Overview of ID-FAST

Investigations on degradation mechanisms and Definition of protocols for PEM Fuel cells Accelerated Stress Testing
Overview of ID-FAST & status at mid-term

- Objectives
- Approach
- Organisation
- Overview of technical progress *(survey 2020)*
- Development of ASTs & Approach towards standardization
The objective of this project is to support and promote the deployment of fuel cell vehicles, through the development of Accelerated Stress Tests (AST) of Proton Exchange Membrane Fuel Cells (PEMFC) components and associated transfer functions allowing to predict the performance degradation during real world operation, and accelerating the introduction of innovative materials in next generation designs.
Objectives & concept

1. Identification of real ageing degradation mechanisms and quantification of their impact, as the basis for the identification of stressors and the development of relevant ASTs

2. Development and application of performance degradation models integrating several degradation mechanisms, for the simulation of accelerated ageing, as a tool for the development and validation of combined ASTs

3. Development and validation of ID-FAST methodology: AST protocols and transfer functions correlating accelerated degradation to real world degradation.

From real ageing data to real ageing prediction

- Identification and analysis of real ageing degradation data: performance decay & mechanisms
- Definition and simulation of stressors effects and accelerating protocols
- Validation of developed AST by correlation with real life ageing
- Proposal of ASTs & transfer functions
- Relevance & lifetime prediction capability
Objectives & concept

“Real world” ageing: components & data from systems

Analyses of degradation phenomena & mechanisms

Component single mechanisms AST SoA & New

Investigations of stressors impact (acceleration) & coupling

ID-FAST combined AST protocols

Validation of relevance (mechanisms & acceleration) at single cell level

Validation of correlation to Real World via Specific Stressing Tests on Stack

REAL ageing on stack

TRANSFER FUNCTIONS

\[ \mu V/h_{\text{REAL}} = TF (\mu V/h_{\text{ID-FAST}}) \]

Two major items for demonstrating the validity

1/ Verification that the same mechanisms are involved qualitatively but also quantitatively
   Representativeness (same alteration of components along with quantitatively consistent degradation of functional properties)

2/ Confirmation that real performance losses can actually be accelerated and also predicted
   Outcomes allowing suitable prediction of stack lifetime is expected as valuable exploitation
How to address representativeness

Most important is accuracy of correlation with real-world data

No meaning to consider even very quick AST tests if not representative of real ageing
PEMFC studies

How to address representativeness

Starting point

Gather aged components from stacks with known operational history and related ageing data

Ageing investigations
(In situ, ex situ experiments & simulation )

Samples from previous projects + SoA stack and components

Realistic Protocols
Load cycles + events

AST Protocols
Load cycles + events

99 kW max cont
114 kW peak (30sec)
(30% N₂ in H₂, 335)

5 kW FC system + 44 kW battery (+ 200 bars hydrogen storage)
Planned method

How to address prediction

Fuel Cell performance evolution / degradation rate during real ageing?

ID-FAST = combined AST
\( f(AST_i, str_i) \)
AST\(_i\) = single AST / component

Increased performance losses
Higher degradation rate \( \mu V/h_{ID-FAST} \)

Direct link

Nominal performance losses
Nominal degradation rate \( \mu V/h_{REAL} \)
From real world aged samples of cells from stacks aged in real systems,

→ AST to reproduce ageing mechanisms inducing faster performance decrease
   (superposition or combination of degradation modes and actual acceleration)

✓ 1\textsuperscript{st} step: validation at single cell level by comparison of AST & real ageing
   → Transfer function (F) with generic validity [public outcome]

✓ 2\textsuperscript{nd} step: validation at stack level of Specific Stressing Test (SST) vs. AST in SC
   → Heterogeneities taken into account / design related [thus non-public outcome]
   → Methodology to define the associated transfer function (G) [public outcome]
# Technical Plan & WPs

**Focusing on scientific and technological R&D activities**

<table>
<thead>
<tr>
<th>4 Main steps</th>
<th>Aim</th>
<th>WPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification or confirmation and quantification of degradation phenomena (morphology, composition and properties of components) involved in real ageing</td>
<td>Determination of major causes of components degradation for real aging case in correlation with operating conditions</td>
<td>WP1 and WP2 mainly</td>
</tr>
<tr>
<td>Analysis of stressors and of their accelerating factor for each single mechanism AST</td>
<td>Identification of stressors and quantification of their impact on degradation</td>
<td>WP2, WP3 and WP4</td>
</tr>
<tr>
<td>Analysis and development of combined AST protocols (superposition of degradation modes and acceleration through coupling)</td>
<td>Definition of combined AST with regard to their relative impact</td>
<td>WP2, WP3, WP4 and WP5</td>
</tr>
<tr>
<td>Validation of combined ASTs and development of transfer functions to link AST ageing in single cell to real ageing in stack, with realistic lifetime estimation</td>
<td>Validation of correlation to real world ageing and definition of a methodology to predict stack lifetime</td>
<td>WP1, WP2, WP3, WP4 and WP5</td>
</tr>
</tbody>
</table>
WP organisation

