24. International Forging Congress

Forging a **Sustainable** Future.

EUROFORGE IFC
24. INTERNATIONAL FORGING CONGRESS 2025

Scientific line:

Innovations in forging

Title: Sustainable Forging Through Physics-Based Digital Twins: Predicting Microstructure to Eliminate Waste and Defects

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Dr. Maxim Zapara received his PhD in Mechanical Engineering from Tula State University in 2004, specializing in damage mechanics of metals under large plastic deformations. Following postdoctoral research at TU Berlin, he joined the Fraunhofer Institute for Mechanics of Materials IWM in Freiburg in 2012. He currently leads the research team "Forging" in the Manufacturing Processes business unit, where his group focuses on characterizing, modeling, and simulating material behavior and microstructure evolution during cold and hot forging processes.

Abstract:

The global transition toward sustainable manufacturing demands revolutionary approaches to steel production and processing. The EU Horizon project AID4GREENEST addresses this challenge by developing physics-based and AI-powered solutions that fundamentally transform how we design and optimize forging processes for maximum efficiency and minimum environmental impact.

This presentation showcases a breakthrough in predictive metallurgy through the development and industrial validation of a physics-based mean-field model capable of predicting microstructure evolution in large-scale steel forgings. Using a multi-tonne steel turbine shaft as a demonstration case, we have successfully bridged the gap between laboratory-scale material science and industrial reality.

Our integrated approach combines extensive experimental validation using GLEEBLE thermo-mechanical simulation with advanced finite element modeling to create a comprehensive digital twin of the forging process. The calibrated model accurately predicts the complex interplay between dynamic recrystallization, grain growth, and thermal cycling throughout multi-stage industrial forging operations spanning over temperature ranges from 800°C to 1250°C.

Key industrial innovations include:

- Predictive Quality Control: Real-time prediction of microstructural heterogeneity, enabling proactive process adjustments
- Waste Reduction: Identification and elimination of "dead metal zones" that compromise component integrity
- Energy Optimization: Strategic thermal management reducing unnecessary reheating cycles
- First-Time-Right Manufacturing: Minimizing trial-and-error approaches through physics-based process design

The model's successful validation against post-forging metallographic analysis demonstrates its readiness for industrial deployment. This represents a paradigm shift from empirical to science-based forging, where advanced microstructure prediction enables manufacturers to achieve superior component quality, while dramatically reducing material waste, energy consumption, and production time.

For the forging industry, this technology offers a pathway to sustainable manufacturing excellence – delivering both environmental benefits and economic competitiveness. As regulations tighten and sustainability becomes paramount, such predictive tools will become essential for maintaining competitiveness in the global market while meeting ambitious climate targets.

The presentation will demonstrate how advanced materials modeling, when properly integrated with industrial processes, can forge a truly sustainable future for our industry.