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The interfacial indentation test to determine adhesion and residual stresses in NiCr VPS coatings

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Abstract

The interfacial indentation test allows determining the interface toughness of a coating obtained by thermal spraying. During this test, a Vickers indentation is carried out on a cross-section of the sample. A crack is initiated and propagated along the interface. An analytical model allows defining an interface toughness representing the coating adhesion. The objective of this study is to compare this test with other tests (tensile adhesive test, shear test) and to specify its applicability. The residual stresses are also estimated by two different methods. Their influence on adherence is discussed in a third part. Those experiments were conducted on NiCr 80-20 VPS coatings with different thicknesses and roughnesses. In particular, it is shown that the interfacial indentation test is the most universal one and that compressive residual stresses improve coating adhesion.

Keywords: Thermal spray coatings; Interfacial indentation; Adhesion; Residual stress; NiCr

1. Introduction

Adhesion of thermal sprayed coating is one of the most important parameters to consider. The development of this surface treatment technique depends on this point since more and more severe loadings are submitted to mechanical parts. The adhesion determination is then one of the main problems in scientific and technical laboratories. Since few decades, the interfacial indentation test is developed and started to be employed by different international teams [1–3]. The goal of this work is to confront this test with other standard tests which allows determining of adhesion and residual stresses in the coatings. Adhesion of NiCr 80-20 vacuum plasma sprayed coatings were determined with EN 582 standardized tensile adhesive test, EN 15340 standardized shear test and interfaciale indentation test. Residual stresses were evaluated with the interfacial indentation test results and the curvature method.

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2. Experimental methods

2.1. Samples preparation

NiCr 80-20 coatings were vacuum plasma sprayed in three different thicknesses (180, 280, 480 μm) on S235 construction steel with three different surface roughnesses (2.3, 4.5 and 6.0 μm Ra). The temperature at the beginning of the spraying process was 350 °C and 500 °C at the end. Particle size of the NiCr powder was −53+20 μm. The nomenclature is presented Table 1. Mechanical properties of coating and substrate were determined by depth-sensing indentation. S235 steel has a hardness of 151 HV, a Poisson ratio of 0.30 and a Young modulus of 200 GPa. NiCr coating has a hardness of 244 HV, a Poisson ratio of 0.31 and a Young modulus of 218 GPa.

2.2. Tensile adhesive test

The tensile adhesive test is one of the few standardized tests to determine interface strength. The European EN 582 and American ASTM C 633 norms are the most diffused and this test is largely used in industrial and scientific laboratories. To

Table 1
Nomenclature

	Coating thickness (μm)	Substrate roughness Ra (μm)	Nomenclature
1	110±20	2.3±0.2	Ni-150-2
2	180±20	2.3±0.2	Ni-300-2
3	480±20	2.3±0.2	Ni-600-2
4	110±20	4.5±0.5	Ni-150-4
5	180±20	4.5±0.5	Ni-300-4
6	480±20	4.5±0.5	Ni-600-4
10	110±20	6.0±0.3	Ni-150-6
11	180±20	6.0±0.3	Ni-300-6
12	480±20	6.0±0.3	Ni-600-6

perform the test, a normalised cylindrical specimen which is coated on its plane face, is bonded, generally with an epoxy resin, to the twin specimen (see Fig. 1). This assembly is submitted to a tensile test until rupture. The tensile strength is obtained by dividing the maximal force by the surface area. During this test, several types of rupture can appear, eventually together [1–3]. It could be i) an adhesive rupture when the failure appears at interface between the coating and the substrate; ii) a cohesive rupture when the failure appears into the coating layer; iii) a failure of the epoxy layer. The use of a bonding layer is a source of problems of various orders. At first, the glue has its own tensile strength which could be less that the coating one. Moreover, the glue can penetrate in the open porosities of the coating and in the case of thin coatings, reach the substrate, forming a glue-coating composite. This composite has then mechanical properties different of the coating one. In the same order, this test is hard to perform since the assembly has to be submitted to a perfectly one-way tensile force. This alignment can be supported by the use of kneecaps on the tensile axis but is never perfect in practice.

