III. Influence of the Substrate Surface Integrity on Nb:MoS_2-Coated Gear Durability for Low Friction Applications –

Izabel Criscuolo, M.Sc. (ITA) / Miguel Danelon, M.Sc. (USP)

Transformations in the automotive industry have stood out in recent years, especially in the electromobility segment. Electric drivetrain components have been subjected to severe changes in requirements increased durability and higher torque efficiency. Tribological coatings are a promising technology for meeting these requirements, mainly because they provide gears with reduced coefficient of friction and more distributed contact stresses. However, there are still gaps in knowledge about how the surface integrity of the substrate influences the overall performance of the coated flanks. The objective of this study is the understanding the influence of both the substrate residual stress state and topography on Nb doped MoS2 coatings for low-friction gear durability. The investigation begins by analyzing the impact of the addition of coating-related processes in the gear manufacturing chain in terms of surface integrity state and coating behavior. It also explores how surface integrity correlated with component load-carrying capacity. The results point out to a potential of almost doubling the contact fatigue lifetime. In addition, the development of a high-speed twin-disc test rig is presented, in which the coatings will be tested under high-speed conditions.

Influence of the Substrate Surface Integrity on Nb:MoS_2-Coated Gear Durability for Low Friction Applications

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Agenda

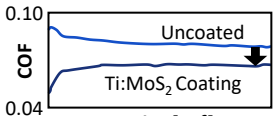
Introduction: *Coating Opportunity*

E-Mobility Trends

- Fewer Gears/Vehicle
- Higher Motor Speed
- Higher Mileage/Vehicle
- Silent Motors

Higher Durability | **Higher Efficiency** | Less NVH Emission

MoS_2 Coatings



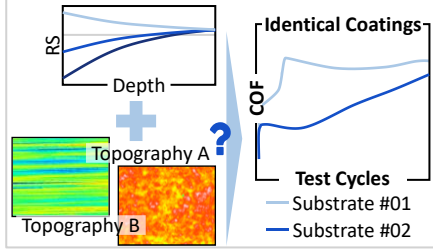
15.4% COF Reduction

Tribological Coatings

- "Coatings sufficiently thin that the substrate has influence on the tribological performance of the system"

Knowledge Gap

Lack of comprehension on how substrate surface integrity influence coating behavior



Objective

Comprehension of the interaction between **Nb:MoS_2 coating** and **substrate surface integrity** for application in **low-friction gears.**

AGMA (2021); Nabot *et al.* (1990); Ding *et al.* (2010); Arslan *et al.* (2010); Pereira Jr. (2014)

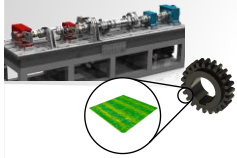
Introduction: *Collaborative Gear Coating Efforts*

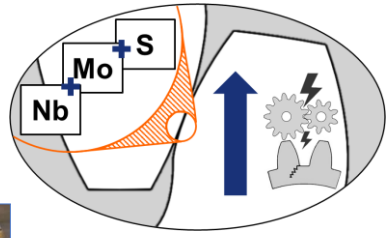
Engrena ITA

FINEP SMART MATERIALS

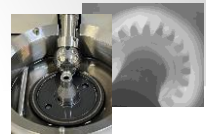
Evaluation of the benefits of Ti:MoS_2 and **innovative Nb:MoS_2 coatings** on gear **durability** and **efficiency**

Surface Integrity and Test Rig Design





Tribology and Thin Film Processing



Gear Manufacturing and Design (Automotive)

EATON

SEW EURODRIVE Gear Manufacturing and Design (Metalworks)

Advanced Metrology

VAS

Sample Geometries

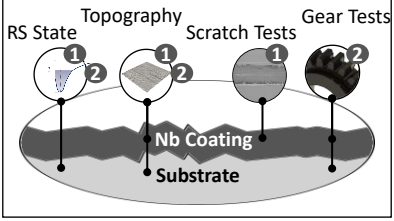
1 Disc Ø40x4.5 mm

2 ITA Gear Geometry

Gear:

