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The FVV Transfer + Networking Event | Spring 2023

Knowledge and technology transfer | New research programme

Science for a
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Material and resource efficiency

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PROJECT 1351 · TMF Crack Path Calculation for Turbocharger Hot Parts
RESEARCH PRIORITY Materials **EXPERT GROUP** Turbo Machines
APPLICATION Turbocharger

PROJECT 1444 · Modelling of Metal-graphite Composites (MeGrav II)
RESEARCH PRIORITY Materials **EXPERT GROUP** Turbo Machines
APPLICATIONS Optimised Plain Bearings, Mechanical Seals

Resource efficiency lowers material and energy consumption, **reducing environmental and climate impacts**

The components of modern powertrain and energy conversion systems that carry exhaust gas are exposed to high mechanical and thermal loads during operation. This can cause the components to crack, thereby reducing their service life. Researchers at TU Bergakademie Freiberg (TUBAF) and the Federal Institute for Materials Research and Testing in Berlin (BAM) have developed software that simulates and predicts the path of a fatigue crack. Novel metal-graphite composites enable higher service temperatures and thus the more efficient operation of machines, motors and engines. In an Industrial Collective Research project, researchers from TU Dresden devised a process control and design strategy for the general methodical development of these materials.

Within the scope of Industrial Collective Research, FVV and its projects help companies make their production more efficient in terms of resources and costs, increase the performance and longevity of components, thereby retaining materials in the circular economy for longer.

Looking into the future with simulations

Many components in engine and turbine construction, in particular hot-running components of turbochargers, are subjected to thermal and mechanical loads that vary over time. This leads to thermomechanical fatigue of the material and the formation of cracks in exposed places, potentially resulting in sub-critical crack growth and even component failure.

Until now, there was no way to predict how a detected crack will behave – i.e. whether it will grow and, if so, in which direction and at what speed. As such, there is considerable uncertainty during the computational design of components subject to such loads. In the field, components with detected cracks are therefore replaced as a preventive action, as the ongoing behaviour of the crack cannot be predicted with a sufficient degree of accuracy. This approach is difficult to justify in ecological or economic terms, especially as turbocharger housings can develop cracks that are not problematic to operation as they do not grow beyond a few millimetres. There is therefore a need for fracture-mechanical methods for evaluating the risk of further growth in detected cracks, and thereby for deciding whether a component can continue to be used or whether it needs to be replaced.

In the project ›**TMF Crack Path Calculation for Turbocharger Hot Parts**‹, a powerful calculation tool was developed for finite element simulation and predicting crack propagation in 3D components at TU Bergakademie Freiberg (TUBAF) [FIGURE 4]. The ProCrackPlast software is based on code initially developed at TUBAF for linear-elastic fracture mechanics (ProCrack). »In the field of thermomechanical fatigue, however, there are

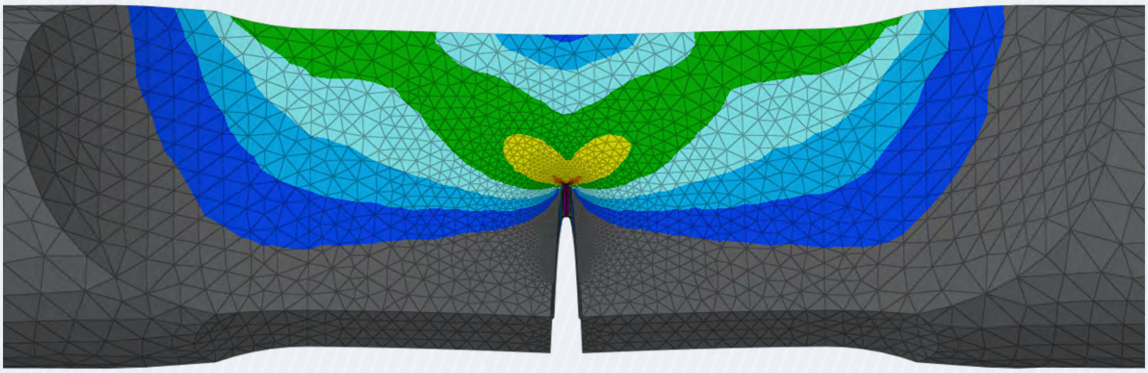

FIGURE 4

SENT sample: simulation result achieved using the simulation software developed in the project. Specifically, the image shows the distribution of stress during the propagation of fatigue cracks in a SENT (single-edge notched tension) sample // TU Bergakademie Freiberg | IMFD additional effects that need to be taken into account, such as a tendency to creep,« comments Professor Björn Kiefer from the Institute of Mechanics and Fluid Dynamics (IMFD). This is why inelastic material models were also used in the expanded simulation environment, some of which had been developed as part of a previous project at the Federal Institute for Materials Research and Testing in Berlin (BAM). The experimental data required by the simulation software to calibrate and validate the models was gathered at BAM during sophisticated investigations [FIGURE 5].

