Production and Reliability Oriented SOFC Cell and Stack DesignProject PROSOFC

(Contract number 325278)

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PROJECT OVERVIEW

- Call topic: SP1-JTI-FCH-2012.3.2 – Improved cell and stack design and manufacturability for application specific requirements
- Application Area: Stationary Power Generation & CHP
- Start and end date: 01.05.2013 – 30.04.2016
- Budget
  - Total budget: 6,806,211 EUR
  - FCH JU contribution: 3,011,000 EUR

AVL

dynardo dynamic software & engineering

DTU

JÜLICH FORSCHUNGSZENTRUM

JRC EUROPEAN COMMISSION

KIT Karlsruher Institut für Technologie

Imperial College London

NEW ENERGY GENERATION SOLID POWER

HTceramix

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

New after TOFC closure

PROJECT OVERVIEW AND MOTIVATION

- Improving the robustness, manufacturability, efficiency and cost of Fuel Cell's state-of-the-art SOFC stacks so as to reach market entry requirements
- Key issues are the mechanical robustness of solid oxide fuel cells (SOFCs), and the delicate interplay between cell properties, stack design, and operating conditions of the SOFC stack.
- The novelty of the project lies in combining state of the art methodologies for cost-optimal probabilistic-based design (COPRD) with actual production optimization.
- Multi-physical modelling concepts must be developed and validated for significantly improved understanding of the production, conditioning and operation of SOFC stacks.
- This understanding is validating experiments and models on multiple levels of the SOFC system and introduction of extensive test programs specified by the COPRD methodology.

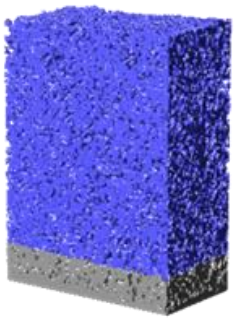
- Stage of implementation: 60 %

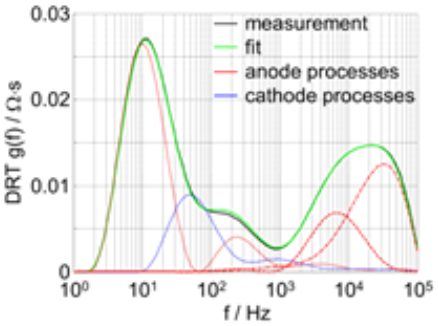
PROJECT TARGETS AND ACHIEVEMENTS

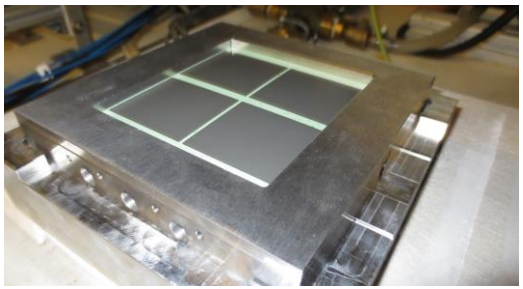
Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
AIP			
Better robustness, better lifetime, improved manufacturing methods	Identify major failure modes and link them to stack design and production using an statistical simulation approach	Major failure modes identified Statistical simulation model linked with stack model	Failure mode: 100 % Statistical approach: 100 %
Real life stack testing	Operation in real life environment >4000 h	On-going stack tests	4000 h test time reached: 80 %
Cost reduction	<500 EUR/kW at 50 MW production	New partner	Possible at high volume and improved stack robustness
Improved manufacturing methods	Yield rate: 95%	New partner	New partner

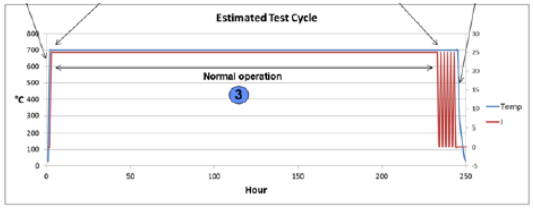
PROJECT TARGETS AND ACHIEVEMENTS

- Common understanding of the methodology for a probabilistic based design optimization approach achieved. Development chain “experiment – homogenized modelling – 3D modelling – probabilistic sensitivity analysis” for design optimization established.
- New multi-scale SOFC stack modelling concept achieved and demonstrated. Calculations about 10^3 faster than standard. This has made it possible to apply COPRD to investigate which parameters are sensitive to the failure of SOFC stacks.
- Microstructure reconstruction for material characterization and electrochemical characterization of single cells for ASR modeling performed
- 7 main failure modes identified and partly modeled for reliability development
- New single cell testing equipment for “close to reality” conditions developed to support CFD simulation









RISKS AND MITIGATION

- Project delay
  - Due to TOFC closure project was significantly delayed
  - Htceramix/SOLID power and EPFL to replace TOFC
  - Transition of results to new stack design
  - Project extension of 1.5 years is asked for
- Stack testing
  - 4000 h stack testing planned to test failure modes. Stack failure cannot be excluded beforehand
- Linking failure modes to design and manufacturing processes by statistical simulation
  - 3D model development progress too slow.
  - Additional AVL support to increase simulation capacity
  - CORPD analysis to be started with simpler 2D structural multi-physics model
- Identification of major failure modes
  - New failure mode may come up during project
  - Can be implemented also at later stage

SYNERGIES WITH OTHER PROJECTS AND INITIATIVES

- DTU is covered partly (33%) by national funds.
- EPFL is covered (100%) by national funds.
- For the development of the reliability program in WP5 and the stack simulation in WP4 AVL will make use of the experience for stationary systems gained in METSOFC, METSAPP and CATION.
- Next to fuel cell testing methodologies developed in FCTESTNET and FCTESQA, knowledge on single cell testing gained in other projects as SOFC600, METSOFC and METSAPP will be of great importance for the work of KIT in this project.
- Imperial has developed expertise in 3D characterization of the microstructure of Ni/YSZ anodes on SOFCLIFE which will be used in PROSOFC.
- The mechanical testing methodologies developed and implemented in the EU projects REAL-SOFC, CORE-SOFC, NASA-OTM, SCOTAS and HETMOC will be of importance for the Jülich contribution in the project.

