Adhesion and ductility of plasma sprayed thermal barrier coatings

ADHESION AND DUCTILITY OF PLASMA SPRAYED THERMAL BARRIER COATINGS.

A.T.J. VERBEEK, J.M. HOUBEN, J.A. KLOSTERMANN
Materials Group, Faculty of Mechanical Engineering,
Eindhoven University of Technology,
Den Dolech 2, 5612 AZ Eindhoven, The Netherlands

ABSTRACT

In this paper the development of a new Tensile Adhesion Test, operating without glue, for Plasma Sprayed Coatings is described. First some general information about bond strength and adhesion tests is given. Next, a description about the new test and some test results of this test are given, together with the results of a conventional Tensile Adhesion Test. On testing the coatings, the failure behaviour has been followed by acoustic emission monitoring.

INTRODUCTION

One of the most important problems one will encounter on applying plasma sprayed (ceramic) coatings, is the bond strength of these coatings. The mechanical behaviour is strongly dependent on the bondstrength. When a coating is subjected to a mechanical, thermomechanical or combined load, failure will often occur at the interface between substrate and coating.

Principles of adhesion

In general, there are assumed to be three principles of adhesion of plasma sprayed coatings: Mechanical Anchoring
The coating fixes itself by anchoring on the peaks and holes at the substrate surface. Adsorption; this is merely a surface effect. It can be divided into three types of bonding: Chemical bonding, Physical bonding or Chemisorption. Metallurgical interactions; diffusion of the coating atoms into the substrate material and also the reverse process.

Adhesion tests

The most widely used test for bond strength testing is the so called Tensile Adhesion Test. There are various kinds of this test, but they all are based on the same principle. A specimen is coated and a metal body is glued to the coating. This construction will be tested in a tensile testing machine. The bondstrength is defined as the fraction of the force at failure and the coating area under tensile stress. According to Strompen [1], four types of coating failure can be determined using tensile adhesion tests. These failure modes are: delamination, breaking down of the glue film, failure in the coating and mixed failure. The latter is a combination of delamination and failure in the coating.

As already mentioned, there are several types of tensile adhesion tests. Only one of these tests, the DIN 50160 is standardized. (figure 1) This test is very easy in use however it has some major disadvantages:
The glue penetrates into the coating, changing the characteristics of this coating. The deposition circumstances vary with the radius of the specimen and the Poisson effect plays an important role at the coating boundary.
Two other tests [2], however not standardized, can be used to avoid the problems involved with the varying deposition circumstances and Poisson effect (figure 1). These are the so called TNO-test and the TUE test, the latter developed at Eindhoven University of Technology.

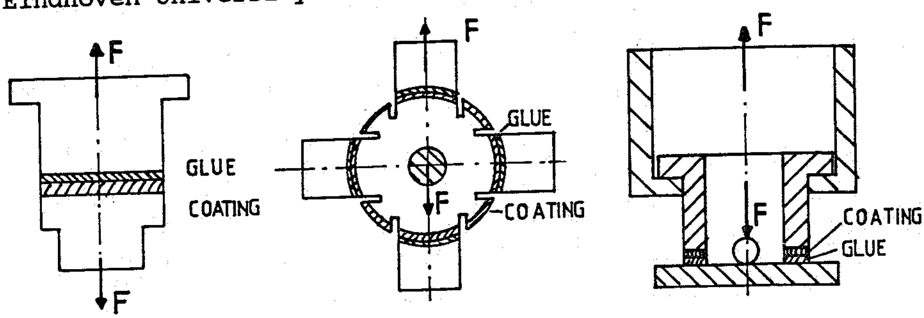

Figure 1. DIN test (a), TNO test (b) and TUE test (c)

DEVELOPMENT OF A NEW TEST

Because of the problems involved with the use of glue that penetrates into the coating and influences the coating characteristics, a new test without glueing, according to an idea of J.M. Houben, has been developed. This test is based on the following principle:. A hollow cylinder is loaded as stated below. (figure 1) In the areas, indicated by the little arrows, a tensile stress will occur. This stress tends to seperate the concentric thin cylinders that form the total cylinder. The stress state in the cylinder can be described by using an Airy stress function [3]. This gives us the following stresses:

radial stress $\sigma_r = f_1(r)*\sin\theta + f_{11}(r)$

tangential stress $\sigma_\theta = f_2(r)*\sin\theta + f_{22}(r)$

shear stress $\sigma_{r\theta} = - f_1(r)*\cos\theta$

$f_1(r)$, $f_2(r)$, $f_{11}(r)$ and $f_{22}(r)$ are functions of the radius

The tangential and radial stresses reach their maximums at $\theta = 90°$, whereas the shear stress is maximum at $\theta = 0°$. In figure 2 the principle of this test and the stress distribution are shown

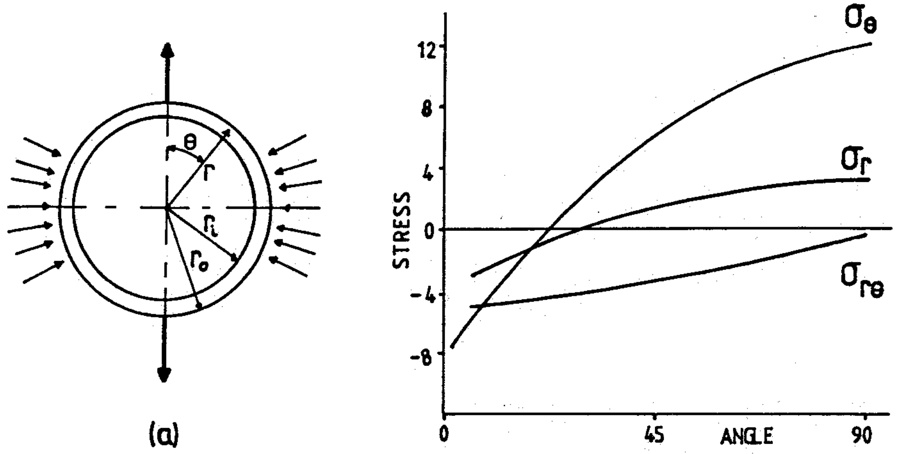

Figure 2. Hollow cylinder loaded by two equal, opposite forces (a) and stress distribution in this cylinder (b)