- **Number of Teeth (z):** 21
- **Normal Module (m):** 2.85 mm

Characterization Plan



Manufacturing Chain

For both sample geometries:

Rolled DIN 20MnCr5 → Machining → Carburizing → Grinding (Gr)

Conventional Processes

Coating-Related Processes

Sandblasting (Sb): → **Compressive RS**

Ch. Etching (Et): → **Roughness** (Grinding)

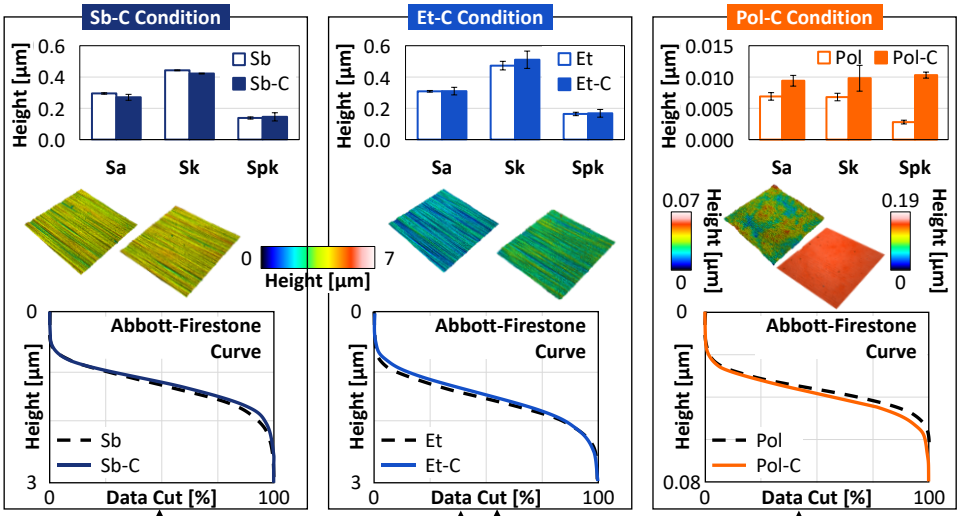
Polishing (Pol): → **Roughness**

** only for discs*

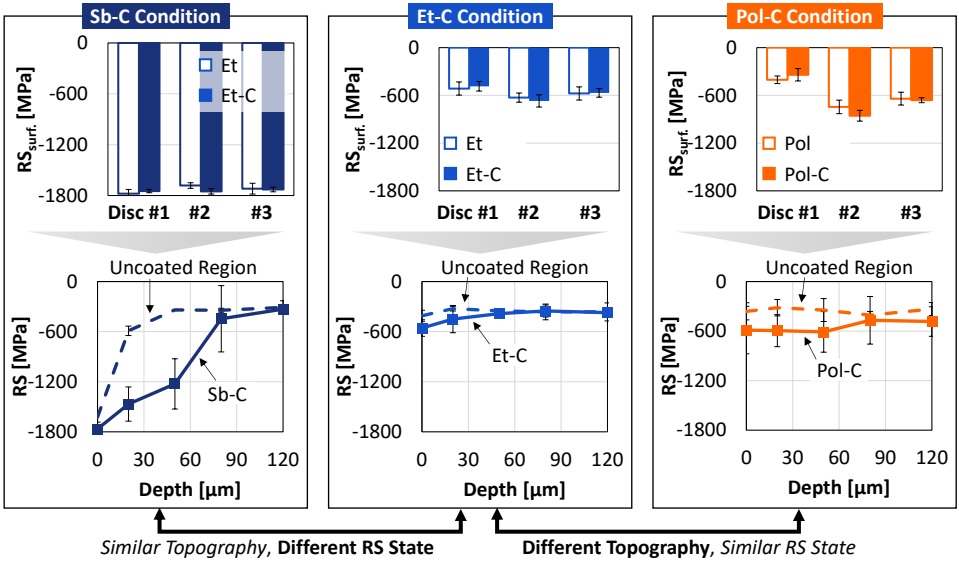
Nb Coating Deposition (C)

