

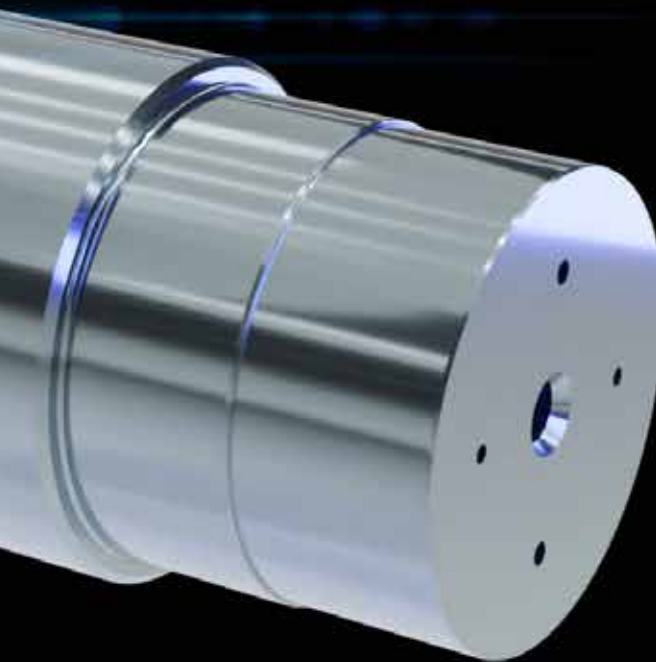


IN FOCUS

RE-POWERING & GEARBOXES

PERFORMANCE ENHANCEMENT IN WIND TURBINE MAIN SHAFTS USING SURFACE COATING TECHNIQUES

Thermal spray and laser cladding significantly improve wear and operational bending fatigue resistance compared to the baseline main shaft material. (Courtesy: Gamesa Gearbox)



Thermal spray and laser cladding coating methods offer strong potential to enhance the performance of main shafts, provided that additive process parameters are rigorously validated and controlled.

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Failures in wind-turbine main shaft assemblies (MSA) are an increasing concern in the industry, both for their frequency and the downtime they cause [1, 2]. The rising power density of turbines, driven by competitiveness, has led to higher MSA failure rates and the appearance of defect types not seen in smaller units. This trend is prompting a reconsideration of MSA design and calculation methodologies [3, 4].

Conventional repairs that restore MSAs to their original design may not be sufficient to extend service life. Surface coating techniques, increasingly applied in recent years, offer a viable alternative by enabling shaft restoration and avoiding scrapping. Compared with full shaft replacement, these methods can provide cost savings and shorter lead times, while also creating opportunities to improve shaft performance and reduce MSA failure rates.

MAIN SHAFT FAILURES AND REPAIR STRATEGIES

Wind-turbine main shaft failures (MSA) are increasingly common. Causes include inadequate bearing design, manufacturing or assembly issues, insufficient maintenance, shaft cracking [5], or current-induced failures [6]. Low rotational speeds complicate early detection through standard temperature or vibration monitoring [7]. See Figure 1.

Repair strategies often focus on selecting a replacement bearing — ideally with greater capacity than the original — to reduce the failure rate of repaired units [8]. Equally critical is ensuring the integrity of the shaft and housing so that bearings perform correctly.

A recurring issue in MSAs is fretting wear on the bearing seat, caused by the hardness mismatch between bearing and shaft (≈ 60 HRC vs. <35 HRC). Fretting is localized surface wear caused by micromotions under load, directly affecting bearing performance and potentially initiating cracks in the shaft (Figure 2).

Reusing shafts offers cost and lead time advantages in MSA repair. Restoration may involve dimensional recovery via additive processes (coatings), or the use of oversized bear-

ings to compensate for wear-related material loss.

Although several additive techniques are available, their adoption remains debated. These processes are relatively unfamiliar, difficult to evaluate analytically, and sensitive to process control. Among the most widely applied and reliable methods are laser cladding and thermal spray (e.g., EAWS and HVOF).

This study presents laboratory tests comparing the wear

and fatigue behavior of baseline shaft material with shafts recovered using laser cladding or thermal spray coatings.

TRIBOLOGY TESTING

Fretting wear is a primary degradation mechanism in shafts, driven by micromotions during operation and the hardness mismatch between shaft and bearing.

