MIFACRIT

Methodology Toolbox for Accelerated Fatigue Testing of FRP Materials: Micro-structural Failure Criterion for Multi-axial Fatigue of FRP structures

State of the art – Background

Smart lightweight structures are among the keys meeting the global challenges. In mobile structures like cars or airplanes, the reduction in mass directly turns into lower energy consumption. A favorite approach is to replace metals by fiber reinforced polymers (FRP). The possibility to additional integration of smart systems into these FRP structures can provide active health monitoring. Passive safety measures can then be stripped down resulting into further mass reduction. Besides this, embedded smart systems can add many more functionalities to the FRP structures. Sensors may multiply: gauge acceleration, pressure, and temperature right at the surface of the structural parts, surveillance features may permanently check the surrounding area visually, by infrared, or by radio frequency, and communication systems may interact with the neighboring objects. When integrating smart systems of second or third generation, the FRP structures can spontaneously establish, restructure, and leave networks of autonomous nodes as, for example, needed for collision avoidance and traffic flow optimization. These smart lightweight structures will then be real cyber physical systems with direct access to the universal internet of things. They will become an important part of the hardware base that brings today's visions, strategies, and concepts for mastering the global challenges of public mobility, energy, safety, and health to life within the next decade.

Creating such lightweight structures with embedded smart systems, a large number of very different materials will be combined at minimum space. The structures will be exposed to changes and gradients in temperature, moisture content, as well as to external static and dynamic forces in all phases of their life, i.e., during fabrication, test, and service. Fatigue and damages will be the consequence ultimately leading to fracture and failure of the system. Therefore, the thermo-mechanical reliability is of vital concern. It needs to be addressed right from the beginning of research on smart lightweight structures also accounting for the various process and environmental conditions. A systematic and scalable set of methodologies and techniques is required. It must be capable of keeping pace with the growing complexity in failure sites and reliability risks when more and more functions are added to the systems.

Objectives

The MIFACRIT project aimed at developing a failure criterion for fiber reinforced plastics (FRP). This criterion shall enable reliability and durability assessments of structural parts and systems of multiple stack-up structures. It shall be deduced from mechanical effects within the microstructure of the fiber reinforced polymer structures in order to cover various mechanical loading conditions. This ambitious goal is achieved through a symbiotic combination of experimental testing and analysis work based on numerical simulation using fracture/damage mechanic concepts.

Description of work

The project is divided into 5 Work Packages (WPs): WP 1 - Test, WP 2 - Simulation, WP 3 - Criterion, WP 4 - Validation, WP 5 - Management. WP 1 and 4 are dominated by experiments while the other two packages are dominated by simulation and theoretical work. MIFACRIT follows the 'V' approach of project structure. It starts with the definition and specification phase in WP 1, in which the inputs of the Clean Sky working group in terms of specific requirements are adopted and the material handed out is analyzed. Then, MIFACRIT proceeds via the simulation preparation, execution, and evaluation steps (WP 2 & 3) to finally arrive at the validation phase (WP 4), which provides results that are readily implementable into the larger effort of the CleanSky working group, i.e., as substantial contribution to the expansion of the lifetime assessment methodology for FRP structures accounting for arbitrary multi-axial loadings.

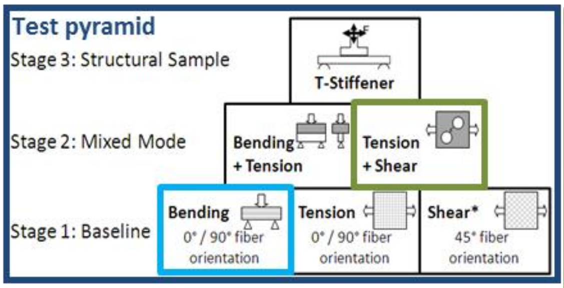
While following the clear path along the 'V', the project MIFACRIT is structured in an upper and a lower part. The upper part is dealing with experiments, i.e., with real objects, at the beginning and the ending stages of the project in order to serve as interface to the real world concerns. In between, the subjects are further studied, analyzed, and brought to solution by involving numerical simulation and in-depth mechanical assessments, which themselves are also backed up by tests and measurements for model calibration and result verification. This numerical computation work forms the lower part of the project structure.

