International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:1, 2012

Adhesion Strength Evaluation Methods in Thermally Sprayed Coatings

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***Abstract*—**The techniques for estimating the adhesive and cohesive strength in high velocity oxy fuel (HVOF) thermal spray coatings have been discussed and compared. The development trend and the last investigation have been studied. We will focus on benefits and limitations of these methods in different process and materials.

***Keywords*—**Adhesion, Bonding strength, Cohesion, HVOF Thermal spray

I. INTRODUCTION

THERMAL spraying with high velocity oxygen fuel (Fig.1) has been very successful in spraying wear resistant WC–Co coatings with higher density, superior bond strengths and less decarburization than many other thermal spray processes. This is attributed mainly to its high particle impact velocities and relatively low peak particle temperatures [3]. As a class of hard composite materials of great technological importance, WC–Co powder cemented carbides are widely used by various thermal spray processes to deposit protective coatings in a large variety of applications such as power plants, oil drilling, turning, cutting and milling, where abrasion, erosion and other forms of wear exist [4]. Less attention has been given to develop thick coatings for repair applications, which is significant interest for the aerospace industry. One challenge is to control the residual stresses through the deposit thickness when a coating to be sprayed is several millimeters thick, and to understand the relationship between these stresses and coating adhesion. The adhesion strength of a coating is depends on the bonding between the coating and substrate as well as on the coating microstructure. Both the bonding and the microstructure are strongly influenced by residual stress distribution.

It is commonly known that the level of residual stresses can significantly change at the coating substrate interface creating delaminations, which in worst cases can cause spallation. Compressive residual stresses at the interface are known to inhibit the formation of through thickness cracks and to improve adhesion bonding and fatigue strength [5], [6].

Adhesion of thermal sprayed coating to a substrate has been a primary concern to engineers ever since thermal spray processes were introduced to various industries. This is because the process cannot be effectively employed for engineering applications if the coating does not bond well to a substrate. Therefore, investigation on the bonding mechanisms of coating-substrate, which is an important element of the theory of thermal spray technology, has attracted a great deal of attention in the past decades [7]–[11].

In this study the methods for evaluation the bond strength of thermal spray coatings in high speed shafts has been studied. We will focus on benefits and limitation of these methods in different process and materials.

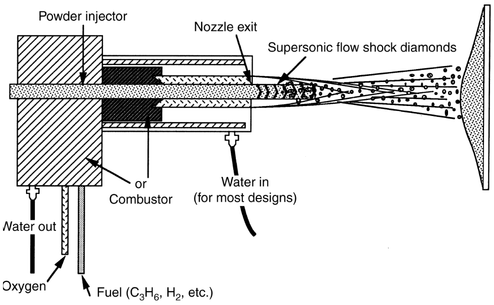

Fig. 1 High velocity oxy fuel Thermal spray process

II. BOND STRENGTH

The bonding between particles and substrates is critical to ensure the quality of coating. Cracking and debonding of the coating from the substrate are two main types of coating failure. Consequently, the structure integrity evaluation of the coatings is important, which can ensure the safety and reliability of coating materials. For this purpose, much research has been focused on the measurement methods of coating bonding strength, and many methods have been attempted [12-17].

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A. Scratching test

The scratch test, originally studied by Benjamin and Weaver [18], is often used to characterize thin hard coatings, such as TiN and TiC **[**19]**, [**20]. In this test, a loaded Rockwell C diamond stylus is drawn across the coating surface under either constant or gradually increasing load. The scratch test has been applied in the evaluation of thermally sprayed coatings. The major problem for utilization is that all the theories were developed based on thin coatings and may no longer be appropriate for bulk coatings. Das et al. [21], in studying plasma sprayed yttria-stabilized zirconia (YSZ) coatings, proposed a method for the determination of the critical load and discussed the effect of the loading rate dL/dt and the scratch table speed dx/dt. Beltzung et al. [22], [23] performed scratch tests on the cross-section of alumina based coatings. A half-cone-shaped fracture was formed as the indenter approached the free surface. The height of this cone can be related to the cohesive strength or intrinsic fracture toughness of the coating. Interfacial cracking may also occur and can be utilized as a measure of the adhesion strength.

B. Tension test

The most commonly used method is the tension test based on ASTM C633 [24]. This test method covers the determination of the degree of adhesion (bonding strength) of a coating to a substrate or the cohesion strength of the coating in a tension normal to the surface (Fig.2). The test consists of coating one face of a substrate fixture, bonding this coating to the face of a loading fixture, and subjecting this assembly of coating and fixtures to a tensile load normal to the plane of the coating. It is adapted particularly for testing coatings applied by thermal spray, which is defined to include the combustion flame, plasma arc, two-wire arc, high-velocity oxygen fuel, and detonation processes for spraying feedstock, which may be in the form of, wire, rod, or powder. This test method is limited to testing thermal spray coatings that can be applied in thickness greater than 0.015 in. (0.38 mm). The limitation is imposed because an adhesive bonding agent is used in the test. Those bonding agents established so far for this method tend to penetrate thermal spray coatings and may invalidate results unless the coatings are thick enough to prevent penetration through the coating. However, this evaluation method assumed that the interface stress was uniform, in other words, it was based on the concept of average interface stress or nominal stress. As a result, it cannot reflect the true interface strength characteristic because of the stress singularity near the interface. The other limitation of this method is the strength of epoxy binder. The glue strength is much less than adhesive and cohesive strength of high hardness cermet coatings such as WC-Co.

