Cold Spray of bond-coat and Atmospheric Plasma Spray of Ceramic topcoat for TBCs

Thermal barrier coatings (TBCs) are used to protect and insulate hot-section metal components in advanced gas-turbine (aircraft and marine propulsion, power generation) and diesel engines., resulting in a temperature reduction of 100-300℃ at the metal surface. Along with other protecting methods (internal cooling & cooling air film), the protected superalloy components can operate at gas temperature well above the melting temperature of the superalloy, thus improving engine efficiency and performance.

TBC systems consist 4 layers (as shown in Fig1.):

1. Internally air cooled Ni-based superalloy;
2. Oxidation-resistant metallic bond-coat (BC);
3. Thermally grown oxide (TGO) scale;
4. Ceramic topcoat.

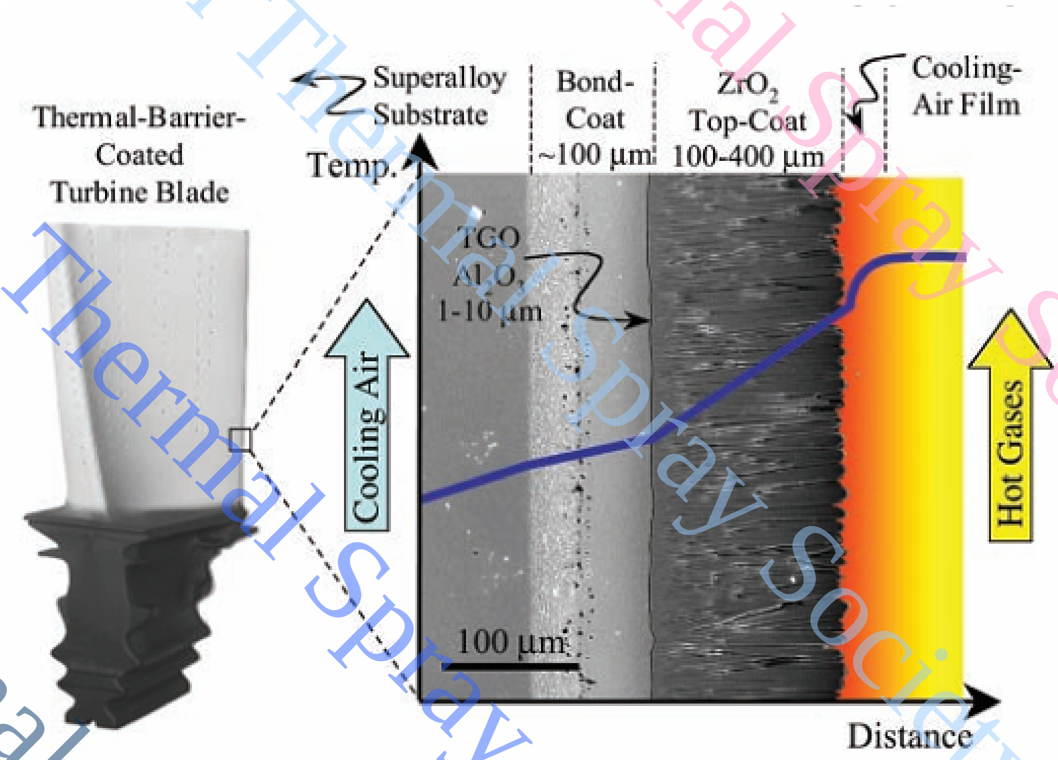

Fig1. Cross-sectional SEM of an EB-PVD (electron beam reinforced physical vapor deposition) TBC, superimposed onto a schematic diagram, showing the common structure of TBC systems and the temperature reduction provided by the TBC.
(Padture NP, Gell M, Jordan EH, Thermal barrier coatings for gas-turbine engine applications[J], Science, 2002, 296: 280-284.)

TBCs can be processed by various surface processing technologies such as EB-PVD and different thermal spraying methods. And thermal spraying methods are more widely used due to their low cost and high depositing efficiency.

