were prepared according to ASTM E466, with the geometries shown in Fig.1.

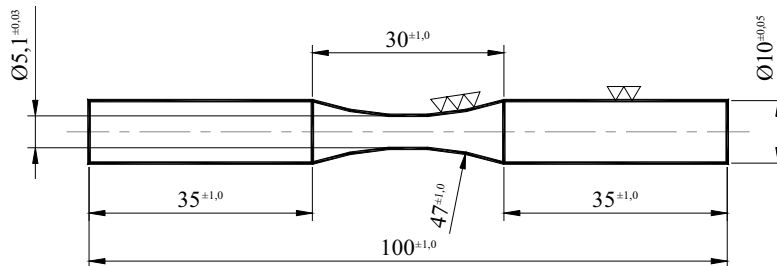


Fig. 1. Axial fatigue testing specimen.

The fatigue test was conducted until fracture or until a number of 10^7 cycles. The tests were conducted at a frequency of 10 Hz with a load ratio of 0.1. We used 16 specimens of the material base without shot peening, 13 specimens of base material with shot peening, 13 specimens of the base material coated with WC-CrC-Ni without shot peening and 11 specimens of base material coated with WC-CrC-Ni with shot peening to obtain S/N curves.

2.4. Microhardness test

The microhardness test was performed in a digital microhardness tester Shimadzu HVM-2T. Several meetings were markings microhardness in the specimen, sweeping it from the surface of the coating to the base material. With these markers it was possible to profile the hardness of the coating WC-CrC-Ni.

2.5. Optical microscopy

Optical microscopy was performed in Epiphot 200 Nikon microscope. The purpose of this analysis was to verify the homogeneity of the interface layer of the coating and measuring the thickness of the coating.

2.6. Scanning electron microscopy (SEM)

The scanning electron microscopy (SEM) was performed to analyze the type of fracture and the origin of fatigue cracks in the specimens fractured. This analysis was performed in a scanning electron microscope JEOL JSM 5310 with tungsten filament operates between 15 to 20 kV in low vacuum technique, in which the images were obtained by the electron scattered at INPE in São José dos Campos, Sao Paulo, Brazil.

3. Results and discussion

3.1 Axial fatigue results

The S-N curve for the axial fatigue tests for the base metal and coated specimen, is represented in Fig. 2.

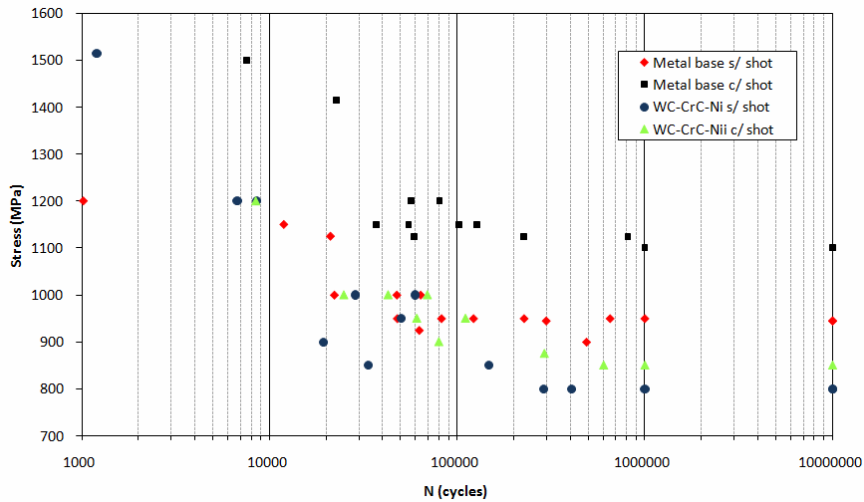


Fig. 2. S-N curve for axial fatigue tests.

The fatigue curves represented in Fig.2 indicated a reduction of fatigue strength of HVOF coated material in relation to the base material. This behavior is probably due to the numerous microcracks generated in the process of deposition. These microcracks are generated by inclusions, both oxides and particulates not rendered, and porosity also influence the generation and propagation of these microcracks. A noticeable improvement in fatigue life of materials that have suffered the shot peening because of compression residual stresses were introduced on the base material, making it difficult to crack nucleation.

