SIEMENS energy

High-Performance Computing Modeling of Material Imperfections of Critical Fossil Power Generation Components

Kai Kadau

Office of FOSSIL ENERGY

HPC4 MATERIALS

- Siemens Energy Inc. will partner with LANL to understand crack nucleation from forging flaws in a project titled "High-Performance Particle-Based Modeling of Damage Nucleation from Forging Flaws in Fossil Power Generation Rotor Components".

https://hpc4mtls.llnl.gov/projects.html

Team

Siemens Energy

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Manufacturing and Service: Gas and Steam Turbines, Generators

The Siemens gas turbines portfolio:
The right engine for every requirement

SIEMENS
Ingenuity for life

Type	Frequency	Model	Output
Heavy-duty gas turbines	50Hz	SGT5-9000HL	593 MW
Heavy-duty gas turbines	50Hz	SGT5-8000HL	481 MW
Heavy-duty gas turbines	50Hz	SGT5-8000H	450 MW
Heavy-duty gas turbines	50Hz	SGT5-4000F	329 MW
Heavy-duty gas turbines	50Hz	SGT5-2000E	187 MW
Heavy-duty gas turbines	60Hz	SGT6-9000HL	405 MW
Heavy-duty gas turbines	60Hz	SGT6-8000H	310 MW
Heavy-duty gas turbines	60Hz	SGT6-5000F	215 to 260 MW
Heavy-duty gas turbines	60Hz	SGT6-2000E	117 MW
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A65	60 to 71 / 58 to 62 MW
Industrial gas turbines	50Hz or 60Hz	SGT-800	50 to 62 MW
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A45	41 to 44 MW
Industrial gas turbines	50Hz or 60Hz	SGT-750	40 / 34 to 41 MW
Industrial gas turbines	50Hz or 60Hz	SGT-700	33 / 34 MW
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A35	27 to 37 / 28 to 38 MW
Industrial gas turbines	50Hz or 60Hz	SGT-600	24 / 25 MW
Industrial gas turbines	50Hz or 60Hz	SGT-400	10 to 14 / 11 to 15 MW
Industrial gas turbines	50Hz or 60Hz	SGT-300	8 / 8 to 9 MW
Industrial gas turbines	50Hz or 60Hz	SGT-100	5 / 6 MW
Aeroderivative gas turbines	50Hz or 60Hz	SGT-A05	4 to 6 MW

Power Generation / Mechanical Drive, Performance at ISO conditions

The HL-class:
When the best from past experience unites with new technologies

SIEMENS
Ingenuity for life

Single tie-bolt rotor

- Proven rotor design with internal cooling air passages for fast (cold) start and hot restart capability
- Rotor Air cooler allows use of proven steel disc design
- Easy rotor de-stacking on site due to disc assembly with Hirth serration and central tie rod