Wear tests followed ASTM G99 and included five groups of test samples (variants):

- ▀ **V#0:** Main shaft base material.
- ▀ **V#1:** HVOF.
- ▀ **V#2:** EAWS.
- ▀ **V#3:** AISI cladding.
- ▀ **V#4:** Inconel cladding.

The counterpart was a 6 mm diameter AISI 440C ball, with certified hardness consistent with bearing surface hardness.

Figure 4 summarizes the test setup and results.

Samples V#1, V#2, and V#3 showed significantly lower wear rates than the baseline (V#0). V#4 did not show meaningful improvement.

HVOF (V#1) delivered the best performance, with significantly the lowest wear rate of all variants.

ROTATING BENDING FATIGUE TESTING

This test compared fatigue performance of baseline shaft material against shafts recovered by laser or thermal spray coatings.

Standard ISO 1143 rotating bending fatigue tests were modified by adding an intermediate bearing support where the coating was applied, to better simulate MSA wind operating real conditions under the bearing shaft surface.

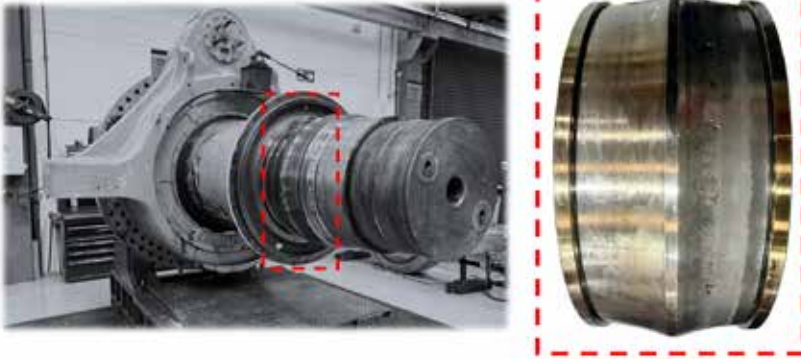


Figure 1: Typical spalling failure [2] in MSA bearing, the most common failure type.

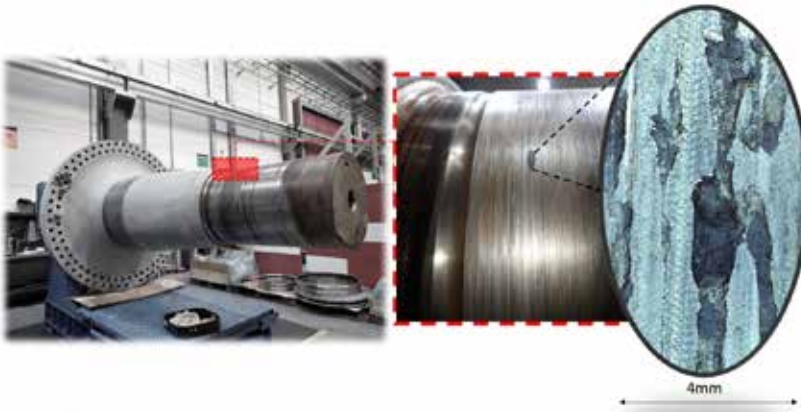


Figure 2: Fretting wear on shaft, under the main bearing inner race surface.

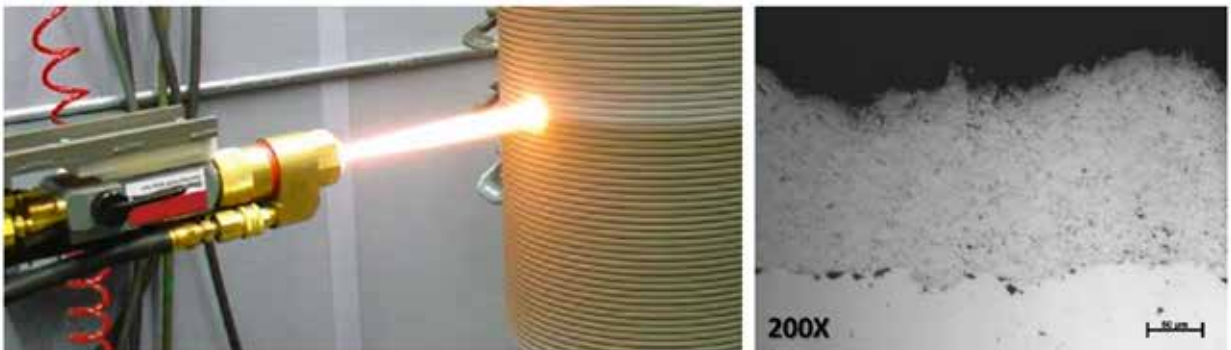


Figure 3: HVOF thermal spray coating process & result metallography.

