Under **pressure**

Dr Andreas Kailer describes his efforts to boost the reliability and longevity of advanced ceramics by using extensive data from engineering applications, numerical simulations and targeted model experiments

What are the main objectives driving the 'Enhanced reliability and lifetime of ceramic components through multi-scale modelling of degradation and damage' (RoliCer) project?

Studies on advanced ceramics have highlighted their exceptional superior mechanical, thermal and tribological properties for many engineering applications. Ceramics are especially well suited for modern rolling and sliding bearings, as well as for metalworking and cutting tools.

However, there are still concerns over the reliability and lifetime of ceramic materials. RoliCer – an EU-funded collaboration of companies that develop and manufacture ceramic materials and components and research institutes that conduct research by means of numerical simulations and experiments to assess materials on the different scales – works to bridge the gap in knowledge between damage, wear, reliability and lifetime of ceramics. The project investigates the damage and degradation of silicon nitride (Si_3N_4) by means of multiscale numerical simulations (atomistic, microscale, mesoscale and macroscale) as well as targeted model experiments. The outcomes of the project are to be validated through industrial testing.

Could you introduce your professional background and explain your role within the project?

I am Head of the Tribology and Advanced Ceramics group at the Fraunhofer Institute for Mechanics of Materials IWM, Germany. I have worked in the field of tribology and the evaluation and optimisation of advanced ceramic materials for components that serve under severe conditions or high loads.

A major part of my research has been focused on developing and qualifying of Si_3N_4 for metal-forming processes and, more generally, its tribological evaluation in rolling and sliding contacts. Si_3N_4 possesses the ideal combination of mechanical, chemical and tribological properties for this field of applications. There are many open questions relating to the assessment of the component lifetime, reliability and efficiency. By combining experimental and numerical methods within RoliCer these questions will be at least partly answered.

RoliCer scales up findings from atomistic and microscale simulations of ceramic material degradation to the component level. What challenges are associated with this methodology?

One of the most challenging aspects of the methodology is that evolving from small-scale models to large-scale models involves several changes, including those related to time. There are many aspects involved in transferring information from the over-simplified, small-scale model into

Advancing **ceramics**

In experiments that mimic real world applications, research at the **Fraunhofer Institute for Mechanics of Materials** is set to improve the design of ceramic materials

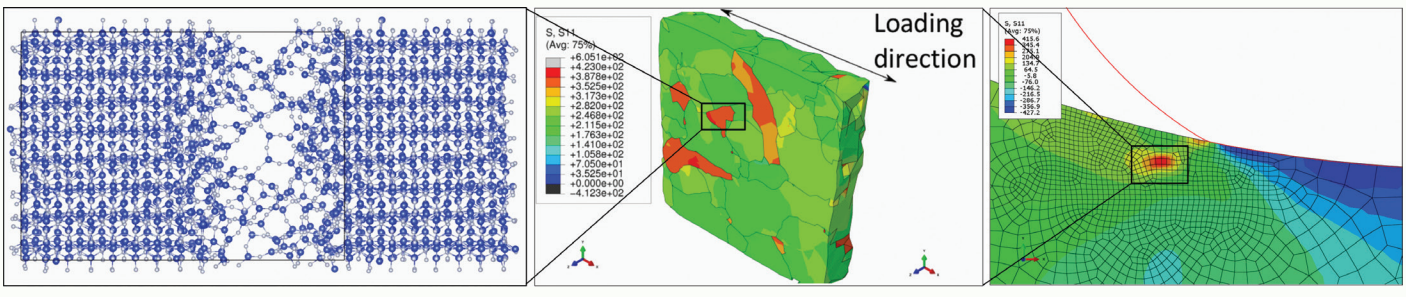
CERAMIC MATERIALS HAVE evolved far beyond their traditional purpose of creating clay products, glass and cement. Today, they are embedded into everyday life and used in nearly every engineering discipline, with further applications in the aerospace, automotive, medical and military fields.

The reason for their widespread use lies in their highly resistant properties. Advanced ceramics are hard, strong in compression and capable of withstanding shearing and tension. They are also able to survive extremely high temperatures – as much as 800 °C under large mechanical loads. Despite these desirable properties, the Achilles' heel of ceramics is their reliability and lifetime. Drs Andreas Kailer and Iyas Khader of the Group Wear Protection, Advanced Ceramics, at the Fraunhofer Institute for Mechanics of Materials IWM in Germany are working to eliminate these weaknesses.

Their research project, 'Enhanced reliability and lifetime of ceramic components through multi-scale modelling of degradation and damage' (RoliCer), is an EU-funded collaborative research project, which includes companies and research institutes from Germany, Austria, the Czech Republic and The Netherlands. It focuses on understanding and modelling the limitations of ceramic materials in order to gain longer lifetimes and better reliability of ceramic components. They are working to achieve this goal by modelling the damage mechanisms they need to prevent. For this, they are combining a chain of computer simulation methods and targeted model experiments.

SMALL SCALE, BIG IMPACT

One approach the researchers have adopted is looking at the basic mechanisms and factors that give way to ceramic damage and degradation. Kailer believes this work will help fill the knowledge gap that currently exists between the microstructural properties of advanced ceramics and their degradation. "The microstructure of any material controls its macroscopic behaviour in a real-life engineering application. Therefore, the degradation of the microstructure will affect the reliability of any component in service," he explains.



Left: an incoherent interface model under stress at finite temperature. **Middle**: damage at the grain boundaries in a microscale simulation.
Right: stress concentration caused by crack formation in conforming contact in ceramics.

the larger-scale model that were not taken into account in the former.

How are calculations of reliable material properties conducted at the atomic level?

