



R3-MYDAS

Mitigating Gearbox Failures in Wind Turbines through Remanufacturing and Material Innovation

October 2025

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Funded by the
European Union

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Introduction

Flender Finland Oy use wind turbines gearboxes to prove the reliability and replicability of remanufacturing through the development and validation in the R3-MYDAS project.

Most of the wind turbine gearbox failures require a high effort to rework or replace components in the field conditions and on other hand failed components are typically replaced with a new production. Therefore LCOE (Levelized Cost of Energy) can be affected by novel means of component repairs and raw material reutilization. LCOE is composed of two parts, capital expenditure and operational costs divided by amount of energy generated. Approximately 75% of the total cost of energy for a wind energy project is related to upfront capital costs, such as the cost of the wind turbine, foundations, electrical equipment and grid connection [1], operation costs are the remaining 25 %, which mainly consist of the maintenance and repair costs.

In this project scope new materials and design methods are created for redesigning, upgrading and remanufacturing for wind turbine gearbox components. In addition, the improvements are directly applicable to new production such as lifetime extension and high torque density enablers for more powerful wind turbines.

Background

Even though there are high-quality standards in design work and workmanship in use, there are still premature failure cases, which are not predictable with traditional fatigue calculation or in the scope of condition monitoring with the current technologies. Failures by subsurface fatigue due to inclusions in the component or lack of oil film in unexpected situations are the most common drivers for the failures, as well as long-term fretting on the compressed surfaces is a typical event.

In torque dense solutions like planetary gearboxes, the initial sub surface failure at the gear tooth is known as TFF (Tooth Flank Fracture), which may initiate from inclusions, impurities or generally from the stress raiser. This makes it problematic to use additive manufacturing methods, which have a risk of deviations coming from manufacturing process, as well as stress raisers in the added material layer or in the bonding layer between the base and coating material. R3-Mydas project aims to prove that additive manufacturing with different materials, different heat treatment methods or even coatings can provide good enough performance, so that the mentioned failure modes are not only repaired, but also the risk of repeat the failure is minimized. Same challenge can be applied also to the journal bearing and flange contact repairs, where an additional material layer is introduced. Bonding layer

quality and the coating material properties are examples of critical parameters for method approval.

Bottleneck for novel technologies for these types of applications is typically lack of understanding of the behaviour and means to mitigate risks in the application level. Therefore, approval processes are long, resource spending and sometimes risky. In standard project scope, specific early phase simulation methods are created and validated for use to increase torque density and reliability at the product level.

Supporting Arguments

For high strength gear materials related failures, the risk assessment for TFF (Figure 1) and mitigation methods are needed and created. The most important part is testing gears to derive limit values for the fatigue strength

regarding TFF and to identify the main influences (gear size and geometry, material influences like grain size or cleanliness as well as influences from the alternative heat treatment methods). This practical data is used to have confidence for simulation models. Additive manufacturing can increase the risk of TFF, for example, if bonding layer cracking occurs at subsurface conditions (See figure 2). This needs to be validated before method is accepted.



Figure 1: TFF failed tooth from a wind turbine gear in an overload test. Sudden single tooth breakage can happen after few thousand operative hours despite design lifetime being over 175 000h leading it to be considered as a premature failure. Root cause in this case was identified as subsurface inclusion bigger than allowed in material specification. [Flender Finland]