WP1 (ZSW)
Real ageing data base: stack components and performance

WP2 (DLR)
Ex-situ characterization of aged samples

WP3 (CEA)
Modelling of ageing mechanisms and simulation of ASTs

WP4 (POLIMI)
Development of AST methodology and transfer function (to real world data)

WP5 (CEA)
Application and validation of AST protocols and transfer functions

WP6
Communication, Dissemination and exploitation

WP7
Management

Advisory group
Partners from industry & R&D
• with interest in later application of the results
• Support and comment of the AST actions
WP organisation

WP1
Real ageing data base: stack components and performance
- Selection and supply of samples aged in real systems (incl. ageing conditions and profile)
- Definition of i) the SoA stack and components for ageing investigations and ii) SoA ageing tests representative of real systems
- Ageing test on SoA components in real conditions

WP2
Ex-situ characterization of aged samples
- Definition of the methods (electrochemical & physico-chemical) and of samples
- Characterization of non aged samples
- Characterization of samples from real ageing in cells and stacks
- Characterization of aged samples from AST

WP3
Modelling of ageing mechanisms and simulation of ASTs
- Modeling of ageing mechanisms
- Analysis and simulation of multi-mechanisms degradation modes
- Simulation of AST including main observed degradation mechanisms

WP4
Development of AST methodology and transfer function* (to real world data)
- Specific single cell hardware definition
- SoA and Development of single cell components AST
- Investigation of stressors and coupling effects
- Analysis of coupling between degradation mechanisms in single cell
- Identification of transfer function from AST to real aging in single cell
- Method to identify the transfer function from aging in single cell to stack

WP5
Application and validation of AST protocols and transfer functions
- Application of combined AST protocols in single cells
- Validation of AST and transfer function from AST to real aging in single cell
- Application of combined stressing protocols in stacks
- Proposal and validation of specific transfer function from AST ageing in single cell to real ageing stack

WP6
Communication, Dissemination and exploitation

WP7
Management

Advisory group
Partners from industry & R&D
- with interest in later application of the results
- Support and comment of the AST actions
Ind: JMFC (GB) – DANA (GE)
Lab: LANL (US) JARI (JP) UCONN (US)
More R&D or industry groups to be contacted (e.g. JRC)
Achievements (survey 2020)

3 major project achievements

- **Post-mortem** determination of **local degradations** and impact of ageing conditions, profiles or specific stressors applied in **real stacks or single cells**
- Advances in **methods to mimic real** states in stack and in diagnostics of catalyst layer-related reversible and irreversible electrochemical losses.
- Assessment of **new protocols** defined for ageing gas diffusion layers operando and for simulating start-up, by coupling modelling and experiments.

In addition

- **Good progress in the support to standardization bodies**: active participation to a new working group within IEC TC105 dedicated to ASTs (in collaboration with SOFC project Ad ASTRA) – **NWIP** to be proposed before end of the project.
3 Major difficulties (survey 2020)

- Delays in getting and setting-up the single cell hardwares originally planned for specific tests to assess and validate ASTs - Some delay induced on models validation, particularly for coupling aspects and definition of combined ASTs. Back-up solutions identified, other single cells selected and project extended by 1 year to recover.

- Difficulties in getting MEAs for stack testing to establish the real ageing data base with the selected reference components. Back-up solutions: MEA assembling with reference components taken in charge by a partner and other supplier identified particularly for the validation process with different MEAs - Tests of stack re-scheduled in line with project extension of 1 year.

- From the first period, less time, technical objects and information available to work on the analyses and AST development of metallic bipolar plates, apart from post-mortem analyses obtained about mid-term - some dedicated tests planned in a metallic single cell during the extension of 1 year.
Future plans and main expected steps (survey 2020)

- Getting more controlled real ageing data on reference stacks. Improving diagnostics for quantification of losses due to multi-mechanism degradation.

- Proposal of combined ASTs based on experiments/models – Check in single cells their impact on degradation rates and define transfer functions.

- Achievement of all couplings (>two mechanisms). Integration of simplified models in the macroscopic code. Long time simulations of all mechanisms

- Applying the validation process: post-mortem comparison of data between AST and real ageing for different MEAs, cells & stacks and AST refinement.

- Extend the approach to metallic bipolar plates as far as possible with specific analyses and tests to be defined/applied in a dedicated single cell.