- **Use air plasma spraying (APS) to deposit the ceramic topcoat of TBCs**

APS is the earliest thermal spraying method used in TBC processing. In 1970s-80s, the entire TBC was processed by APS. However, the potential in APS is mainly on ceramic topcoat manufacture. The bond coating is usually deposited bye vacuum plasms spray (VPS) to avoid the oxidation of metal.

Nowadays, although we have developed topcoat processing method (EB-PVD) that can obtain better serving quality, APS is still the most widely used technique in topcoat processing. Such a condition is mainly determined by its advantages shown as below.

1. Structural advantage in thermal insulating:

The depositional mode of APS results in a lamellar structure of the topcoat, as shown in Fig2. Comparing to bulk material and EB-PVD topcoat (Fig1), such a structure lowers the ceramic's thermal conductivity significantly, thus greatly improves insulating ability of the TBC system.

2. No size limit on components:

Since the chamber size is limited, EB-PVD and VPS (vacuum plasma spraying) all require the components to be smaller than some size. Thus, even airplane engine's combustor can not be prepared, nevertheless F, G grade land based gas turbine components. Contrastively, APS can deposit coatings on almost all components.

3. Lower cost and higher efficiency:

As a proven technique, APS devices have been optimized to a high cost performance. Along with other factors, APS method provides a much lower cost. At the same time, lower environment requirement leads to a higher efficiency.

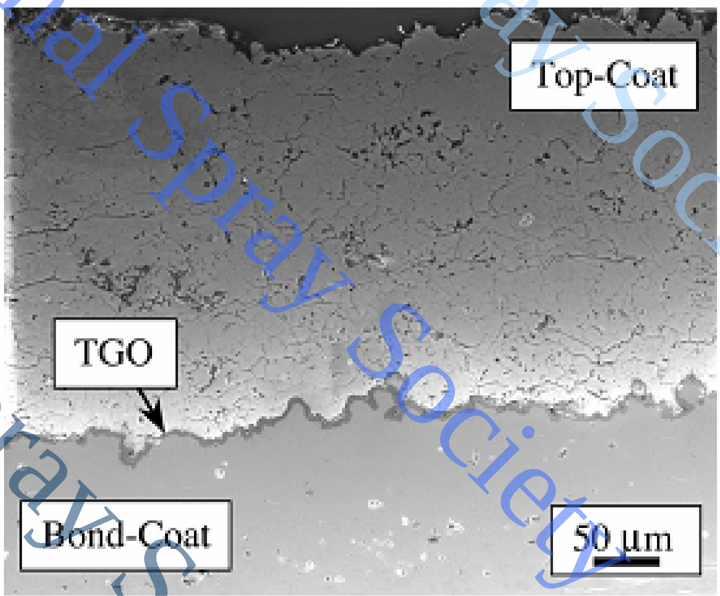

Fig2. Cross section SEM of thermal cycled APS TBC. [1]

The APS method also has its disadvantages that limit its use.

1. Undulate interface

Since APS bonds the coating with substrate through mechanical bond, an undulate substrate surface is required, as shown in Fig2. Such interface morphology generates great and uneven stress during thermal cycling, possibly resulting in unexpected failure. As the airplane engine always experience thermal cycling, APS TBCs are limited to unimportant components.

2. Breaking strength

While increasing the insulating ability, the lamellar structure of the topcoat lowers the breaking strength of the topcoat, thus reducing the thermal cycling life of the TBC.

With higher thermal insulating, higher processing efficiency, lower cost but also lower thermal shock resistance, APS TBCs are used on almost all componets that do not experience fierce or frequent thermal cycling. Land-based gas turbine for power generation is the most obvious example.

To widen the use of APS TBCs, we must develop and optimize the microstructure of APS coating to provide better thermal cycling resistance without lower the coating's insulating ability.

- **Use Cold spraying (CS) to deposit the metallic bond coat**

The metallic bond coat is designed for oxidation resistance and reducing the thermal expansion mismatch stress between substrate and topcoat. The bond coat should be dense and little oxidized to provide better service.

