

Analysis of Differences in Characteristics of *Coating* HVOF Based on Nickel and *Coating Plasma Spray* Based on Zirconia on Gas Turbine *Blades*

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Abstract - *Blades* of gas turbines operate at high temperatures and in hot gas environments that can trigger oxidation, corrosion, and degradation of protective layers. This study compares the microstructural characteristics of nickel-based *coating High Velocity Oxy Fuel* (HVOF) and zirconia-based *coating plasma spray* on gas turbine *blades* at power generation industry in Indonesia. Data were obtained through metallographic observation of *coating* cross-sections before and after operation. Initial observations showed that the coating system consisted of a *superalloy* substrate, a nickel-based HVOF layer with a thickness of 0,220 mm, and a zirconia-based *plasma spray* layer with a thickness of 0,499 mm. After operation, the HVOF thickness decreased to 0,094 mm, while the *plasma spray* decreased to 0,284 mm. These changes were followed by microcracks, oxidation, indications of delamination, and layer degradation. The nickel-based HVOF *coating* showed a denser structure and served as a *bond coat* that supported adhesion and corrosion protection. The zirconia layer produced by *plasma spray* had a *lamellar* and porous structure, making it effective as a *thermal barrier coating*, but more vulnerable as a path for oxygen ingress when exposed to thermal cycles. These results emphasize the importance of periodic *coating* evaluation to maintain the reliability of *hot gas path* components.

Keywords: coating, HVOF, plasma spray, zirconia, gas turbine blade, microstructure.

I. INTRODUCTION

Gas turbines are one of the main pieces of equipment in power generation systems because they can convert heat energy from combustion into mechanical energy to rotate a generator. Components in the *hot gas path* area, especially *blades*, receive heavy loads because they are in direct contact with hot gases, oxygen, combustion particles, and repeated thermal cycles. Such operating conditions make *blade* surfaces

vulnerable to oxidation, high-temperature corrosion, erosion, and deterioration of mechanical properties.

The *coating* layer is used to slow surface damage without replacing the base material of the component. *Thermal barrier coating* systems in gas turbines generally use a combination of a metallic *bond coat* and a ceramic *top coat*. Padture *et al.* (2002) explained that TBC acts to resist heat flow to the substrate, while Clarke and Levi (2003) emphasized that the working ability of the layer is strongly influenced by material, porosity, and structural changes during operation.

The *High Velocity Oxy Fuel* (HVOF) method produces layers with high particle impact energy, low porosity, and strong bonding to the substrate. This character makes nickel-based *coating* suitable as a bonding layer as well as protection against oxidation and corrosion. Zirconia-based *plasma spray*, especially YSZ, is widely selected for thermal protection layers because of its low thermal conductivity and its ability to form a *lamellar* structure that helps resist heat transfer (Vaßen *et al.*, 2010; Sampath *et al.*, 2012).

Problems arise when the *coating* has passed through its service period. Exposure to high temperatures and the *start-up* and *shut-down* processes can trigger microcracks, oxide growth, increased porosity, and delamination. These changes need to be interpreted through microstructural observation so the actual condition of the layer can be identified before further damage occurs to the *blade*. This study prepares a comparison of the initial microstructure and the post-operational microstructure of nickel-based HVOF *coating* and zirconia-based *plasma spray*.

The discussion is directed toward two main points. First, reading the initial condition of the layers to see the function of each *coating* in the *blade* protection system. Second, assessing changes after operation to understand the potential decline in layer performance. The results are expected to become consideration material for inspection, *repair*, and *re-coating*

activities on *hot gas path* components in power plant maintenance units.

II. RESEARCH OBJECT AND METHOD

2.1 Research Object

The object of the study was a gas turbine *blade* used in the working environment of power generation industry in Indonesia. The analysis focused on two protective layers, namely nickel-based *coating High Velocity Oxy Fuel* and zirconia-based *coating plasma spray*. Observations were made before operation and after the component had undergone use within a certain operating range.