Agenda

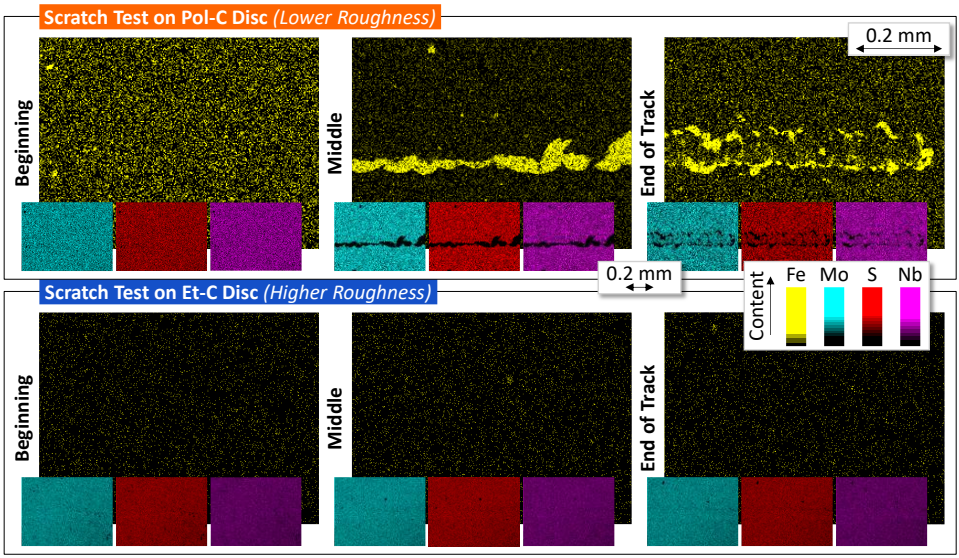
Topography Induced by Coating Deposition