Results

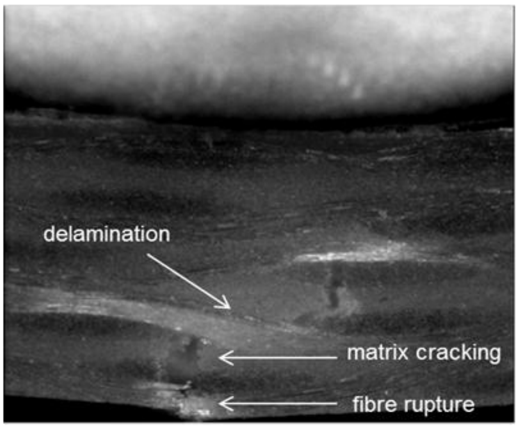
In the multi-load expansion step, the fracture tests in bending, tension, and shear mode have all shown very similar micro-structural failure modes. The failure simulation adopted in WP1 includes the prominent damage mechanism as fiber damage under tensile and compressive loading and matrix damage under combined tension/compression and shear loading situations. In the attempt of finding a proper mechanical criterion for the crack initiation in IS-400 structures, the scenarios have been extracted from the observations. Fiber/Polymer delamination or rather matrix damage due to shear failure dominates the crack propagation. After losing the support from each other, the fibers and/or polymer ligaments fail. The covering polymer film breaks at its minimum thickness first triggering the fracture of the fibers at the location of minimum support takes place first and causes the rupture of the thin polymer cover film. Mechanical criteria have been compiled for further in-depth analysis.

The realized procedure of capturing elastic properties as well as failure/damage properties of one-ply and multiply composites is in principal working. First testing samples showing combined loading stress situations in dedicated local areas have been experimentally investigated by simple tensile testing up to the point of complete rupture. Suitable FE models have been set up and simulated taking into account the captured elastic properties as well as failure/damage properties from previous work packages. The final failure pattern and also the follow up of damage/crack propagation trough the specimens reflected by the simulation results. Whilst these results are in a good agreement with experiments further enhancements are necessary to enhance the reliability of all captured parameters – the shear stress related properties especially. Dedicated experiments for shear loading could overcome the current uncertainties regarding this data.

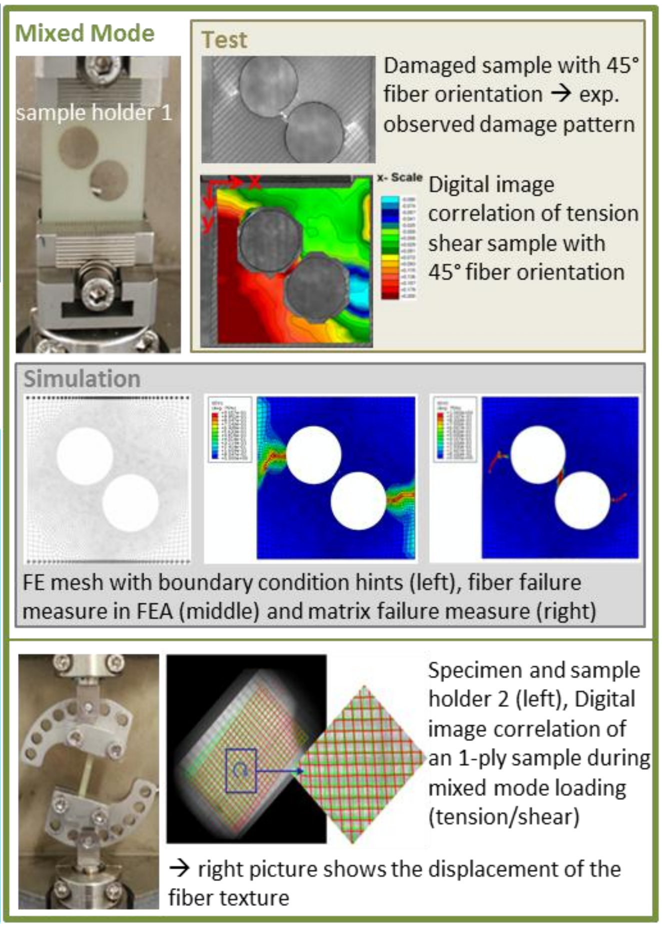
Altogether, the finalized work on upgrading the methodology toolbox shows a promising way to realistic estimations of fatigue and failure in the up-coming smart lightweight structures.



The WPs consisted of two complementary parts. One was the mechanical characterization of the delivered material IS 400, the second the extension of the tests to mixed mode loading and failure measure in FEA.



Crack propagation in a composite layup (IS 400, 5 ply) under bending load



Project Summary

Acronym:	MIFACRIT
Name of proposal:	Micro-structural Failure Criterion for Multi-axial Fatigue of FRP Structures
Technical domain:	Long life structures
Involved ITD	Eco Design
Grant Agreement:	323474
Instrument:	Clean Sky
Total Cost:	199.870,00 €
Clean Sky contribution:	149.903,00 €
Call:	SP1-JTI-CS-2012-01
Starting date:	01.09.2012
Ending date:	30.11.2013
Duration:	15 months
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