3.2. Microhardness test

With the microhardness test was possible to trace the curve shown below.

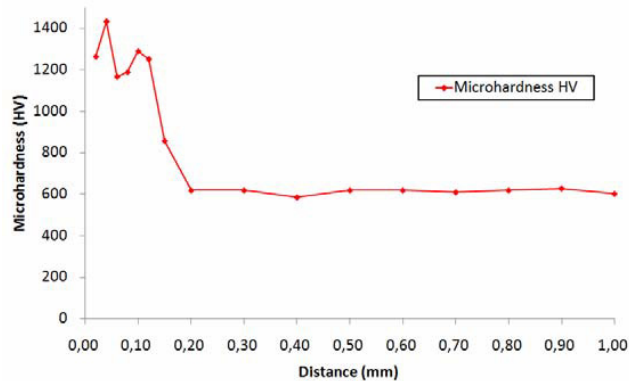


Fig. 3. Microhardness. 100g. WC-CrC-Ni.

Based on Fig. 3, we can see that the microhardness of the coating of WC-CrC-Ni is about 1300 HV, very similar to the hardness of electrodeposited chromium coating, which is about 1250 HV. You can also verify an approximate thickness of the coating, which in this case is between 100 and 120 μm . Note that the microhardness in the coating undergoes some changes because there empty, oxides and particulates not rendered under the deposition process.

3.3. Optical microscopy

Figure 4 represents the cross section of AISI 4340 steel coated WC-CrC-Ni. It is noted that the coating showed a good homogeneity, increase in roughness at interface coating/substrate due to aluminum oxide blasting increasing adhesion and that the deposition process did not affect the microstructure. The average thickness of the coating was 120 μm .

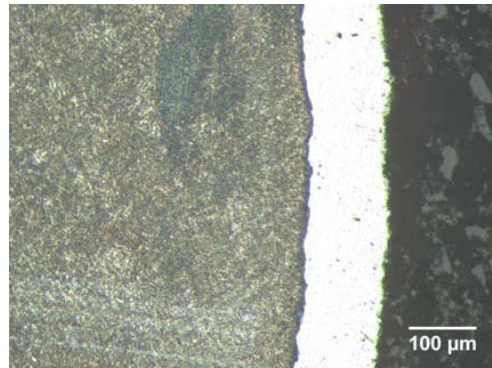


Fig. 4. Light microscopy of AISI 4340 steel coated WC-CrC-Ni.

3.4. Scanning electron microscopy (SEM)

The crack surface was analyzed by scanning electron microscopy. See Fig. 5 and Fig. 6.

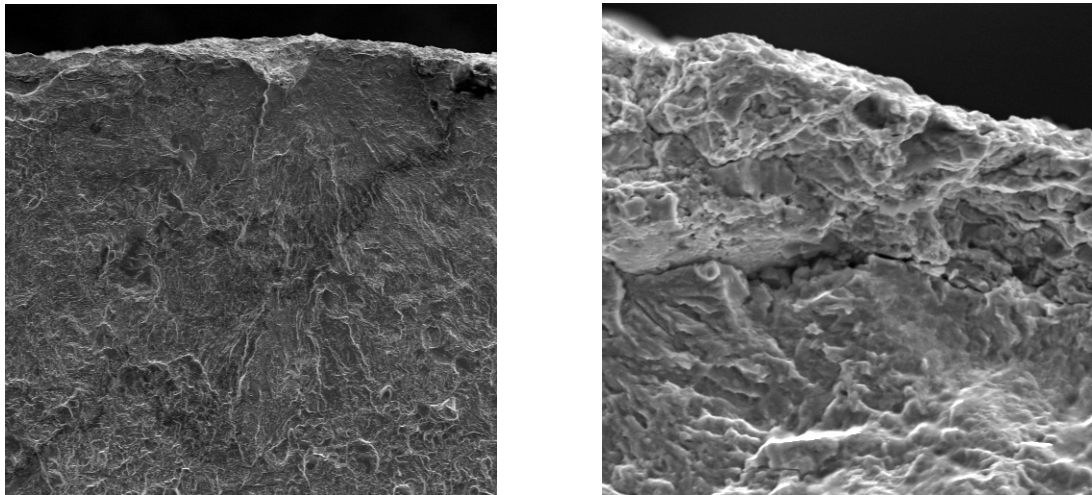


Fig. 5. (a) Scanning electron microscopy of AISI 4340 steel coated WC-CrC-Ni.200x. (b) Scanning electron microscopy of AISI 4340 steel coated. 2000x.

