# PhD proposition

**Title of thesis:** MICMAC - Impedancemetrical Monitoring of Bonded Assembly Ageing

**Laboratories :**

Institut de Recherche en Energie Electrique de Nantes Atlantique (IREENA – UR 4642)

Institut de Recherche en Génie-Civil et Mécanique (GeM – UMR CNRS 6183)

**Description of the subject:**

Bonded assemblies are now an attractive alternative to welded or bolted solutions. This multi-material assembly method distributes stresses without substrate modification (drilling, heating, etc.), thereby saving weight.

However, there are many preconceptions about the reliability of bonding. In particular, its sensitivity to thermo-hydro-mechanical stresses limits its durability. It is therefore essential to develop characterisation techniques that can be used both to certify the quality of a bonded assembly at the end of the manufacturing process and to check that the assembly is in good material condition during in-service monitoring.

The water content field is generally identified by macroscopic gravimetric monitoring and then calculated using an identified mathematical model. Recently, a method of measuring the refractive index using fibre optics has been developed which allows the local water content to be estimated. This method has shown interesting results, but remains intrusive and requires specific instrumentation.

In addition, the literature shows the presence of an interphase layer between the adhesive and the substrate, where water diffuses more rapidly and accelerates the degradation of the assembly [4,5]. Despite some clues in the literature, understanding the origin of the mechanism(s) involved is still rather difficult, mainly due to the difficulty of tracking the local water content field.

This project proposes an innovative method to identify the water content and its gradient by obtaining a map of the complex permittivity of the polymer adhesive using electrochemical impedance spectroscopy [1]. This water content field will be obtained by model inversion based on electrical impedance measurements between different judiciously placed electrodes.

Figure 1 summarises the proposed approach. It includes a number of elements:

- Literature study (problems of wet ageing of polymeric materials, method of characterisation of water content, method of characterisation by impedance measurement, electrostatic modelling).

- Definition of the experimental framework (choice of materials and geometry, ageing conditions).

- Determine the mixing law to obtain electrical permittivity and charge factor as a function of water content [2].

- Develop a numerical electrostatic model to obtain the inter-electrode capacitance matrix. This model could be based on the floating potential method [3] or any other method deemed relevant after a literature review phase.

- Optimise electrode shapes and dimensions to increase sensitivity to different diffusion laws.

- Implement a model inversion procedure.

- Establish an experimental measurement protocol to determine the water content field.

- Validate the field obtained by other experimental means (macroscopic measurement and use of model, local measurement by optical fibre [4-5]).

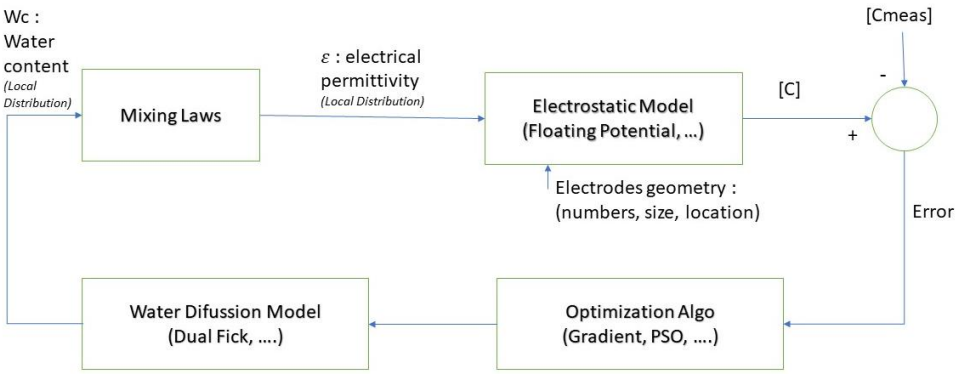


Figure 1 : Methodology

The originality of the project lies in the development of a non-intrusive, unbiased method for identifying the water content field at the heart of the material. In this way it will be possible to improve the ageing monitoring of all materials in a humid or submerged environment, in particular those used in the MRE context (bonded assemblies, submarine cable insulation), and the results will contribute to the identification and development of new water diffusion models that will allow the most accurate prediction of the life of materials.

The dual approach of modelling and measurement is key to the success of this project, where initial measurements in a highly controlled and simplified environment will validate the modelling hypotheses. The models will then be used as an invaluable aid in adjusting the measurement protocols to ensure good sensitivity. These different iterations will help to define the validation limits of the results.

References:

- [1] S. Chevalier, B. Auvity, J. C. Olivier, C. Josset, D. Trichet, M. Machmoum, “Detection of Cells State-of-Health in PEM Fuel Cell Stack Using EIS Measurements Coupled with Multiphysics Modeling”, Fuel Cells journal, Volume 14, Issue 3, pages 416–429, June 2014

- [2] Sihvola, A. (2000). “Mixing rules with complex dielectric coefficients. Subsurface sensing technologies and applications”, 1(4), 393-415.

- [3] Konrad, Adalbert and M. Graovac. (1997) “The floating potential approach to the characterization of capacitive effects in high-speed interconnects.” IEEE Transactions on Magnetics 33: 1185-1188

- [4] Grangeat, R., Girard, M., Lupi, C., Leduc, D., & Jacquemin, F. (2020). Measurement of the local water content of an epoxy adhesive by fiber optic sensor based on Fresnel reflection. Mechanical Systems and Signal Processing, 141, 106439.

- [5] Grangeat, R., Girard, M., Jacquemin, F., & Lupi, C. (2022). Method of characterizing the interphase’s mean water diffusion properties of a bonded assembly in immersion. The Journal of Adhesion, 98(3), 207-226.

**Job**

Planned start date: beginning of academic year 2024

Funding method: Public (regional call for projects + Weamec)

**Profile required:**

M2 research degree or equivalent in materials, electrical engineering or physics.

A multidisciplinary profile in these fields will be particularly appreciated.

An aptitude for modelling and experimental practices.

Excellent ability to synthesise information and good writing skills

A good level of English

**Location:**

IUT Saint-Nazaire / CRTT

(57 rue Michel Ange 44600 Saint-Nazaire; 37, boulevard de l'université 44600 Saint-Nazaire)

**Recruitment procedure:**

Send your application, including CV, covering letter and M1 and M2 grades, to the contacts below by 10/07/2024.

**Contact and supervision:**

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