Editorial

Advanced Evaluation of Thermally Sprayed Ceramic Coatings

Thermal spraying has developed as a technology to apply a variety of coatings to almost any substrate. Since the development of plasma spraying in 1960s, coatings have been extended to all kinds of materials from metals to ceramics that are not vaporized in the high temperature of a plasma jet. The sprayed coatings have been successfully used in many industrial fields such as steelmaking, petroleum and chemicals, textile, electronics, aeronautics, shipbuilding, pump and paper, and so forth to enhance wear resistance, heat resistance, and corrosion resistance of structural materials, a development that has mainly advanced by empirical methods.

As coating property requirements become more and more sophisticated, successful utilization of thermally sprayed ceramic coatings must be based on a better understanding of coating structure and properties and the relationship between them. Such understanding comes from effective examination and evaluation of coatings. Furthermore, the effective evaluation of coating properties is very important in the application of a coating and in quality control. Recently, it has been recognized that it is important to understand the chemical and physical phenomena involved in spraying processes and coating formation for the further development of coating technology and controlled coatings.

The properties of coatings can be considered to depend on their structure, as is usually the case for all structural materials. The coating exhibits a layer structure due to the formation mechanism by which a stream of droplets impact a substrate surface, flatten to disks, and then solidify and cool rapidly to deposit a coating. However, because flattening and solidification of each individual droplet occurs extremely rapidly, direct observation of these processes is almost impossible during coating formation. The only means is to examine the microstructure of the coating and then form conclusions from these facts.

Generally, porosity is found in a coating, and in some cases, unmelted particles are also included. On the other hand, individual flattened particles show very fine grains with metastable crystal structures because of rapid solidification and cooling. Based on these facts, the coating structure is qualitatively characterized by the porosity and unmelted particles, and so forth, which are mainly assessed by the observation of microstructural cross sections. The relation between structure and properties is also examined on the basis of the microstructure of such a cross section. However, due to the limitation of direct observation using a microscope, and the ambiguity of whether or not porosity arose from sample preparation, quantitative observations are not possible. Recent investigations into the relation between properties and porosity reveal that the change of porosity could not be always related to the properties. Furthermore, the evidence related to the elastic modulus and thermal conductivity of coatings indicates that the properties of a coating would depend largely on the poor bonding between flattened particles. Thus, the properties of a coating result in lower values compared with the same bulk material, despite the fine microstructure of individual flattened particles. These facts indicate that the bonding between flattened particles might play a very important part in determining properties of a coating.

However, despite much work on direct observation of the coating microstructure, the detailed structures of a ceramic coating, such as the structure of individual flattened particles and the bonding state between these particles, are still unknown. Therefore, it is impossible to clarify the relation between coating properties and structure and establish effective evaluation methods for the coating. This also arises because the conventional testing methods, especially for mechanical properties of a coating, do not give satisfactory results. Based on the fact that bonding between flattened particles in a ceramic coating is poor (revealed by using the copper electroplating method and the results of conventional testing methods), it is considered that only a method that is based on appropriate statistics is effective for ceramic coatings.

The ACT-JP (Arata Coating Test with Jet Particles), which is based on the blast erosion test, could allow a relative measurement of bonding between flattened particles with high reproducibility and small scatter in test results. All such methods are characterized by allowing thermal spray materials to be discriminated from conventional ones. This program has been continued at the Research Center for High Energy Surface Processing (Thermal Spray Center in Osaka University). It is expected that by developing effective evaluation methods, not only for ceramic coatings but also metallic coatings, then a better understanding of the coating structure, properties, and their relationship will be reached. Such studies would further provide fundamental understanding of the formation mechanism of coatings, especially phenomena occurring during flattening and solidification when a droplet impacts on a cold surface. Thermal spraying technology will be further developed in the New Surface Modification Center at Osaka University, established on April 1, 1996, on behalf of the Thermal Spray Center.

Research on the microstructure of thermally sprayed coatings has revealed much about the structure of the coating. A thermally sprayed coating consists of flattened particles and has a layered structure. An individual flattened particle is the basic unit in a coating. The structure of a thermally sprayed coating is concerned with the structure of flattened particles—including an average thickness and the occurrence of microcracks in ceramic particles and bonding at the interface between flattened particles. The characterization of the structure of plasma sprayed Al_2O_3 coatings using the copper electroplating technique reveals the existence of a great deal of nonbonded interface area and a bonding rate of 32% for the typically used coating. The pores in a thermally sprayed coating include the nonbonded interface area and vertical cracks in ceramic lamella as well as the usual spherical pores. The structure and property evidently illustrate that the lamellar structure of limited bonding at the interfaces between flattened particles dominates the coating properties.

Therefore, it is necessary to improve the property and structure of ceramic and metal coatings in order to apply thermally sprayed coatings to more areas within industry, to reduce or eliminate pores, and to strengthen the bonding force between flattened particles in coatings.

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