C. Micro indentation test

The indentation techniques are used to determine the mechanical properties of thermal spray coatings [25], [26]. Young's modulus of the coatings is usually determined by Knoop indentation test [27]. The coating toughness has been measured by Vickers indentation test, where it is necessary to measure the indent diagonals and the crack lengths produced during the test [28]. In recent years, the interfacial indentation test is proposed to characterize the adhesion properties of plasmas prayed coatings [29]. This methodology requires Vickers indentation test to be performed on the coating–substrate interface at different applied loads. Using interfacial indentation test and defining a critical load necessary to initiate a crack, the apparent fracture toughness could successfully describes the adhesion of coatings to their substrates. The major advantage of this methodology is that it does not require using any adhesive glue such as in tensile test [30].

Fracture toughness of coatings (K_C) was determined by Vickers indentation method [28] and following equation was used to compute KC [28]. The so-called interface indentation test developed by Lesage and Chicot [8] was used to determine the apparent interface fracture toughness (K_{Ca}). This test consists of loading Vickers indenter with different applied loads at the coating–substrate interface, measuring the value of the half-diagonal of the indent (Fig. 3).

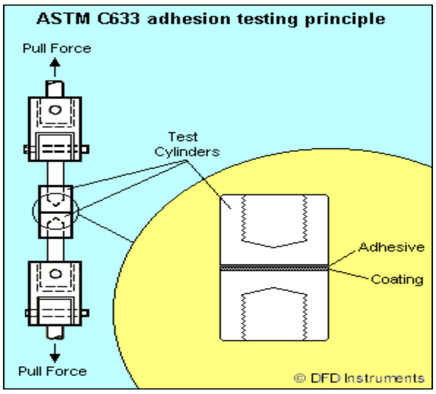

Fig. 2 Tension test of coated sample

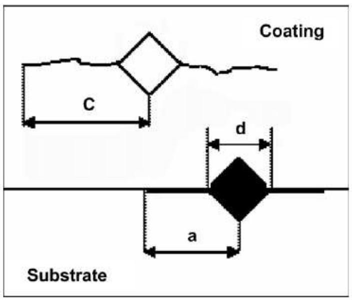

Fig. 3 Schematic of the Vickers indentation impressions at the interface and the cross-sectional surface of the coating

D.Three point bend test

This method is based on the force moment of coating which plays an important role in the cracking of coating. The fracture behavior of a ceramic reinforced metal-base coating prepared by high velocity arc spraying (HVAS) technology in three-point bending test was studied by MA Chong et al. [31]. In their study, the three-point bending test under steady-load was carried out, and the fracture behavior of the coatings was observed and analyzed (Fig.4). Furthermore, to explain the fracture behavior characteristic of the coatings, the finite element analysis (FEA) was adopted to analyze the stress distribution near the interface between the coating and the substrate. In the load-on process, the crack initiation on the side face of the specimen is observed by using a long-range micro-telescope. The load versus load-point displacement curve of specimen can be presented in a one such Fig.5.

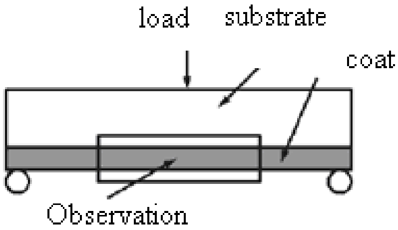

Fig. 4 Schematic of observation location

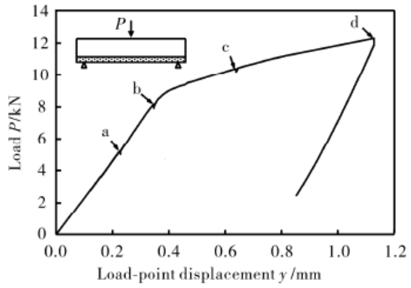

Fig. 5 Load versus load-point displacement curve obtained

III. CONCLUSION

The evaluation methods and the trend of studies on the bonding strength has been introduced and discussed.

A summery of conclusions is as follow:

- Developing A new approach – binder independent- for testing of adhesive and cohesive strength in high adhesion strength coating such as WC-Co coatings is an important necessity.
- The fracture toughness as a representative method can be use for parametric study in thermal spraying instead of conventional method when the bond strength of coating is much more than epoxy strength.

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