RS State Induced by Coating Deposition



Influence of Topography on Coating Behavior



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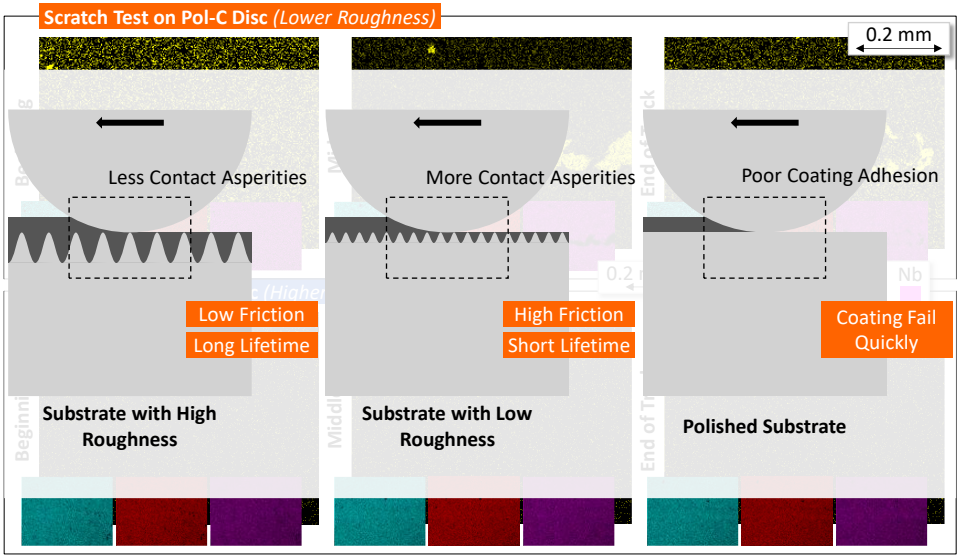
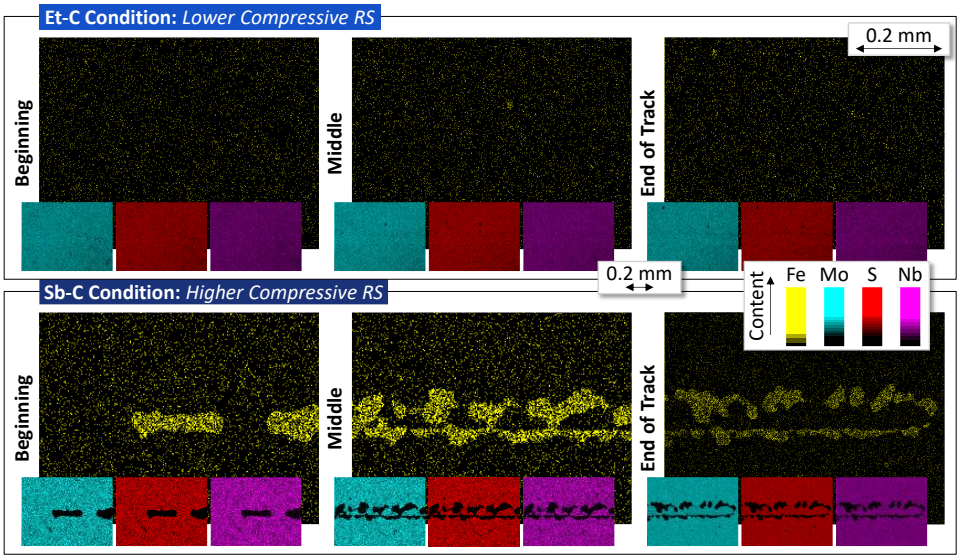
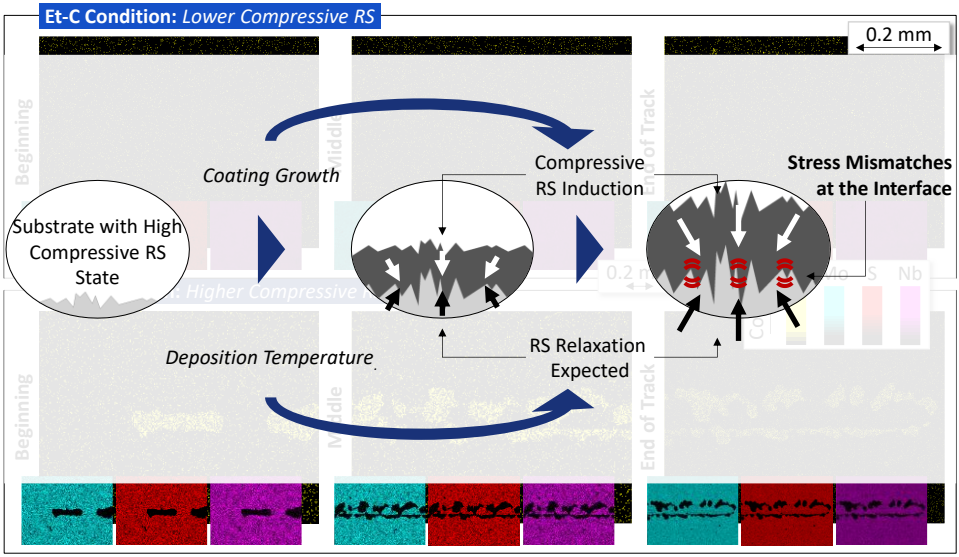