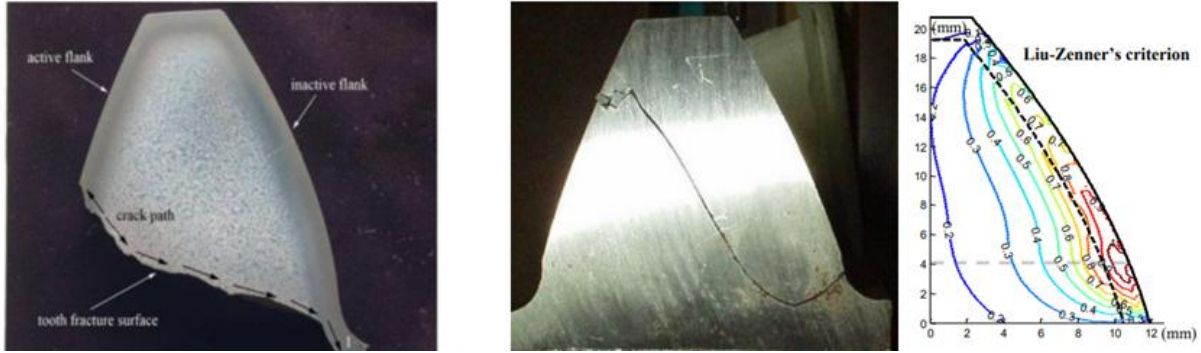


Figure 2: Simulations and practice show that the highest risk for TFF is below the case hardening layer. [2]

For journal bearing related failures alternative material pairs and safe operation methods under mixed lubrication conditions are created. Mixed lubrication conditions may occur during turbine installation phase or long unpowered idling periods. Project work consists of material models and material related performance limit definitions. New coatings are required to have robust performance for remanufactured / manufactures components. Simulation models are proven by practical tests.

For Journal bearing and flange connection related failures (Figure 3), the risk assessment for the bonding layer strength is needed and the surface robustness validation against the application loads in the contacts. It is typical to have different kinds of cracks in the additive manufacturing processes. For example, cladding process can introduce several crack types as shown in Figure 4.

Generally better material knowledge and understanding of premature failure modes listed above increases also the confidence in the recycled or partially recycled raw materials for product update purposes.



Figure 3: Left side asperity contacts and wear at journal bearing at testing component. Right side flange connection with initial fretting and wear from gear box level overload testing. [Flender Finland]