DISSEMINATION ACTIVITIES

- Closed workshop on simulation approach, September, Lyngby, 2013
- 1st invited workshop on SOFC mechanics, Lucerne, 2014
- PROSOFC Poster at the FCH-JU review programme day, Jürgen Rechberger (AVL), Nov. 2013
- PROSOFC Poster at the FCH-JU review programme day, Peter Prenninger (AVL), Nov. 2014
- Article on Danish National News ("Fuel Cells of the Future Withstands Everything" ☺), Dec. 2013
- PROSFOC presentation at IEA Modeling Annex, Jülich, Jan. 2015, Henrik Lund Frandsen (DTU)
- Presentations at the 39th Intern. Conf. and Expo on Advanced Ceramics and Composites, Daytona, Jan. 2014
  - Mechanical properties of sealants and cells, Jianping Wei (Jülich)
  - Mechanical Properties of Ni-YSZ Anode Materials for Solid Oxide Fuel Cells , De Wei Ni (DTU)
- Invited talk at EMN Ceramics Meeting 2015, Jan. 2015, Kawai Kwok (DTU)
- Journal Papers
  - "On the measurement of ceramic fracture toughness using single edge notched beams", X. Wang, and A. Atkinson, J. European Ceramic Society 35 (2015) 3713-3720.
  - "Measurement of Mechanical Properties Using Slender Cantilever Beams", L.J. Vandeperre, X. Wang and A. Atkinson, submitted to J. European Ceramic Society (2015)
  - Greco, F., Frandsen, H. L., Nakajo, A., Madsen, M. F., & Van herle, J. (2014). Modelling the impact of creep on the probability of failure of a solid oxide fuel cell stack. Journal of the European Ceramic Society
  - Wei, J., Pećanac, G., & Malzbender, J. (2014). Review of mechanical characterization methods for ceramics used in energy technologies. Ceramics International, 40, 15371–15380.
  - Kwok K, Jørgensen PS, Frandsen HL.(2015) Computation of effective steady-state creep of porous Ni-YSZ composites with reconstructed microstructures. Journal of the American Ceramic Society

DISSEMINATION ACTIVITIES

- Papers in the proceedings of the European Fuel Cell Forum, Lucerne 2014

1. *Topology Optimization based homogenization technique for stack designs with complex geometry*
   Yuriy Elesin, Mads Find Madsen and Thomas Karl Petersen (TOFC)
2. *Thermo mechanical FEA of SOFC*
   Matej Smolnikar, Vincent Lawlor, Paul Siegfried Hassler, Mario Brunner, Hannes Hick, Kurt Salzgeber & Juergen Rechberger (AVL)
3. *Accelerated creep of Ni-YSZ anodes during reduction*
   Henrik Lund Frandsen, Fabio Greco, Malgorzata Molin, De Wei Ni, Peter Vang Hendriksen (DTU)
4. *Micromechanical Modeling of Solid Oxide Fuel Cell Anode Supports based on Three-dimensional Reconstructions*,
   Kawai Kwok, Peter Stanley Jørgensen, and Henrik Lund Frandsen (DTU)
5. *Development of residual stresses in a multi-layer tape-casted Solid Oxide Fuel Cell after sintering*
   Benoit Charlas, Christodoulos Chatzichristodoulou, Kawai Kwok, Henrik Lund Frandsen (DTU)

EXPLOITATION PLAN/EXPECTED IMPACT

- SP will establish a stack manufacturing line with a capacity of 50 MW annually within the next 3 years. This manufacturing plant is expected to create about 100 direct jobs at SP. Core strategic manufacturing partners have and will invest in their respective equipment and tooling; a similar number of jobs will be created at their offices, and the core suppliers are all based in Europe. One important conditions to construct the manufacturing plant is to achieve a sufficient level of confidence of durability and robustness of the stacks, i.e. confidence and validation of the expected stack life-time (20'000 hrs according to the business plan). Successful execution of PROSOFC will strongly consolidate the level of technical confidence to implement such a manufacturing line.
- AVL sees increasing customer interest for stationary SOFC systems in the 10 – 1000 kW range. AVL as a system integrator will benefit from a successful project regarding the availability of robust and cost-optimized stacks. This is a major step for the commercialization of SOFC systems. Furthermore, the experience which will be gained by the development of the reliability program will have a direct impact on commercial system development projects. AVL will also further develop its commercial CFD simulation tool "AVL Fire" towards full stack simulation.
- DYNARDO will use the results to prepare the market entry with their products in the – for DYNARDO – new field of fuel cell technology. DYNARDO will make use of the PROSOFC results in the development process for specific modules and tools within their proprietary software package optiSLang. The software will then contain additional analysis capabilities such as the treatment of spatially correlated random properties and processes which can be applied in different engineering fields. DYNARDO will license these tools to third parties.
- For KIT, DTU, JRC, IC and Jülich as a research organization their work does not create a direct commercial impact on their "products" but there will be an "exploitation" with respect to scientific publications and a further increase of our knowledge in the field of SOFC testing, characterization and modeling, which will be used in new projects in the future.