Influence of Residual Stress on Coating Behavior



Influence of Residual Stress on Coating Behavior



Agenda

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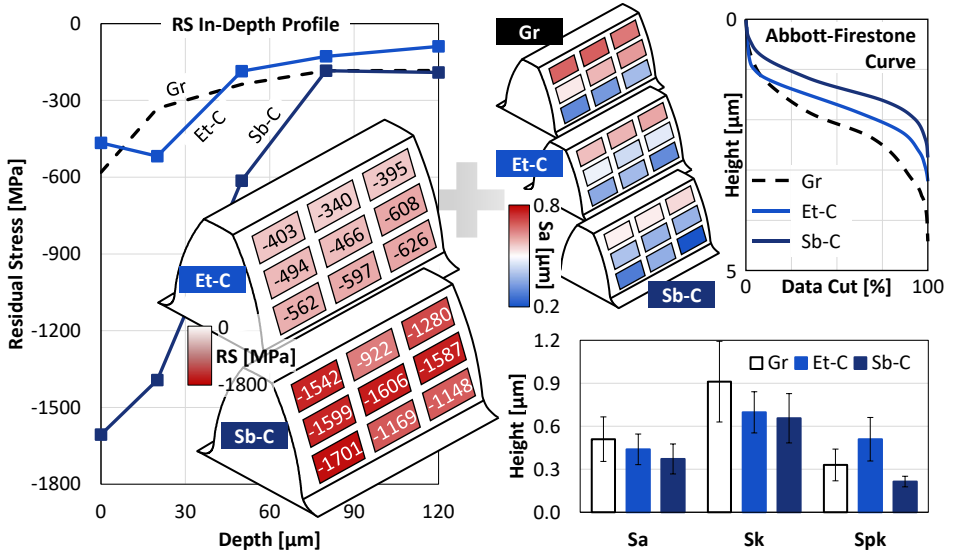
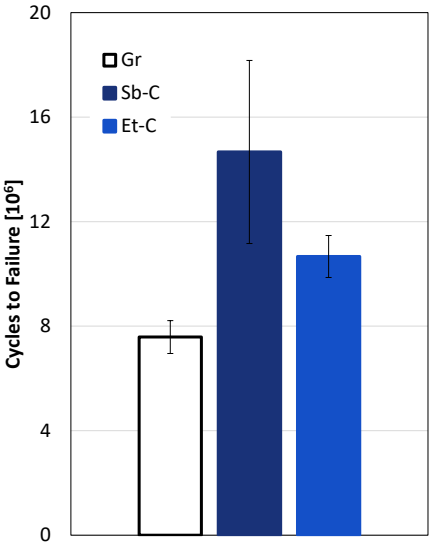
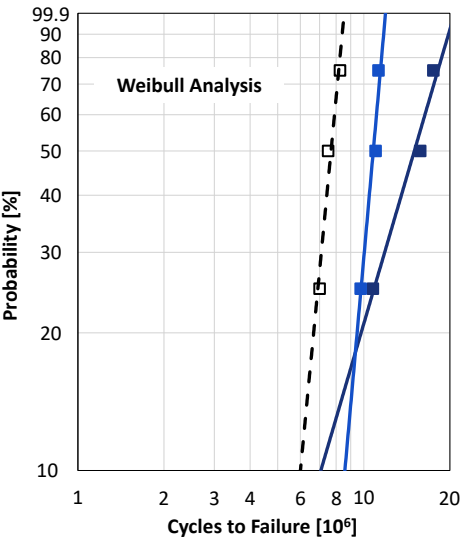
2. Manufacturing Effects on Surface Integrity and Coating Behavior
3. Influence of Coating on Gear Durability
4. Summary and Outlook