Calculations and simulations at the atomic level provide insight into phenomena and may explain what happens on larger scales. A clear example is fracture: the occurrence of fracture on the atomistic level shows the orientations and planes at which fracture is most likely to occur on larger scales.

In what manner does the stress intensity factor affect the design of ceramic materials?

Stress intensity factor is an indicator of the stress state at the crack tip in ceramic materials. It is used to predict fracture, and hence failure, in ceramics. Stress gradients within the material may influence the stress intensity factor, directing towards certain design or loading recommendations.

Could you discuss the material combinations with enhanced properties you hope to see developed?

Since ceramics are applied in various fields, no one material combination can be expected to portray a magic recipe. In RoliCer, we are targeting two groups of applications: bearings and manufacturing tools. With bearings, the ceramic rolling components are subjected to severe mechanical contact stresses. With manufacturing tools, the ceramic tools undergo high mechanical and tribological stresses at high temperatures. We are working on designing two distinct materials capable of sustaining the loading conditions pertaining to each type of application. This being said, both material combinations must be economically feasible for production as well.

Most of your work has been based on developing theoretical models, modelling tools and techniques. What will industrial testing of components involve?

Parallel to the numerical simulations, the research work in RoliCer focuses on both material design and implementation in the industry. The testing phase will involve using material grades developed within the project to manufacture rolling components that will be examined in full-scale hybrid bearings tests and rolls that will be tested in a nickel-base superalloy wire rolling mill.

Throughout the project, the researchers will also look at the impact of thermal, mechanical and tribological loads on ceramic components, as well as the effect of adhesion between ceramics and metals. They will use the findings from their research to develop comprehensive knowledge on the most relevant degradation and damage mechanisms. Armed with this knowledge-based system, Kailer and Khader will be able to create new composites and to reach the optimal design of advanced ceramics with improved lifetimes and systems with superior robustness.

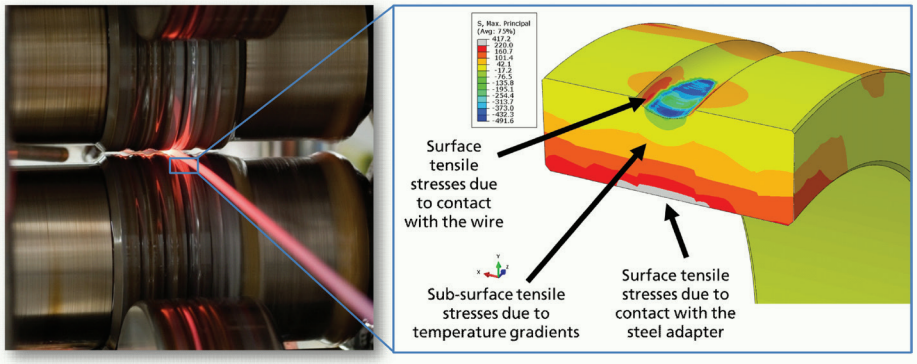
KEEPING IT REAL

Since the RoliCer project will be creating new materials, the researchers have set up their work in the lab so it reflects real world scenarios. This will help to ensure that any predictions for the lifetime of a product are true to actual applications. "By linking the findings from several simulation scales with real applications, RoliCer will deliver information to ensure the cost-efficient manufacturing of high quality rolling tools and bearing elements," Kailer highlights. The results also have wider applications throughout the engineering fields including developing ceramic gears, sliding and friction systems and machine elements that are subjected to severe mechanical, thermal and tribological loading.

JUST THE BEGINNING

The work conducted by the RoliCer team is on track to be translated for application in industrial and technical settings. "The outcomes of RoliCer will help to broaden the range of technical applications significantly, because there will be opportunities for fast and efficient design of robust high-performance systems using ceramic components," Kailer notes.

In addition to providing new insights into ceramics, the RoliCer project has also provoked new questions that will guide future research. In fact, Kailer has already begun to develop a follow-on project will focus on developing of materials with extended functionality capable of working under severe operating conditions. He is also working on integrating computation mechanical engineering methods alongside the experimental programme.



Stress distribution in a ceramic roll in hot rolling high strength wires.

INTELLIGENCE

ROLICER

ENHANCED RELIABILITY AND LIFETIME OF CERAMIC COMPONENTS THROUGH MULTI-SCALE MODELLING OF DEGRADATION AND DAMAGE

OBJECTIVES

To bridge the gap in knowledge between the microstructural properties and degradation phenomena of ceramic materials to improve their design and lifetime.

PARTNERS

Fraunhofer IWM Freiburg (coordinator) • **The SKF Group** • **FCT Ingenieurkeramik GmbH** • **Böhler Edelstahl GmbH & Co KG** • **Institute of Physics of Materials (IPM ASCR)** • **Montanuniversität Leoben** • **Karlsruhe Institute of Technology** (KIT)

FUNDING

EU Seventh Framework Programme (FP7)

CONTACT

Dr Andreas Kailer
Head of Group Wear Protection, Advanced Ceramics

Fraunhofer Institute for Mechanics of Materials IWM
Wöhlerstr. 11
9108 Freiburg
Germany

T +49 761 5142 247
E andreas.kailer@iwm.fraunhofer.de

www.rolicer.eu

ANDREAS KAILER is Head of the Tribology and Advanced Ceramics group at Fraunhofer IWM. He specialises in the analysis of tribological, mechanical and thermal properties of advanced ceramics. He is looking to improve the technical applications of ceramic materials, especially those involving rolling and sliding elements, and to develop metal forming and cutting tools.

IYAS KHADER is Assistant Professor at the German-Jordanian University and a consultant for Fraunhofer IWM. He specialises in experimental analysis and finite element modelling of tribological systems that involve advanced ceramics in various manufacturing processes.

RoliCeR

Fraunhofer IWM