Figure 5 summarizes the test setup and results.

All coated specimens performed better than the baseline (V#0). Although these results may appear inconsistent with prior studies [9, 10], the difference lies in the modified test boundary conditions, designed to replicate real MSA operational conditions, and not just to evaluate the difference between baseline material and coated mechanical properties. The configuration of this test, including bearing support, allowed evaluation of the fatigue effect of coatings under realistic conditions, where the previously described improvement in wear resistance played a significant role in crack nucleation.

Failure morphology varies by coating type. In uncoated and thermal-spray-coated specimens (V#0, V#1, V#2), fractures originated at the surface. In contrast, in laser-cladded specimens (V#3, V#4), failures initiated below the surface within the heat-affected zone (Figure 6).

For uncoated specimens (V#0) and those with metal spray (V#1, V#2), fractures were located at the bearing interface. The origin was linked to fretting, with localized oxidation and plastic deformation generating oblique micro-cracks from which fatigue cracks propagated. These nucleation points appeared around the full specimen circumference. After nucleation, cracks propagated with smooth textures and beach marks, and the final rupture occurred through brittle overload, visible as a rough and shiny surface.

In laser-cladded specimens (V#3, V#4), fractures originated 2-4 mm beneath the surface, likely in the heat-affected zone. Crack initiation was con-

centrated in a region opposite the brittle overload fracture zone. Fatigue cracks then propagated until final brittle overload failure occurred.

CONCLUSIONS

Laboratory tests confirm that both thermal spray and laser cladding significantly improve wear and operational bend-

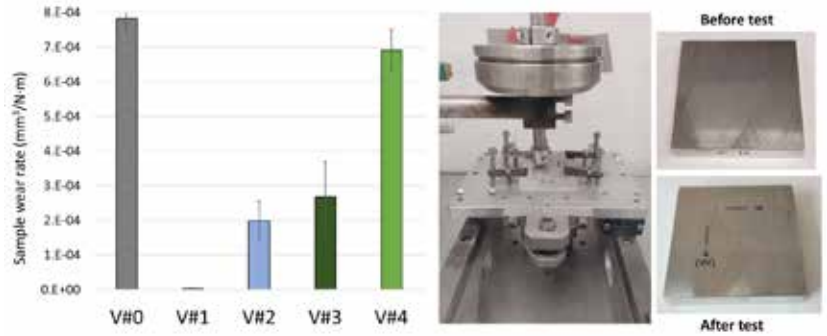


Figure 4: Wear tests according to ASTM-G99:2023.

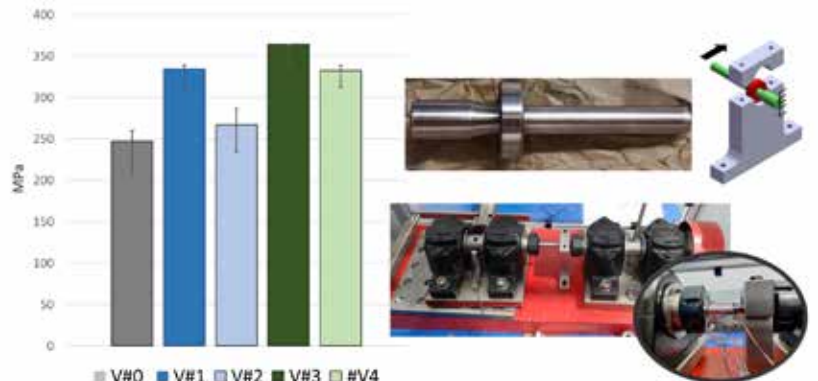


Figure 5: Bending fatigue according to mod. ISO-1143 (50% failure probability).



Figure 6: Failure morphology differences between metal & laser coatings.



ing fatigue resistance compared to the baseline main shaft material.

These coating methods therefore offer strong potential to enhance the performance of (refurbished) main shafts, provided that additive process parameters are rigorously validated and controlled. Special attention must be given to risks such as adhesion failures in sprayed coatings or crack formation in the transition zones of laser cladding. ✂

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