- Go-on with the contribution to standardization of ASTs for PEMFC with ID-FAST outcomes and involved partners
Technical progress by WP - Selected items

- From MTR presentation
Ageing and degradation characterizations

- Selection of aged samples from stacks of previous projects
  
  
- Specification and application of endurance test protocols reproducing real ageing in controlled conditions

  Single cells & stacks

→ Assessment of phenomena to support modelling and empirical AST developments
Ageing and degradation characterizations

- Selection of aged samples from stacks of previous projects
  
  CF. WP1 & 2

- Post-mortem specific analyses on each stack component
  
  CL, GDL, Membrane, BPP samples
  
  Spatially & vertically resolved distributions
  
  Elemental compositions / Morphology changes / Properties changes

Electron microscopy on the CCM and Pt catalyst

Electrochemical measurements on aged MEA samples from stacks

Pore Size Distribution of GDLs

IR thermography on BiPolarPlates

Assessment of phenomena to support modelling and empirical AST developments
Modeling of MEA components

- Modelling of MEA material degradation mechanisms
  - Pt nanoparticles degradation
  - Corrosion of carbon support related to Start-Up / Shutdown
  - GDL material degradation impact on properties
  - Membrane degradation implemented in cell model

First coupling of single mechanisms
- Effect of catalyst degradation onto membrane chemical degradation
- Effect of catalyst layer degradation (ECSA) on SU impact (C corrosion)

Assessment of stressors impact / Support to AST development and validation
Development of new ASTs

- GDL AST
  - SoA data about impact & ex-situ tests
  - New in-situ tests & method to assess impact of identified stressors

- Start-up AST
  - Similar impact confirmed by comparison to real start-up

→ AST development before further combination and validation
Technical achievements - Selected items

- From material supplied for PRD2020
Development of specific single cell hardware for protocols validation

Legend: Differential Single Cell drawing
AST development and ex-situ characterization

Legend: ”ID-FAST post-mortem analyses by Electron Microscopy – Effect of SU/SD ”
Modelling and validation of local conditions in a selected cell design

Legend: ID-FAST simulation of ASC cell design - Current density distribution
Development and validation of models for components properties simulation

Legend: modelling and simulation of GDL properties
Coupling of models for the simulation of multi-mechanisms degradation

Legend: Scheme of the coupled catalyst and membrane degradation model
### Analysis of SoA mechanisms and AST

**Aim:** to propose new conditions and/or new protocols applicable for in-situ operando tests

<table>
<thead>
<tr>
<th>AST</th>
<th>Mechanisms</th>
<th>Reference AST</th>
<th>Improvement</th>
<th>Indexes (Measurement technique)</th>
</tr>
</thead>
</table>
| Cathode activity loss        | PGM dissolution and ripening             | DOE, IEC, JARI Based on potential cycling    | potential limits, slew rate, wave form and flow rate | • Mass activity  
• ECSA loss (CV)  
• mass transport R (lim. I)  
• ionomer conductivity (EIS) |
| Cathode Catalyst support degradation | Carbon corrosion  
Consolidated for cathode, but stressors not fully understood | DOE, IEC, JARI  
Consolidated, based on OCV and humidity cycling | Based on potential cycling or simulated start-up     | • Mass activity  
• ECSA loss (CV)  
• mass transport R (lim. I)  
• ionomer conductivity (EIS) |
| Membrane                     | Chemical and mechanical degradation      | DOE, IEC, JARI Consolidated, based on OCV and humidity cycling | Not a priority                                       | • Hydrogen crossover  
• Ion conductivity  
• Electric resistance |
| Porous layers degradation    | Hydrophobicity loss, mechanical ageing   | Ex-situ not harmonised                       | in-situ AST                                          | Not defined                                                        |
| Bi-polar plates degradation  | Corrosion                                | Ex-situ not harmonised                       | Ex-situ and in-situ                                  | Not defined                                                        |
Development of ASTs & Approach towards standardization

- Approach to link « real » life and ASTs: definition of a transfer function

Aim: to enable reproducing but faster cells performance degradation and predicting losses expected when ageing the cells in conditions representative of real usage.
AST protocols & Standardization approach?
To be considered within IEC TC 105 AHG11 Working Group

- **Mechanisms**
  - Single mechanism / single component → SoA ok
  - Coupling of mechanisms → less knowledge

- **Conditions or stressors**
  - **Generic**
  - **Specific**?

- **Procedure**
  - Single / Multiple profiles / Combination?
  - In-situ / operando ... ?
  - Included diagnostics: electrochemical / post-mortem ex-situ?

- **Validation process included?**
  - Criteria for representativeness?
  - Boundaries for materials and components?
  - Boundaries for the hardwares?
  - Prediction considered?
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