GERMANY

# Thermally Sprayed Functional Coatings for Industrial Components

**The bulk material and the component surface are often subject to different requirements. Thermally sprayed functional coatings enable mechanical, tribological, chemical, electrical, and thermal surface properties to be tailored. This article focuses on three processes used at Rauschert: liquid-fuel high-velocity oxy-fuel spraying (HVOF-LF), gas-fuel high-velocity oxy-fuel spraying (HVOF-GF), and atmospheric plasma spraying (APS). They differ primarily in particle heating, particle velocity, and the resulting coating microstructure. The material portfolio includes cemented carbides, oxide ceramics, and metallic alloys such as 316L stainless steel. A development example involving an electrically insulating coating on a bearing outer ring demonstrates how vacuum-assisted sealing and resealing after final machining prevented further surface flashover under the specified wet test conditions.**

## Component requirements

Damage to components often initiates at their surfaces, where wear, corrosion, and electrical or thermal stresses act, while the bulk material continues to carry the mechanical load. Thermally sprayed coatings therefore allow the surface to be tailored to these local service conditions without changing the entire component material.

Typical examples include shafts, rollers, cylinders, sliding surfaces, and bearing surfaces. Depending on the application, the coating must protect against wear and corrosion, provide the required surface finish or ensure electrical insulation.

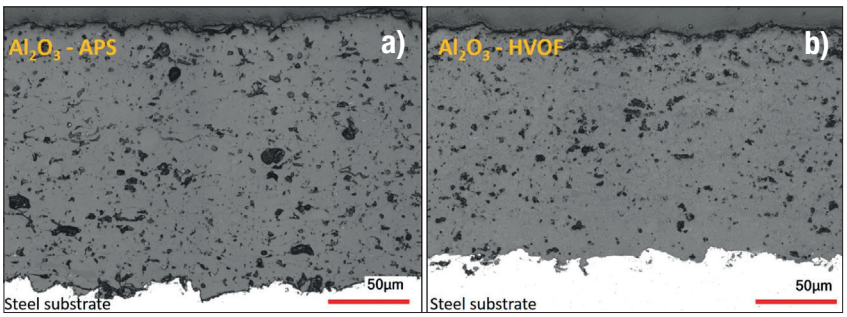



*Fig. 1*
*Example microstructures of industrial coating systems: a) HVOF-LF-sprayed coating and b) APS-sprayed ceramic coating* *Source: Rauschert*

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## Thermal spray processes and coating quality

During thermal spraying, powder particles are heated in a flame or plasma and, depending on the process and material, may become partially or fully molten before being accelerated toward the component. Upon impact, molten or semi-molten particles flatten into splats or lamellae, which accumulate to form the coating. The balance between particle heating and impact velocity is therefore crucial to the resulting coating microstructure.

In both HVOF-LF and HVOF-GF, high particle velocity strongly affects the coating microstructure. Both processes can produce dense coatings with low porosity. Particle

heating and acceleration are governed by fuel type and state, torch design, powder particle size, and process parameters. If these factors are not properly matched, the resulting coating may contain unmelted particles, pores, and transformed or oxidized phases [1, 2].

APS is characterised by high thermal input and lower particle velocities than HVOF. The high plasma temperature enables reliable deposition of high-melting-point oxide ceramics. APS coatings often exhibit a more pronounced lamellar structure, higher porosity, distinct interlamellar boundaries, and microcracks. In some applications, such as thermal barrier coatings, this structure can be advantageous. Studies of $Al_2O_3$ have shown that APS coatings can exhibit higher porosity and a greater degree of phase transformation than HVOF coatings [1, 3].

Fig. 1 shows representative microstructures of an HVOF-LF coating and an APS ceramic coating, while Tab. 1 provides a qualitative summary of the main process and coating characteristics.

*Tab. 1*
*Qualitative comparison of typical process and coating characteristics for HVOF-LF, HVOF-GF, and APS (based on [1–3])*

| Criterion | HVOF-LF | HVOF-GF | APS |
|---|---|---|---|
| **Process characteristics** | high particle velocity; particle state depends on torch, liquid fuel (HVOF-LF), fuel gas (HVOF-GF) and process parameters | | high thermal input; lower particle velocity |
| **Typical coating structure** | dense; low porosity can be achieved; incompletely heated particles and phase transformations are possible | | a more lamellar structure; usually higher porosity, pronounced lamella boundaries, and microcracks |
| **Critical process factors** | powder size, particle heating, carbide retention, and oxidation | | phase transformation, component temperature |

*Tab. 2*
*Selected thermal spray coating materials, properties, and application examples*

| Material/System [1] | Typical properties and functions | Process | Application examples |
|---|---|---|---|
| **WC-Co / WC-CoCr** | very hard; high resistance to abrasive and erosive wear; carbide retention is process-critical [2] | HVOF-LF, HVOF-GF | shafts and rollers, pump parts, sealing surfaces, and bearing surfaces |
| **316L** | austenitic stainless steel; corrosion-resistant; coating performance depends on porosity and oxidation [4] | HVOF-LF | corrosion protection, repair, and dimensional restoration of shafts and industrial equipment components |
| **$Al_2O_3$** | hard, chemically resistant, and electrically insulating; moisture sensitivity depends on the coating structure [1, 5] | APS; HVOF depending on powder and torch | bearing outer rings, electrical insulation coatings, rollers, and guides |
| **$Al_2O_3$-$TiO_2$ (97/3; 94/6; 87/13; 60/40)** | wear-resistant; hardness and damage tolerance depend on $TiO_2$ content and coating structure [1] | APS; HVOF depending on powder and torch | textile guides, sliding surfaces, and pump components exposed to wear |
| **$ZrO_2$-based $ZrO_2$-$Y_2O_3$ (92/8) $ZrO_2$-CaO (95/5)** | low thermal conductivity; thermal cycling behavior depends on stabilizer type, porosity, and coating structure | mainly APS | thermal barrier coatings and components exposed to high temperatures |
| **$Cr_2O_3$** | high hardness and resistance to sliding wear [1]; suitable for finely finished functional surfaces | APS; HVOF depending on powder and torch | sealing and sliding surfaces, pump sleeves, and textile guides |