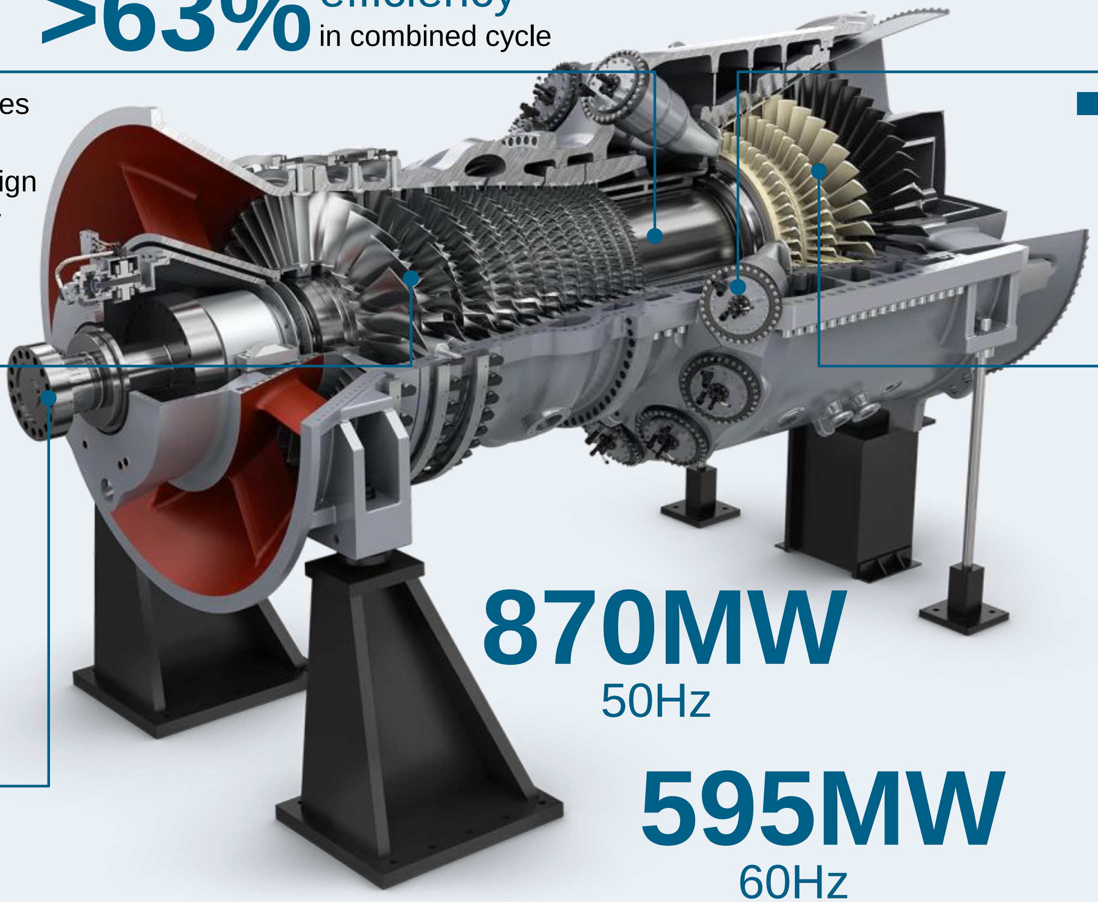
12- stage compressor

- Variable-inlet Guide Vanes and two stages of fast-acting Variable-pitch Guide Vanes (VGV) for improved part load efficiency and high load transients
- Third generation harmonized compressor
- High efficiency due to evolutionary 3D blading
- All rotating compressor blades replaceable without rotor lift or rotor de-stacking

Bearings

- Hydraulic Clearance Optimization (HCO) for reduced degradation and clearance losses

>63% efficiency in combined cycle



870MW 50Hz

595MW 60Hz

in combined cycle 1x1 / 1S

Combustion

- Advanced can annular combustion system with dual-fuel capabilities (12/16 combustors)

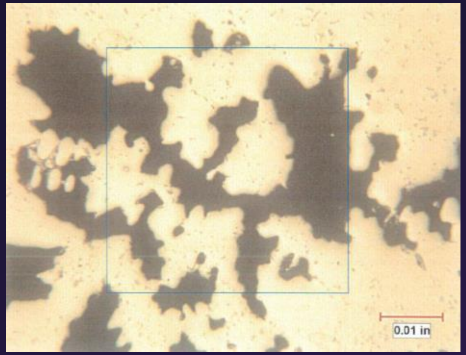
4-stage turbine

- High cycling capability due to fully internally air-cooled turbine section
- Super-efficient internal cooling features for blades and vanes
- 3D four-stage turbine with advanced materials and thermal barrier coating
- All turbine vanes and blades replaceable without rotor lift; vane 1, blades 1 & 4 replaceable without cover lift

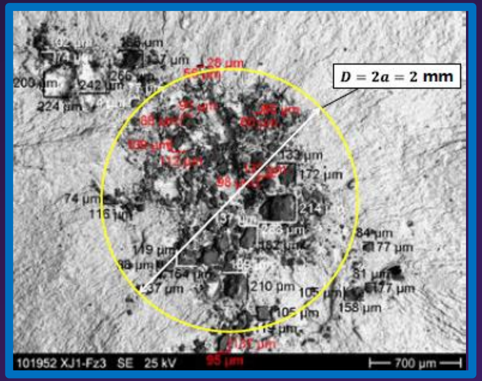
Flexibility | Performance | Serviceability