It can be seen in Fig. 5a and 5b that the crack propagated in the core and interface coating / substrate. This is due to microcracks generated by the process of the thermal spray coating. As we have a difference of mechanical strength (hardness) very wide gap between the coating and the substrate, the crack tends to move the interface into the substrate, because the mechanical strength of the substrate is much lower when compared with the coating.

You can also verify the above figures that there was no delamination between the coating and substrate, in other words, the coating adhered efficiently to the substrate, thereby ensuring the efficiency of thermal spray.

Fig. 6a and 6b it is observed that the thickness of the coating does not match the thickness of the project (120 μ m). This is because at the time of fracture of the specimen, a layer of the coating fell off, leaving only 40 μ m coating.

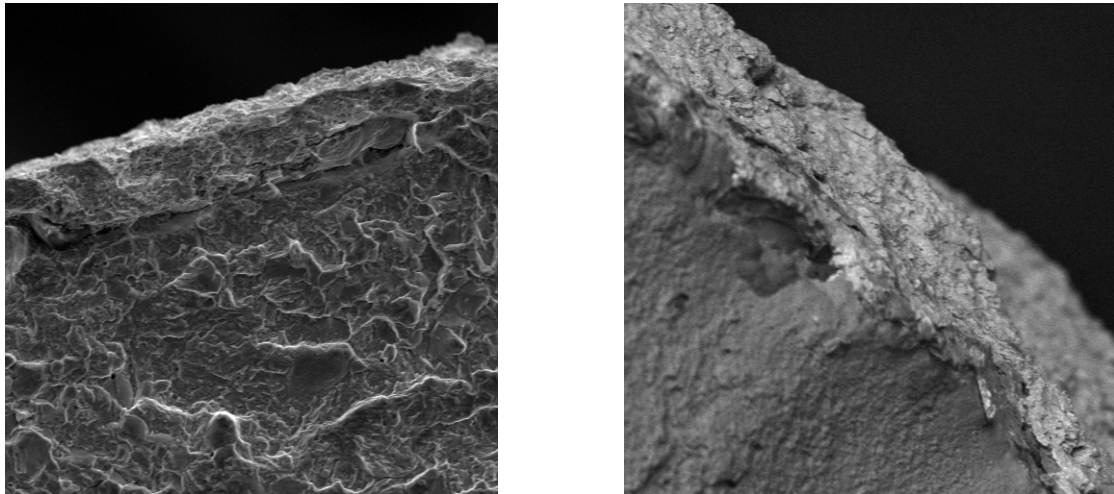


Fig. 6. (a) Scanning electron microscopy of AISI 4340 steel coated WC-CrC-Ni.750x. (b) Scanning electron microscopy of AISI 4340 steel coated. 750x.

4. Conclusions

- Experimental results that the deposition process of coating WC-CrC-Ni via HVOF caused a reduction in fatigue resistance of AISI 4340 steel, however, when compared to electroplated chrome, has a greater resistance to fatigue.
- The shot peening treatment proved effective in restoring the fatigue life of AISI 4340 steel coated.
- HVOF coatings treated by shot peening is equipped with hard chrome coatings when compared with resistance to fatigue, corrosion and wear.

5. Author Artwork

Rafael Gustavo Bonora is member of Fatigue and Aeronautical Materials Research Group-DMT/FEG/UNESP, Guaratingueta, Brazil.

Acknowledgements

The authors thank Fatigue and Aeronautical Materials Research Group-DMT/FEG/UNESP and are gratefully to support provided by FAPESP through the processes numbers 2006/03570-9.

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