Flat tensile specimens with cracks were used to determine crack growth at temperatures between 20 and 700 degrees Celsius, thereby creating robust data for quantifying crack propagation. In addition, the researchers simulated all tests using a finite element-based calculation procedure.

ProCrackPlast can now be used in development on a cross-application basis – i.e., wherever combustion engines with turbochargers or turbines with housings made of the typical cast iron material NiResist D5S are deployed. The material parameters are pre-built into the software. The user enters the geometry of the component, adds the expected mechanical and thermal load change, and receives a prediction for the probable behaviour of a crack.

Industrial partner Rolls-Royce Solutions coordinated the project, and Dr Andreas Koch, Senior Manager Structural Mechanics & Thermal Analyses, is extremely satisfied with the developed simulation environment: »For us, it is also interesting to know in which direction a crack is growing and how it will develop if I drive a few thousand cycles more than was actually planned.« Engineers can take several design-related actions

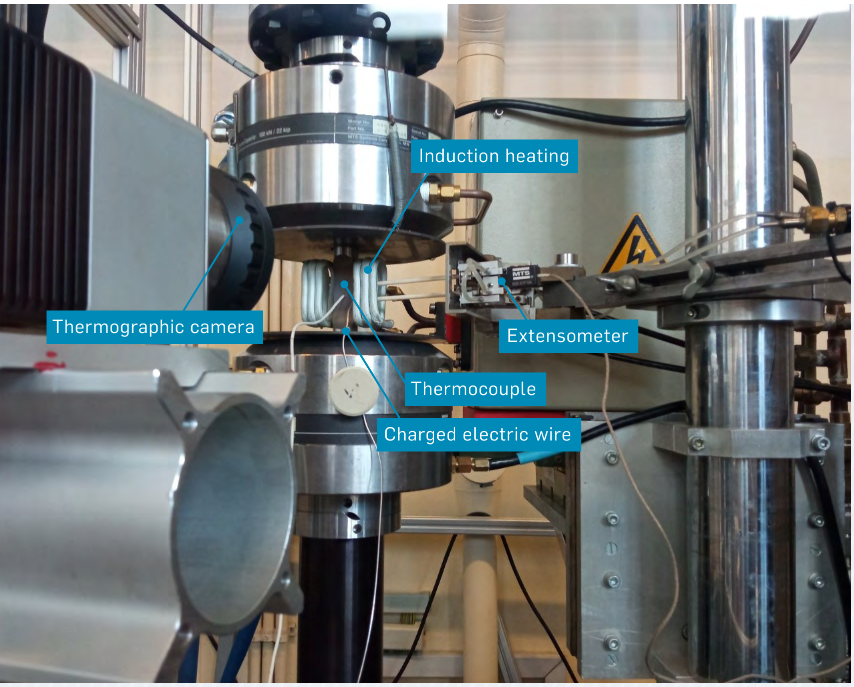

FIGURE 5

BAM test bench: all crack propagation tests were performed in air on a servo-hydraulic testing machine

// Bundesanstalt für Materialforschung und -prüfung to minimise crack formation: »During the design phase, relevant areas can be designed for lower thermomechanical loads by dimensioning the wall thickness in critical areas to suit the respective load,« explains Dr Koch. As such, ProCrackPlast means maintenance intervals can be extended, while expensive components no longer need to be replaced as a precaution in the event of acceptable cracks – saving time in the process.

The calculation software has already been used for design at Rolls-Royce Solutions and was applied to a custom geometry. Now it is important to gather experience according to Koch. In the future, the researchers in Freiberg want to further improve the software and methodology, optimise the models' precision and conduct more reference experiments. Although only one material was analysed during the project, Professor Kiefer sees the need to perform tests using other materials to thus validate the method's transferability.

