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NOVEL TEST METHODS FOR TRIBO/MECHANICAL PROPERTIES IN THE CONTEXT OF ALTERNATIVE FUELS

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1. Introduction

Alternative fuels such as hydrogen, ammonia, and methanol are becoming increasingly important to meet global climate goals. However, their impact on mechanical and tribological properties is not yet fully understood. This creates a pressing need for the development of novel experimental methods to establish reliable design criteria for components exposed to these fuels. To date, hydrogen embrittlement has been the most extensively studied in this context [1].

2. Methodology and Results

To address the challenges posed by alternative fuels, the experimental methods at the Chair of Mechanical Engineering were systematically expanded. A key challenge lies in ensuring safety, as hydrogen is flammable over a wide range of concentrations, while ammonia and methanol are highly toxic. Consequently, small volumes and permanently sealed systems were prioritized in the design and implementation of the test setups.

2.1 Mechanical Properties – Hollow Specimen Technology

The hollow specimen technology offers several advantages, including small gas volumes, high pressure resistance, and the ability to conduct tests at elevated temperatures. The technology was further developed to meet the specific requirements of our laboratory as depicted in Figure 1. Recently, a new standard, ISO 7039:2024 [2], has been established for this method. The main challenges were the design of a clamping system within the test rig and the precise manufacturing of the internal bore with diameters of 2.4 mm and 3 mm. A specialized process was developed to polish the internal surface and measure its roughness using a Mahr contour measurement system. Additionally, a procedure was devised to mount and purge the specimens, ensuring the required purity inside the sample. Tests can now be performed using gas mixtures at pressures up to 1000 bar and temperatures up to 600 °C, achieved through inductive heating.

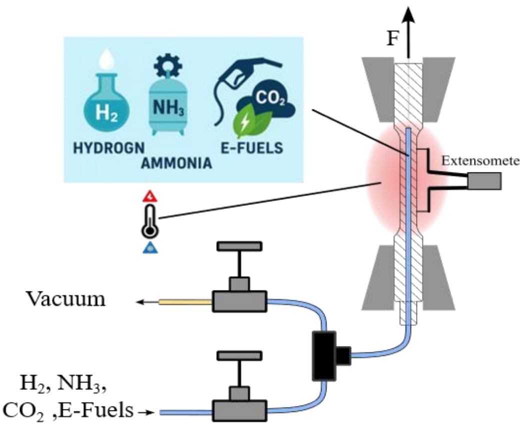

Fig. 1. Hollow specimen technology

In this study the steel 17-4 PH was used as a benchmark material as it shows a high sensitivity to hydrogen embrittlement. Tensile tests were conducted at a low strain rate of 5e-5 [1/s] (SSRT). Figure 2 presents a comparison of results for 200 bar hydrogen, 200 bar argon, and a solid specimen used as a reference. A 90% reduction in elongation at fracture was observed in hydrogen compared to argon. However, the Young's modulus, Yield strength and ultimate tensile strength did not change.

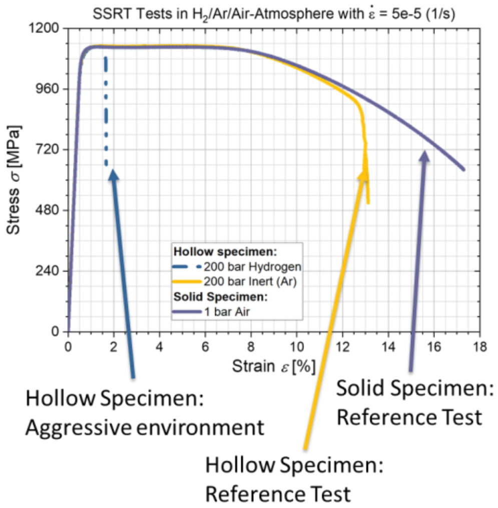

Fig. 2. Results SSRT (hollow specimen technology)

Figure 3 illustrates the effect of hydrogen on fatigue properties as low cycle fatigue tests (LCF) were performed. When plastic strain components are present, the number of cycles to failure decreases, and the scatter in results increases.

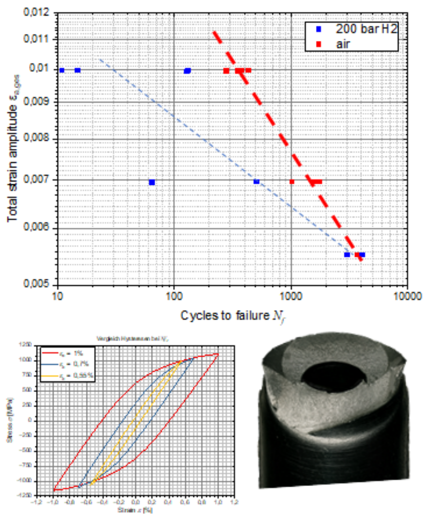

Fig. 3. Results LCF (hollow specimen technology)

2.2 Tribological properties

To investigate the effects of different atmospheres on tribological conditions, such as those in ball bearings, a novel test cell based on the ball-on-rod principle was developed. In this setup, three balls are pressed radially onto a rotating rod.

Key challenges included the implementation of a magnetic feedthrough, which eliminates the need for moving seals, and the integration of a specialized measurement system to record contact forces in-situ. The autoclave's dead volume was minimized to meet safety requirements. Figure 4 depicts the realized design.

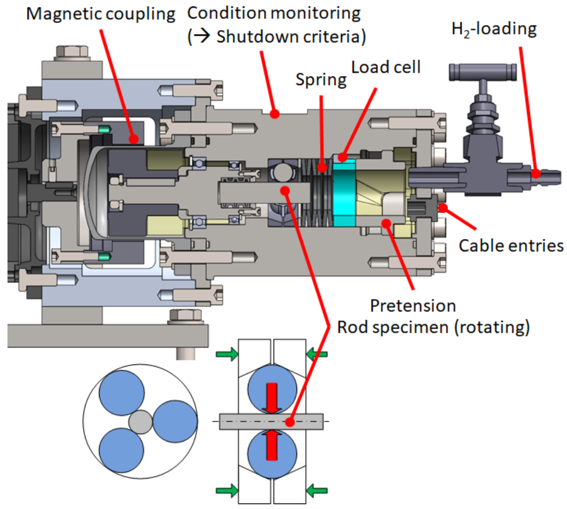

Fig. 4. Ball-on-rod test configuration

In addition, a model test configuration for Ring-on-Liner contacts was set-up enabling the testing under hydrogen and methanol atmospheres under lubricated conditions.

3. Conclusions / Outlook

The results demonstrate the feasibility of these complex test setups and their ability to simulate challenging environmental conditions safely. Future work will focus on expanding the range of testable gases and refrigerants.

Hollow Specimen Technology:

- Investigating the influence of notches, where localized plastic deformation occurs, by introducing internal notches into the specimens.
- Correlating LCF results with autoclave tests under comparable specimen conditions.

Tribological systems:

- Ball-on-Rod: Implementing an improved in-situ force measurement system for aggressive environments and enhancing the cage guidance system for better performance.
- Ring-on-Liner: Enhance towards ammonia.

References

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[2] ISO 7039:2024, Metallic materials — Tensile testing — Method for evaluating the susceptibility of materials to the effects of high-pressure gas within hollow test pieces, 2024