When this hollow cylinder is coated, the tensile stress around $\theta = 90$ °, will try to delaminate the coating from the cylinder if we assume that the adhesion strength of the coating is less than the cohesion strength of the substrate or coating material. Further, the test specimens have two, oppositely placed joints, just at the points the specimen is loaded in the tensile testing machine. At these joints, the coating is removed to avoid cracking of the coating during the early stages of the adhesion test. During the tensile adhesion test, delamination can be observed in the force vs. replacement curve of the tensile testing machine. At the point of delamination, the stiffness of the coated cylinder decreases, resulting in a dip in the force vs. replacement curve. With the help of the finite element methode, it is now possible to determine the stress at which the coating delaminates. When the Young modulus of the coating has the same value as the young modulus of the substrate, the stress at delamination easily can be determined by applying the already mentioned analytical formulas. In figure 3 the test principle, together with a typical force vs. replacement curve is shown.

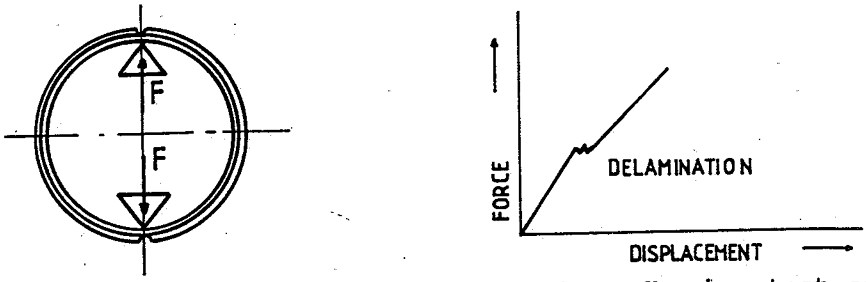

Figure 3. Testprinciple of new tensile adhesion test and a typical force vs. replacement curve.

TENSILE ADHESION TESTING OF THERMAL BARRIER COATINGS

Thermal Barrier coatings are ceramic coatings with a very low thermal conductivity. Usually they are produced by means of powder plasma spraying. As coating material, partially stabilized ZrO_2-8wt%Y_2O_3 is used.
To test the adhesion strength of the Thermal Barrier Coatings, the new test and the TNO test were used.
The coatings were sprayed with an arc current of 600 Amps, a Ar to H_2 ratio of 150 to 15, a spraying distance of 100 mm and a powder grain size of 22.5 to 45 μm. This resulted in a very dense coating of about 0.3 mm thickness on the disks and a coating of about 1 mm thickness was sprayed onto the cylinders. The coating on the cylinders showed cracks, perpendicular to the coating surface at regular distances.
The substrates were gritblasted before spraying.
The metal bodies were glued to the disks with a one component epoxy glue with a adhesive strength of about 70 N/mm².
During the tensile adhesion test the failure process was monitored by acoustic emission evaluation.

The coating failure observed at the TNO test was coating delamination and sometimes mixed failure. The bond strength of the coatings varied from 31.4 to 38 N/mm².
During the test a continuous Acoustic Emission Activity was measured, indicating that crack formation occurred not only at the final delamination of the coating, but already before this delamination. At the moment of delamination, however, the Acoustic Emission activity strongly increases.

On testing coatings with the new developed test, two types of coating failure were observed. The coating only delaminated around θ = 90°, a gap between the coating and the cylinder can be observed, or a piece of the coating around θ = 90° is totally removed. At one specimen, the coating delaminated next to the joint. The acoustic emission signal shows very sharp peaks at the moment of delamination. Before the delamination also acoustic emission activity is measured.
The duration of the events, measured before the delamination, varies from 1 μs until 500 μs, while the events measured at

delamination vary between 200 and 5000 μs. The beginning of the delamination can be observed by increasing acoustic emission activity (hits vs. time ratio) and an increasing duration ot the hits. The final delamination of the coating can be heard as a dry "plopping" sound, and is seen as very high acoustic emission peaks. The amplitudes of these final peaks reach up to 100 dB.
After testing, the failed coatings were examined by light microscopy. It was shown that the perpendicular cracks, already present in the coating had not been growing. So the measured acoustic emission signal must be caused either by microcracks (those couldn't be observed) or cracks at the interface coating substrate.

When the acoustic emission signals of the cylinder test are compared to the signals obtained by the TNO-test, it can be remarked that the first one shows a more reproducable signal. At the cylinder test, failing can be observed as increasing acoustic emission activity followed by a sharp peak. During the TNO test no direct relationship between acoustic emission activity and failure mode was found. The signals measured at the mixed failure mode, were sometimes the same as the signals measured at a coating totally delaminating.

CONCLUSIONS

However the bondstrengths that have been measured by the two tests, are very different and cannot be compared, the TNO test as well as the cylinder test deliver very reproducable results. Delamination has shown to be a process that does not occur suddenly but is preceded by the formation of little cracks. The absence of glue at the cylinder test is a great advantage, the coating characteristics are not changed due to penetrating glue. Further the failure mode is very reproducable, no mixed failure occurs. Also the acoustic emission signal of the coating is very reproducable.

ACKNOWLEDGEMENT

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