Surface Integrity after Coating Deposition

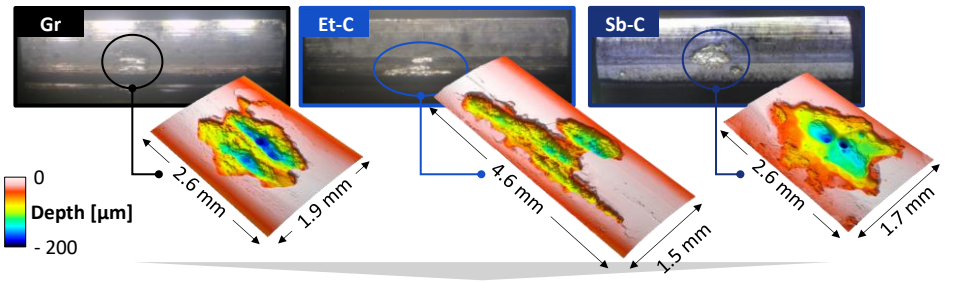


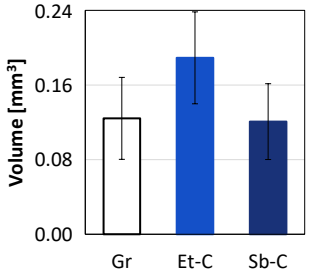
Fatigue Lifetime

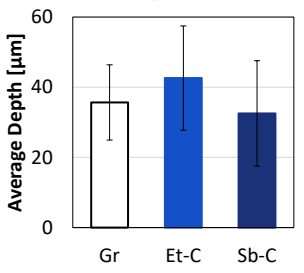


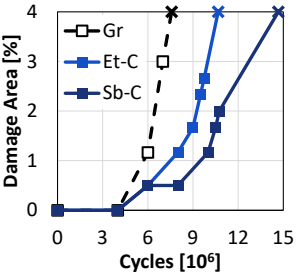


Fracture Morphology

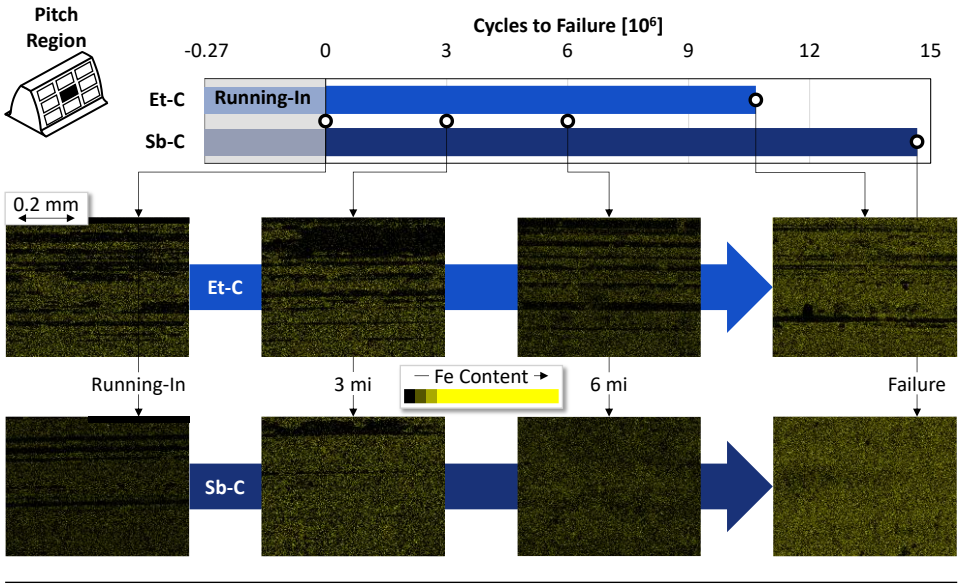




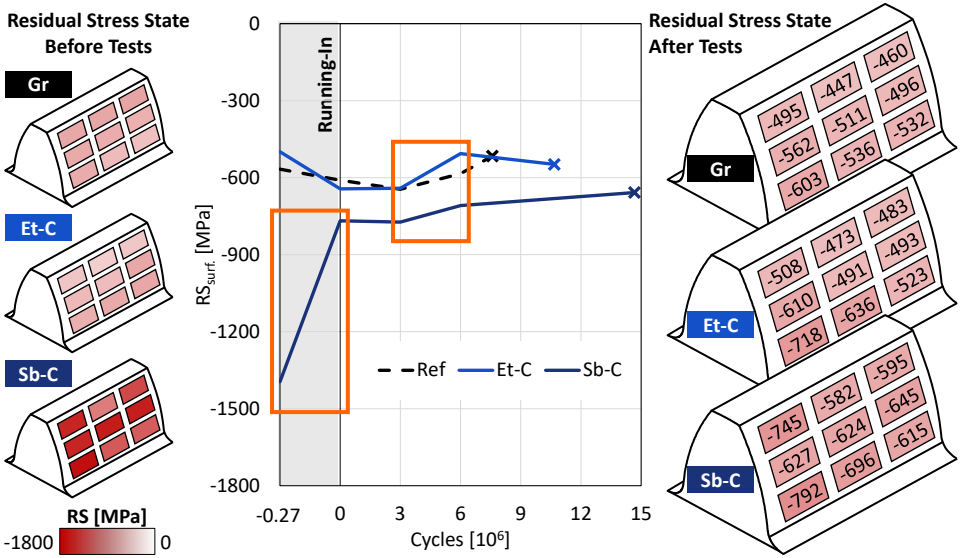




Coating Adhesion along Fatigue Tests



Residual Stress State along Fatigue Tests



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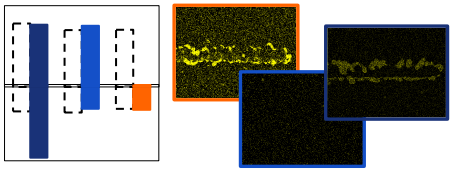
Summary

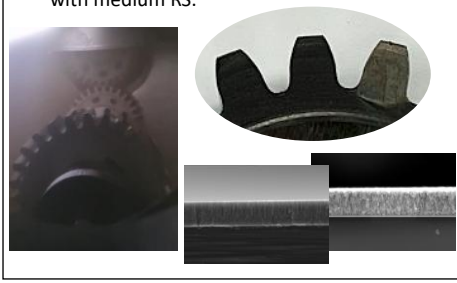
The Nb coating behavior is influenced by the substrate surface integrity, which can be tailored by the manufacturing chain

- Roughness had a positive effect on Nb coating behavior
  - Nb coating in valleys is protected and continues to act between surfaces
- Compressive RS had a negative effect on Nb coating behavior