Figure 1: Gas turbine *blade* used as the observation object (PT PLN Nusantara Power UMRO JP-1, 2026)

2.2 Metallographic Testing Procedure

Testing used the metallographic method on the cross-section of the *coating*. The specimen went through the stages of *cutting*, *mounting*, *polishing*, and *etching* so the layer boundaries could be seen clearly under the microscope. The prepared surface was then observed at a scale of 200 micrometers to read layer thickness, pore shape, *interface* condition, microcracks, oxidation, and possible delamination.

This approach was selected because the microstructure becomes an early indicator of *coating* quality. A dense and homogeneous structure leads to better bonding, while excessive porosity, microcracks, or layer separation can indicate reduced protective ability. Qian *et al.* (2022) also

emphasized that *top coating* thickness is an important parameter in evaluating *thermal barrier coating* because it relates to heat insulation ability, bonding strength, and layer service life.

2.3 Data Sources and Analysis Limitations

The main data came from practical work documentation, microstructure images, and layer thickness measurements on the *blade* specimen. These data were treated as field data that described the actual condition of the *coating* before and after operation. Literature was used to strengthen the interpretation of degradation mechanisms, not to replace observation results.

The analysis was limited to microstructural observation and layer thickness. Chemical composition testing, microhardness testing, adhesion testing, and thermal simulation were not included because they were not available in the practical work data. Even so, metallographic reading still provides an important picture of microcracks, porosity, oxidation, and indications of delamination that are directly related to *coating* reliability.

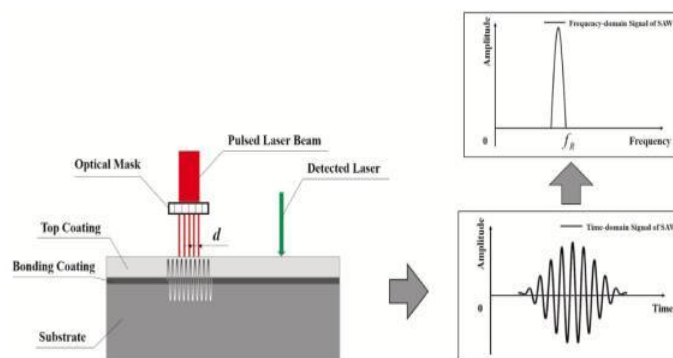


Figure 2: Principle scheme of *thermal barrier coating* thickness measurement using the *grating laser acoustic spectrum* method (Qian *et al.*, 2022)

III. RESULTS AND DISCUSSION

3.1 Coating Microstructure Before Operation

The initial microstructure image showed three main parts, namely the *superalloy* substrate, nickel-based HVOF *coating*, and zirconia-based *plasma spray coating*. The HVOF layer was located between the substrate and the zirconia layer. Its shape was denser and relatively homogeneous, while the *plasma spray* layer on the outermost part appeared rougher, porous, and *lamellar* in structure.

This arrangement matches the concept of *thermal barrier coating*. The substrate functions as the main load-bearing material, nickel-based HVOF becomes the *bond coat* that supports adhesion and oxidation protection, while zirconia

becomes the *top coat* that receives direct heat exposure. Differences in characteristics among layers are actually needed because the working load of the *blade* is not only mechanical, but also thermal and chemical.