[1] All compositions are given as [mass-%]

## Coating materials and component processing

Cemented carbide coatings based on WC-Co or WC-CoCr are primarily used to protect against abrasive and erosive wear. Their performance is governed not only by hardness but also by carbide retention, binder composition, grain size, and porosity [2]. Depending on their composition, oxide-ceramic coatings can provide wear protection, electrical insulation, or thermal protection [1].

Rauschert's material portfolio also includes austenitic stainless steel 316L, which is processed by HVOF-LF. This metallic coating can be applied locally to rebuild worn areas, restore dimensions, and provide corrosion protection where the coating system has been validated for the relevant service conditions. Local application can avoid manufacturing the entire component from 316L and is particularly advantageous when repairing or refurbishing existing components. For HVOF-sprayed 316L, spray conditions affect oxygen content and porosity. Connected porosity can impair coating quality and corrosion performance [4]. Tab. 2 lists the material systems used by Rauschert and their typical applications.

The ability to coat a component depends on spray gun access, the available component-handling and torch-motion systems, the cooling strategy, and subsequent machining requirements. Typical components include shafts, rollers, cylinders, flat surfaces, and sealing surfaces. Non-axisymmetric components, complex geometries, and selected areas can also be coated, provided that the target surfaces are accessible to the spray gun. Components with diameters up to 1000 mm and lengths up to 4000 mm can be coated in-house. A specialised partner can accommodate larger components with diameters up to 1500 mm and lengths up to 6000 mm.

After the required coating thickness, machining allowance, and final surface finish have been defined, the component is cleaned, degreased, masked, and grit-blasted. The coating is then applied and, where required, sealed. Finally, it is machined or ground to the specified dimensions and surface finish. An additional seal-

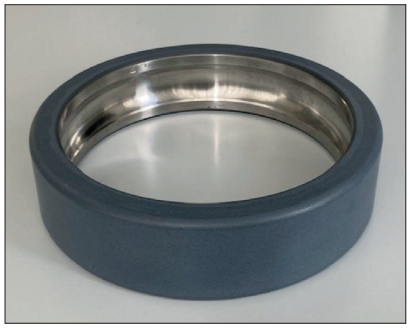


*Fig. 2*
*Ceramic-coated bearing outer ring*
*Source: Rauschert*

ing step may be performed if machining exposes further porosity.

**Development example: electrically insulating coating for a bearing outer ring**

Fig. 2 shows a ceramic-coated bearing outer ring. The objective was to achieve reliable electrical insulation under high-humidity conditions and during direct contact with a liquid. During testing, surface flashover occurred along the coating surface or the edge regions. The porous structure of the ceramic coating was considered a contributing factor because moisture ingress can reduce electrical resistance [5]. Mechanical finishing may expose previously subsurface pores or defects, facilitating liquid penetration and reducing insulating performance.

Based on this assessment, the process sequence was modified. The coated surface was vacuum-impregnated with a sealant to promote penetration into the interconnected pore structure. It was then machined to its final dimensions and surface finish. Because machining could expose additional pores or defects, the coating was sealed again afterward. Under the specified test conditions, no further surface flashover occurred.

The electrical test method was also improved. Initially, the bearing outer ring was contacted internally by a metallic fixture and externally by a rigid copper band. Because the band covered only the cylindrical surface, excluded the edge regions, and did not conform uniformly, it was replaced with a flexible conductive silicone band. This improved contact but still left the edge region untested.

To increase the test coverage, the current test configuration contacts the bearing outer ring electrically from the inside via a metallic fixture and places it in a bed of small metal spheres. The spheres provide multiple electrical contact points on both the cylindrical surface and the edge regions, thereby testing a larger and more relevant area than the previous band electrodes. The combination of the internal fixture and the bed of spheres also simplifies the test arrangement.

**Conclusion**

Thermally sprayed coatings enable surface properties to be tailored to mechanical, tribological, chemical, electrical, or thermal requirements. In practice, however, performance is not determined by the coating material alone. The spray process, process parameters, component preparation, post-treatment, finishing, and test method must all be matched to the application.

Rauschert operates three thermal spray processes: HVOF-LF, HVOF-GF, and APS. The material portfolio includes cemented carbides, oxide ceramics, and 316L stainless steel. These materials support applications ranging from wear protection and electrical insulation to localized rebuilding, dimensional restoration, and validated corrosion protection. The material, process, post-treatment, and final machining are selected according to the component geometry and service conditions.

The development example demonstrates that coating performance cannot be assessed independently of post-treatment and test design. Vacuum-assisted sealing, resealing after final machining, and a test arrangement covering both the cylindrical surface and the edge regions prevented further surface flashover under the specified test conditions.

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