Material Imperfections – Engineering Model

Turbine Blades – Cast Porosity

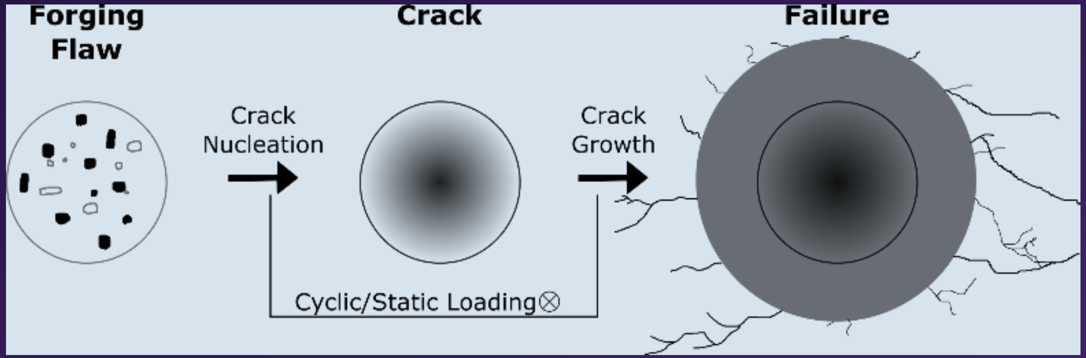


Rotor Disks – Forging Flaws



Life Model

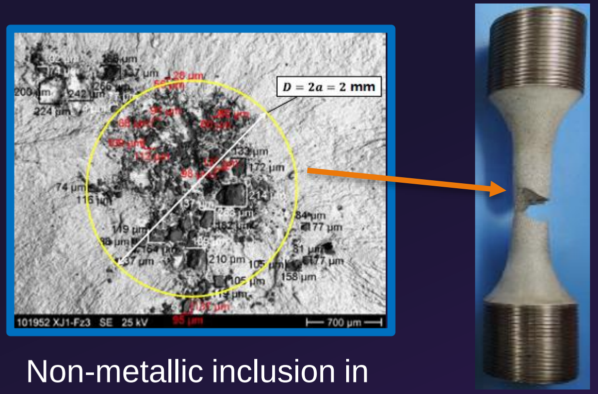
$$N_{flaw} = N_{Nuc} + N_{FM}$$



[1] K. Kadau, P. Gravett, C. Amann, *Probabilistic Fracture Mechanics for Heavy-Duty Gas Turbine Rotor Forgings, J. Eng. Gas Turbines Power 140, 062503 (2018).* (DOI 10.1115/1.4038524)
[2] F. Radaelli, K. Kadau, C. Amann, P. Gumbsch, *Probabilistic Fracture Mechanics Framework Including Crack Nucleation of Rotor Forging Flaws*, Proceedings ASME Turbo Expo 2019, pp. GT2019-90418, Phoenix, AZ, USA (2019). (DOI 10.1115/GT2019-90418)

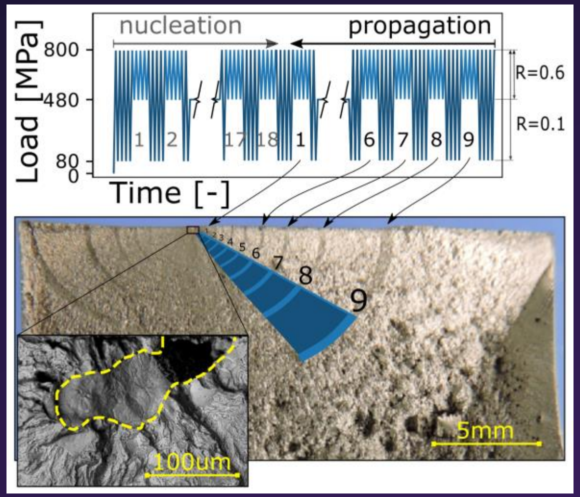
Material Imperfections – Experimental Data