The widely used MCrAlY bond coats are now mainly processed by VPS and HVOF (high-velocity oxygen fuel). VPS could form dense and little oxidized coating, but this method is expensive and have size limit on components. HVOF could produce dense coating and cost less, but oxidation of the particles during spraying is inevitable due to the free-oxygen and high temperature.

Cold spraying, also called cold gas dynamic spraying, is a newly developed (1990s) thermal spraying technology. In cold spraying, a coating is formed through plastic deformation of the spray particles in the solid state during impact. Comparing to other thermal spraying, it has a higher velocity and lower temperature (Fig3).

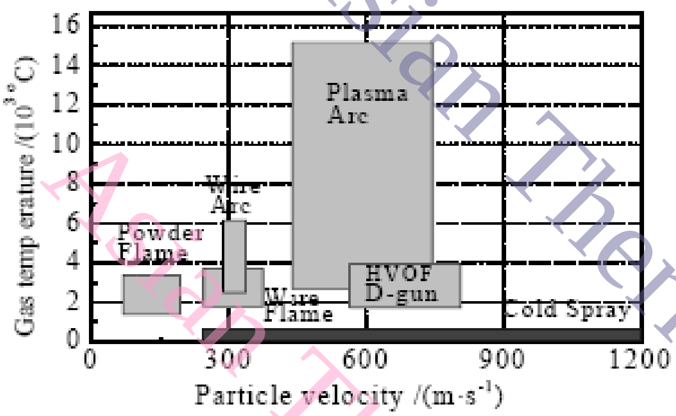

Fig3. Gas temperature and particle velocity distribution of different thermal spraying methods.

The nature of cold spraying well correspond the requirement of the metallic bond coat.

1. Dense

The formation of the cold sprayed coating is based on high velocity impaction. With proper spraying parameters, the spray particles could obtain sufficient plastic deformation, thus resulting in a rather dense coating as shown in Fig3. Along with heat treatment, we can get a bulk-like structure.

2. Oxidation free

Metal particle oxidation during thermal spraying is caused by 2 reasons: temperature & atmosphere. VPS controls atmosphere to avoid oxidation, while cold spraying using a relatively cold gas. The gas temperature during cold spraying is low enough (<600℃) to avoid oxidation.

MCrAlY bond coats have been produced through cold spraying in our laboratory and the expected structure was achieved (Fig4).

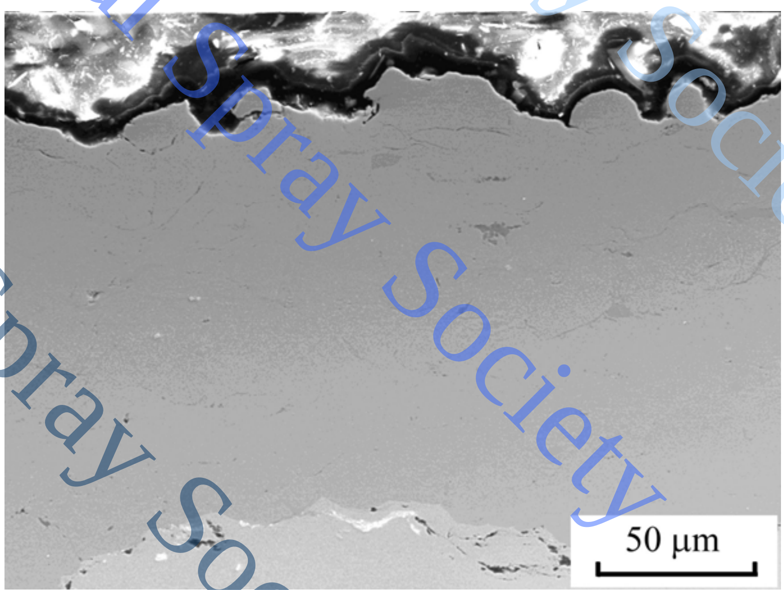

Fig4. Cold sprayed MCrAlY coating.