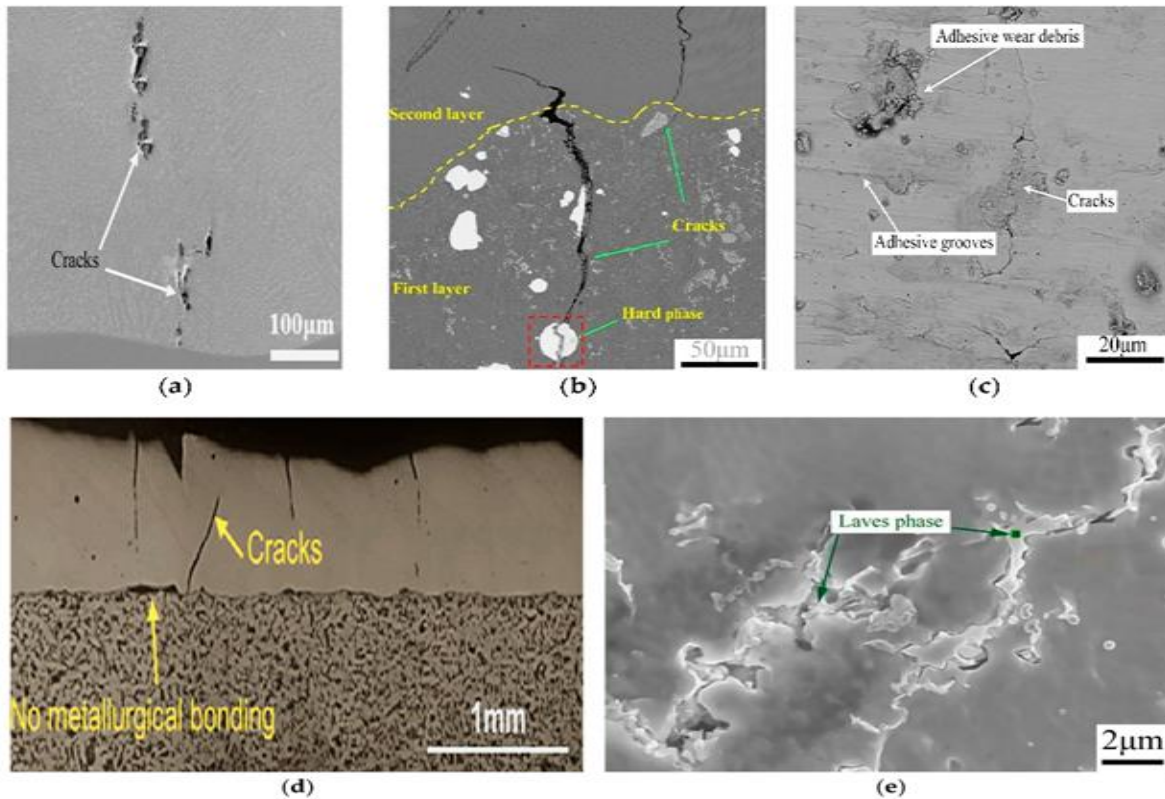


Figure 4: Different crack forms: (a) hot crack, (b) cold crack, (c) cladding crack, (d) interfacial matrix crack, and (e) Lap crack. [3]

Counterarguments & Rebuttals

Primary question is whether remanufactured components have the same performance or technical reliability as new components, because of the increased uncertainty coming from new practices. Also, there is a question whether the component has utilized its lifetime besides primary failure mode and after the remanufacturing some other new issue occurs.

In this application, there is initial requirement of extreme long design lifetime; 20-30 years, which means that in fatigue point of view parts are designed for theoretically infinite lifetime, considering the number of load cycles. When repairing the premature failures one can expect the part still has the same "infinite" load carrying capacity, which is further increased to higher probability if the material and process produce high quality subsurface conditions.

Conclusion

In R3-Mydas it has already been tested that additive manufacturing and updated material pairs to journal bearings can be the economically and technically better than initial design.

Repair method to the initial axle material can also be confirmed. Figure 5 illustrates the Stribeck curve as one possible validation method for different laser clad sources and robustness against the asperity contact with results from different alternatives. Differences in performance can be observed from the summary as well.

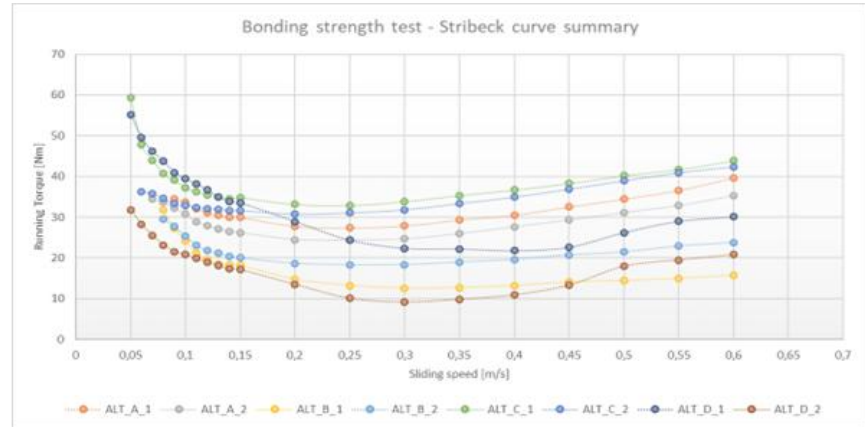


Figure 5: Laser clad journal bearing and variation between different alternatives.

Repairing flange connections is also feasible due to relatively low contact pressure. This means that the loading to the bonding layer is low and that requirements for the bonding layer are not that high. In the project, one such method has already been tested successfully.

For gears the initial repairs have been applied and are to be tested soon, however as a general note the component is much more challenging than others investigated in this project. At multilayer cladding, it is difficult to have homogenous material structure. Gears are loaded with 1500...2000 MPa contact pressures, which makes the critical crack size leading to failure relatively small. For gear remanufacturing there is risk of limited load carrying capacity and therefore more development is needed in highly loaded parts.

References

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- [3] B. Cui, P. Zhou, and Y. Lv, "Research progress in and defect improvement measures for laser cladding," *Materials*, vol. 18, no. 13, p. 3206, 2025, doi:10.3390/ma18133206