The software including user manual is available to all FVV member companies, alongside the identified material parameters and fatigue crack models. A live demonstration of the software was conducted and questions answered during a workshop. Transferring the results to industry is a simple process: vehicle manufacturers forward the corresponding specifications to the turbocharger manufacturers, while fabricators of exhaust gas systems or computational service providers also benefit directly from the software. »Until now planning has erred on the side of caution, with components being designed with thicker walls which are then heavier than they need to be,« explains Dr Koch. The better the simulation, the less conservative manufacturers will need to be when building parts in the future, saving weight, material and costs.

However, the limits of the evaluation concept also became apparent during the course of the project. One of the problematic aspects is describing creep strain accumulation, creep damage and oxidation-induced embrittlement, which primarily occur at high temperatures and long hold times. Approximate approaches have been suggested for these cases, but these still need to be validated through appropriate long-term tests. »We were also unable to sufficiently investigate the influence of alternating loads of tension, thrust and torsion (mixed-mode loading) on the growth of fatigue cracks. Thus, there is certainly potential for a later project concerning this,« says Professor Kiefer. The ProCrackPlast software contains plausible fracture hypotheses for such load cases, but these still need to be specified.

FIGURE 6

Prototype flange sleeves made of graphite infiltrated with aluminium or magnesium // TU Dresden | ILK

Modern metal-graphite composites for more efficient machines and engines

Advances in performance and efficiency in mechanical and plant engineering mean that materials are exposed to higher working temperatures. On plain bearings and mechanical seals in particular, increasing speeds or system pressures mean that higher operating and emergency running characteristics need to be guaranteed. As the system temperature rises, however, increased fretting occurs in the friction surfaces, which results in high maintenance and repair costs and wear-related downtimes and failures.

Conventional plain bearing materials such as polyimides, bronze or white metals reach their mechanical limits at higher temperatures: the disadvantage of the frequently used polymers is the relatively low continuous service temperature of no more than 250 degrees Celsius.

> In the future, it will be possible to operate machine tools, compressors, combustion engines and aircraft engines only through using materials that are resistant to wear and high temperatures.

In the project ›**Metal-graphite Composites for Plain Bearings (MeGrav I)**‹ (FVV project number 1330), aluminium or magnesium alloys were pressed into the pores of graphite under high pressure using a squeeze-casting process. This metal-infiltrated graphite is seen as a promising alternative thanks to its self-lubricating properties, its high-temperature stability and its good mechanical characteristics. In the follow-up project ›**Modelling of Metal-graphite Composites (MeGrav II)**‹ René Füßel and his team from the Institute of Lightweight Engineering and Polymer Technology (ILK) at TU Dresden are now evaluating how high temperatures influence the material. In addition, a process control and design strategy for developing metal-graphite products is being drawn up for the first

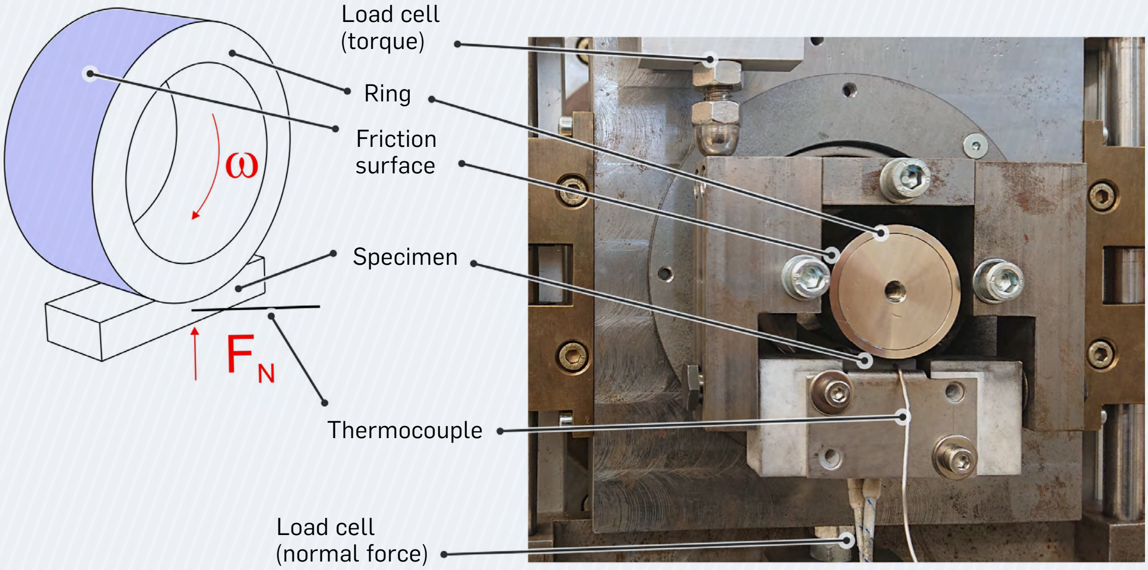

FIGURE 7

High-temperature friction test bench with in-built block-on-ring tester // TU Dresden | ILK