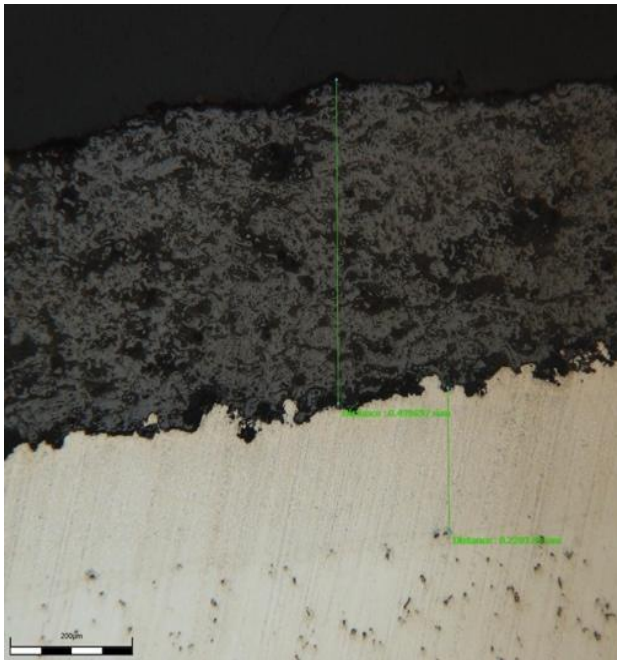


Figure 3: Coating microstructure before operation with a scale of 200 micrometers

The thickness of the zirconia-based *plasma spray coating* in the initial condition was recorded at around 0,499 mm. This value shows the function of the layer as a *top coat* that resists heat from combustion gases. The nickel-based HVOF layer had a thickness of around 0,220 mm and served as a *bond coat*. Its position between the substrate and zirconia is important to increase adhesion, resist oxidation, and reduce the risk of ceramic layer detachment.

3.2 Coating Microstructure After Operation

The post-operational image showed clear changes in both layers. The thickness of the *plasma spray coating* decreased to around 0,284 mm, while the thickness of nickel-based HVOF decreased to around 0,094 mm. In addition to thickness reduction, microcracks, color changes in the *interface* area, indications of oxidation, and local separation between layers were observed.

The reduction in thickness indicates that the layer experienced material loss during operation. The causes may come from a combination of high-temperature exposure, hot gas flow, oxidation, and repeated thermal stress. The easiest change to see was in the outer layer because the *top coat* was the first part facing the operating environment.

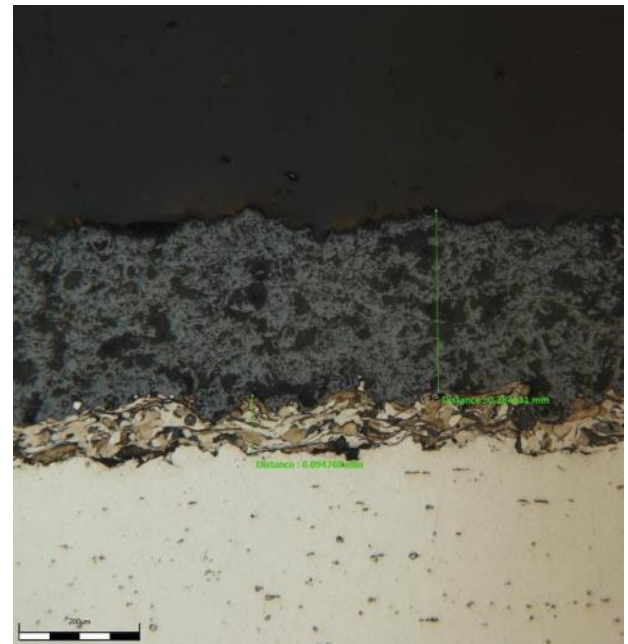


Figure 4: Coating microstructure after operation with a scale of 200 micrometers

Microcracks were mainly visible in the zirconia layer, which had higher porosity. This type of crack can form due to repeated thermal stress, especially when the temperature rises and falls during operation. Differences in the thermal expansion coefficient among the metal substrate, nickel *bond coat*, and ceramic *top coat* increase the possibility of internal stress formation. Oxidation in the *interface* area can also weaken bonding because oxide layer growth adds local stress and encourages delamination.

Indications of delamination need attention because layers that begin to separate can develop into *spallation* in the next cycle. When the *top coat* is lifted, heat and oxygen more easily reach the *bond coat*. This condition accelerates the formation of *Thermally Grown Oxide*, reduces adhesion, and decreases the ability of the *coating* to withstand high temperatures.