  - Stress mismatches at the interface lead to poor Nb coating adhesion



Gear fatigue lifetime was improved in both Nb coated conditions

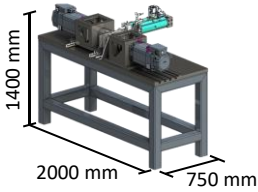
- Nb coated gears with **prior sandblasting improvements of 95%.**
- Gears subjected to chemical etching and Nb coating deposition (Et-C) **showed an improvement of 38%.**
- Nb coating was fully removed in high compressive RS gears but remained in valleys with medium RS.



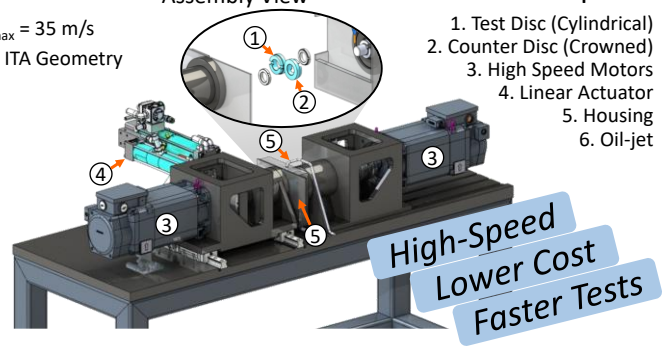
… How to deal with the high-speed and giga cycles expected for e-mobility?

Operating Conditions

- n_1 up to 12,000 rpm ↔ $v_{R,max}$ = 35 m/s
- Equivalent to 35,000 rpm at ITA Geometry
- P_H up to 3 GPa
- SRR: -200%/200%



Assembly View



Main Components

1. Test Disc (Cylindrical)
2. Counter Disc (Crowned)
3. High Speed Motors
4. Linear Actuator
5. Housing
6. Oil-jet

High-Speed Twin Disc Test Rig