time. As the industrial partner, Rolls-Royce Deutschland is providing the sample material and the requirements catalogue [ABBILDUNG 7]. One typical field of application for metal-graphite composites is plain bearings in compressors, explains Dr Susanne Schrüfer from Rolls-Royce Deutschland: »If we can achieve a continuous service temperature of 300 degrees Celsius or more in the future, that would be a big step forward. But everything above 250 degrees is a success.«

The influence of the manufacturing parameters on the final product should be investigated in the design phase: »We want to determine how the manufacturing parameters vary and identify their influence on the characteristics,« says Füßel, adding: »In other words, if the material is infiltrated at 670 bar, it will have a certain sliding friction coefficient.« The different infiltration grades are to be evaluated in terms of their physical properties in order to develop an appropriate quality method. To this end, semi-finished products with different parameters were manufactured from the raw graphite.

René Füßel's team has performed around 450 friction tests and 250 mechanical tests, including three-point bending tests, over the last few months. With a cycle time of approximately one day per test specimen, this is a time-consuming process, despite having two machines running in parallel. The researchers are conducting the tests from room temperature up to approximately 300 degrees Celsius – and even up to 450 degrees Celsius for different ageing conditions [FIGURE 8]. One goal of the modelling is to predict wear rates based on parameter variations in the process. »At a low infiltration pressure, the sliding friction coefficient should be lower, while at higher pressures it should be higher,« says Füßel. He believes this will make it possible to predict the required maintenance intervals in the future: how long can machines be operated before they need servicing and before wear parts need to be replaced?

According to René Füßel, it is already becoming evident that there are no expected significant differences in mechanical or tribological characteristics thanks to the extremely robust manufacturing process. Even fluctuating manufacturing parameters barely impact the performance of the material. »This is a very positive result for the application itself, as we always achieve consistently high quality. But it makes modelling more difficult,« explains Füßel.

With the gathered data, the team will press ahead with the modelling over the coming months. Without wanting to pre-empt the final report, Füßel makes the following comment: »There are hard application limits, but within these limits the system is highly stable.« During the tests, it was revealed that although the magnesium-infiltrated graphite has a lower wear rate, magnesium is less resistant to heat than aluminium. Moreover, it has a tendency to spontaneously ignite at very high temperatures of more than 500 degrees due to its reactivity – which is why several companies are reluctant to process magnesium.

The research results will benefit bearing manufacturers, but also mechanical and plant engineers and material suppliers that manufacture the metal-infiltrated plain bearings and seals in an injection moulding or die casting process. The machines used to produce polymer or graphite seals up to now can continue to be used in the future. While, as Dr Schrüfer explains, the first plain bearings and seals made of the new material could be used relatively quickly in the mechanical and plant engineering or automotive industry, it will take several years to transfer the results to the aviation industry: »This requires suppliers that deliver the desired quality, acceptance standards and suitable quality assurance methods. Depending on the application, this can take at least three years.« //

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AUTHORS

Richard Backhaus, Wiesbaden
Mathias Heerwagen, Leipzig

EDITORS

Petra Tutsch and
Martin Nitsche, FVV

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Transfer // Industrial Collective Research (IGF) empowers companies to solve joint research and technology problems on a science-based approach. It provides access to a continuous stream of new knowledge they can use to create their own products, processes and services. Industrial research and development benefits from the fact-/field-based collaboration with the science community, universities and non-profit research institutions, on the future of technology. This creates innovative power in industry and excellence in research, teaching and learning.

Networking // The research implemented by the FVV is based on a long-term cooperation between the partners. In spring and autumn, around 300 experts meet regularly at the FVV Transfer + Networking Events. This report from the science series FVV Prime**Movers.** Technologies. summarises the main results.

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Lyoner Strasse 18 | 60528 Frankfurt / M. | Germany
+49 69 6603 1345 | info@fvv-net.de

www.fvv-net.de