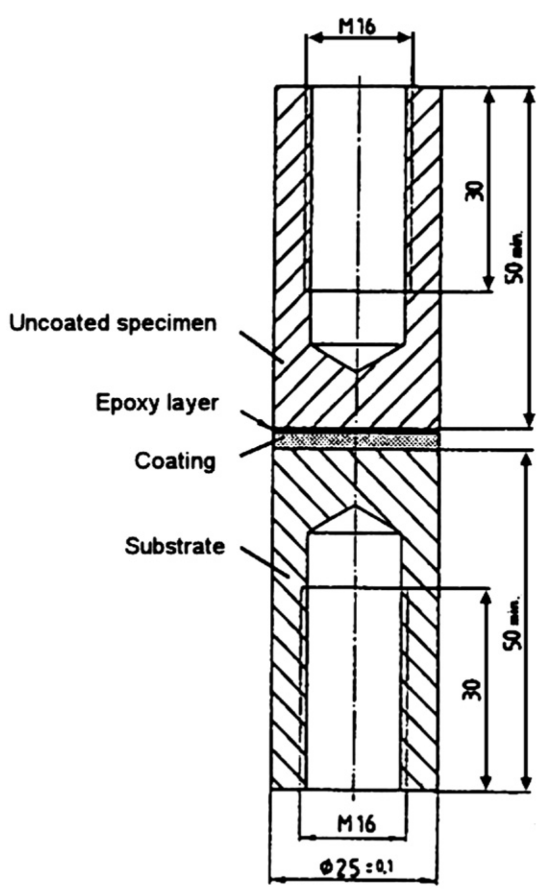

Fig. 1. Assembly of an EN 582 tensile adhesive test specimen [4].

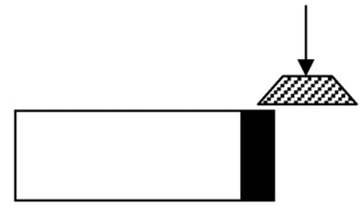

Fig. 2. Shear test according to EN 15340.

2.3. Shear tests

The principal advantages of this test are the absence of bonding agent, the speed of execution and the absence of preparation contrary to the test carried out on a tensile testing machine. However, this test presents some limitations. For example, it is not possible to calculate the relevant shear strength when the rupture is mixed or cohesive. The thickness of the coating is also a limitation because the load is applied to the coating roughly to 50–100 μm of the interface. In order to be applied correctly without slip, the loading must relate to a substantial share of the coating. This is why the test is recommended for coating thickness higher than 150 μm [5]. Moreover, there is a bending moment at interface. The shear test is performed with a tool applying a shear force to the coating (Fig. 2). This test is standardized according to EN 15340. A specimen is shear loaded with a hard metal machining tool in a plan parallel to the interface one. The load is increased until the coating failure. The shear strength is the force necessary to produce this failure of the coating.

2.4. Interfacial indentation test

The interfacial indentation test is more and more employed to replace other tests [3,6]. The principle of this test is to perform a serial of Vickers indent in a sample section to create and propagate a crack along the interface between the coating and the substrate (see Fig. 3). The crack is located in the plane of

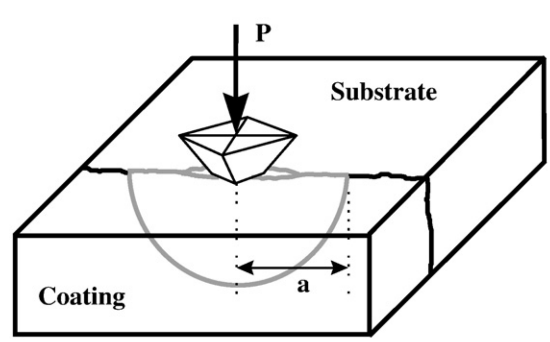

Fig. 3. Interfacial indentation test schematic representation [7].