The thickness changes can be summarized as follows: the zirconia-based *plasma spray coating* changed from 0,499 mm to 0,284 mm, while the nickel-based HVOF changed from 0,220 mm to 0,094 mm. These figures show that both layers not only experienced morphological changes, but also lost part of their protective material after receiving operational exposure.

3.3 Comparison of Layer Characteristics

The nickel-based HVOF layer showed a denser structure compared with *plasma spray*. This condition is in line with the HVOF principle, which uses high particle velocity so the particles strike the substrate with high kinetic energy and form

a dense layer. Wu *et al.* (2021) showed that the HVOF process can improve wear resistance and corrosion resistance on metal surfaces because the formed *coating* tends to be compact.

The zirconia layer produced by *plasma spray* had a *lamellar* form and more visible porosity. Porosity in *thermal barrier coating* is not always harmful because it can help reduce thermal conductivity. However, connected pores and microcracks can become oxygen entry paths toward the *bond coat* area. When oxygen reaches the *interface* at high temperature, the oxide layer grows and gradually drives a decrease in bonding strength.

This phenomenon explains why the zirconia-based *plasma spray* layer appeared to experience more noticeable morphological degradation. This layer is the outermost protector, so it receives direct exposure from hot gases. Nickel-based HVOF remains important because it supports interlayer bonding, but its thickness reduction shows that the *bond coat* is also affected by long-term thermal cycles and oxidation.

3.4 Implications for Component Reliability

Coating degradation does not immediately mean the *blade* has failed, but microstructural changes indicate that protective ability has begun to decrease. Thickness reduction, microcracks, and delamination can increase the chance of direct substrate exposure to high temperatures. If left untreated, the *superalloy* substrate can lose protection from oxidation and corrosion, causing the service life of the component to decline.

The maintenance strategy needs to place *coating* inspection as a routine activity after certain operating cycles. Metallographic observation, thickness measurement, and surface crack inspection can help determine the time for *re-coating* before the layer reaches a critical condition. For *maintenance* units, the combination of nickel-based HVOF and zirconia-based *plasma spray* remains relevant for gas turbine *blades*, but application quality and operating history must become the basis for maintenance decision-making.

3.5 Technical Recommendations

The observation results show that visual inspection alone is not enough to ensure the condition of the *coating*. Components may still look intact from the outside, but microcracks and *interface* degradation may already have begun to form in the layer cross-section. Therefore, metallographic examination needs to be combined with periodic thickness measurement and operating history documentation.

Re-coating should be considered before the protective layer loses its main function. When the *plasma spray* becomes thinner and more porous, thermal protection decreases. When HVOF becomes thinner, *top coat* adhesion and oxidation resistance also weaken. Maintenance decisions need to view both layers together, not only one layer.

Further research can add microhardness testing, adhesion testing, chemical composition analysis, and SEM-EDS observation. These additional data will help explain the relationship between microstructural changes, thickness reduction, and the mechanical properties of the *coating* more strongly.

IV. CONCLUSION

Based on the results of microstructural analysis of nickel-based *coating High Velocity Oxy Fuel* (HVOF) and zirconia-based *coating plasma spray* on gas turbine *blade* components, the following conclusions were obtained:

1. The initial microstructural characteristics of the *coating* showed that nickel-based *coating High Velocity Oxy Fuel* (HVOF) had a denser, more homogeneous structure and low porosity, while zirconia-based *coating plasma spray* had a *lamellar* structure with higher porosity that served as a *thermal barrier*.
2. Microstructural changes after operation showed degradation in both *coatings* in the form of microcracks, oxidation, delamination, and reduced layer thickness. Zirconia-based *coating plasma spray* tended to experience more significant degradation, while nickel-based *coating High Velocity Oxy Fuel* (HVOF) still showed better structural stability as a bonding layer.

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