Specimen with Forging Flaws

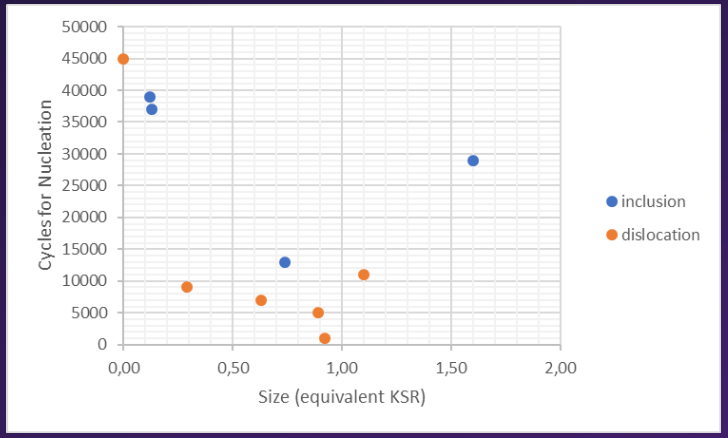


Non-metallic inclusion in metal matrix area cut-up

Evaluation of Experiments



Cycles to Crack Nucleation

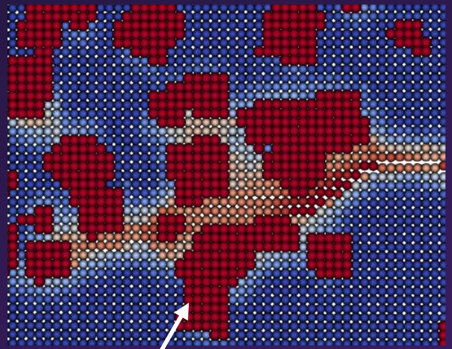


- Development of engineering model for crack nucleation N_{Nuc} of material imperfection based on experimental data

$$N_{flaw} = N_{Nuc} + N_{FM}$$

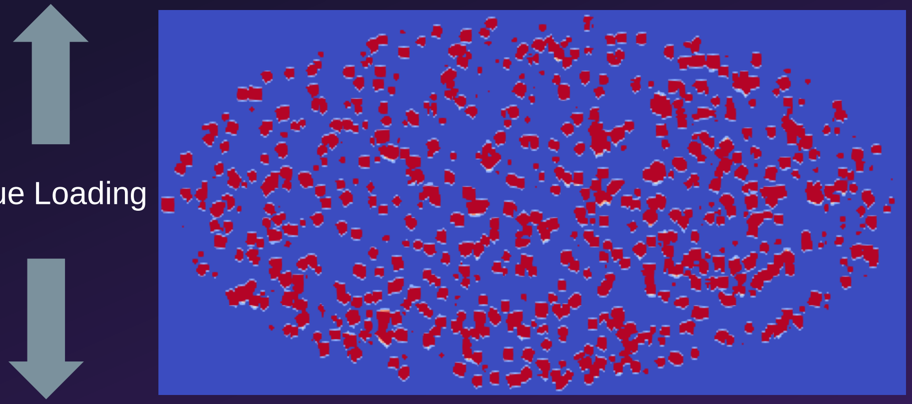
Material Imperfections – High Performance Computing

Peridynamics Simulation of Forging Flaw Fatigue Crack Nucleation Processes



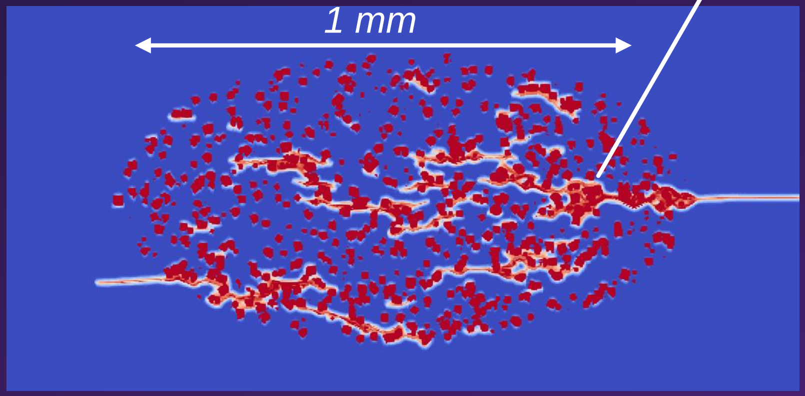
- Reliability, transferability, statistics → HPC modeling
- Los Alamos Grizzly HPC Cluster, 100 million material points
- Non-metallic inclusion (red) distribution in metal matrix (blue)
- Damage generation under fatugue loading (white-red)

Fatigue Loading



Initial Local Nucleation at Inclusions ~ 1000 Cycles

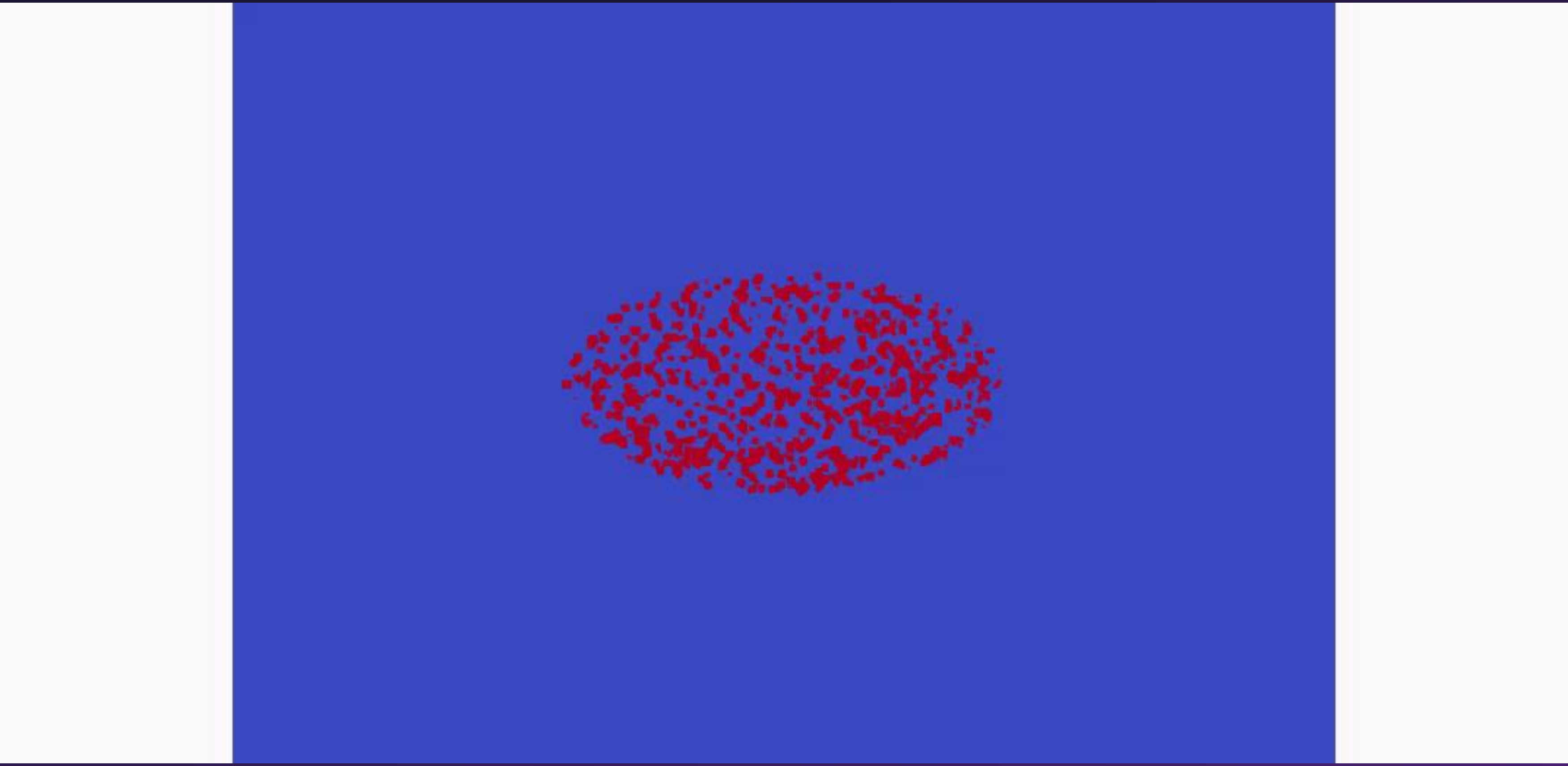
Cycles



Crack Nucleation ~ 10 000 Cycles

Material Imperfections – High Performance Computing

Peridynamics Simulation of Forging Flaw Fatigue Crack Nucleation Processes



Outlook

- High performance computing in support of FE efficiency/cost/emissions, power generation industry
- Material imperfections in large rotating forged components and cast blades
- Additive manufactured components, powder-based repair methods etc.
- Probabilistic models, transferability

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(ID: “Understanding Crack Nucleation”)