# DIGITAL TWIN FOR STRUCTURE HEALTH MONITORING OF SMART COMPOSITES : NUMERICAL APPROACH


A. Ragoubi[1,*], J. Casimir[2], J. Brocail[3], R. Le Goff[1] , A.Agazzi[1] and P.Dewailly[1]

1: Centre Technique Industriel de la Plasturgie et Composite, Centre technique, France
2: QUARTZ, Laboratoire de Recherche, France
3: ESTACA, Pôle Mécanique des Structures Composites et Environnement, Ecole d'ingénieurs, France,
*Corresponding author (ameni.ragoubi@ct-ipc.com)

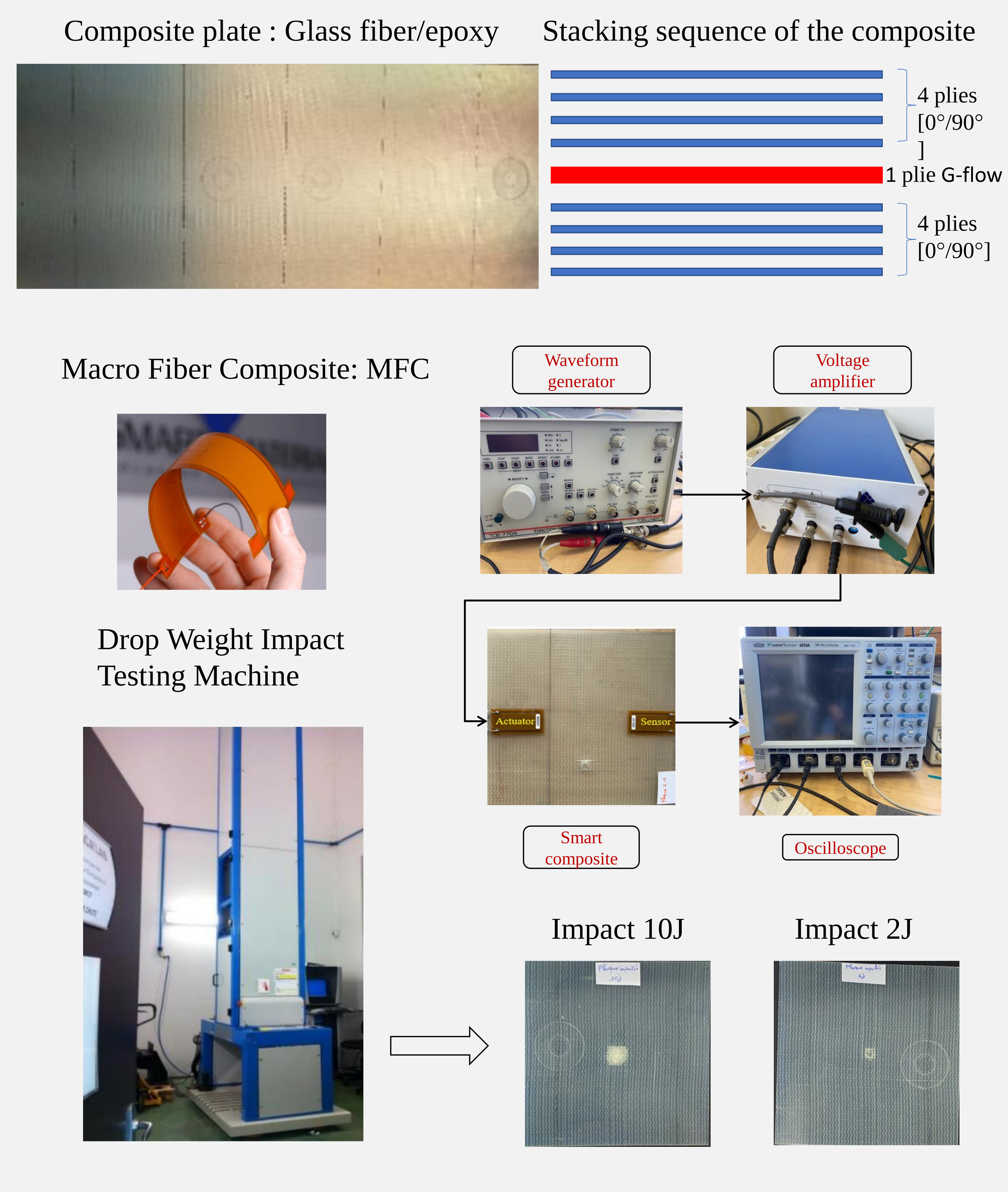

## Context

Structural health monitoring (SHM) has become increasingly used to detect damage in composite structures. Improved SHM methods aim to facilitate the identification and characterization of damage mechanisms. In this context, researchers are developing new SHM methods based on machine learning algorithms and digital twins [1,2]. These last have no single definition [3;4]. However, the most common one defines a digital twin as a virtual representation of a specific physical object, which uses data collected from that object to link the digital and physical parts. The approach in this work is based on the combination of numerical simulation tools and machine learning algorithms to develop a SHM method based on the digital twin.

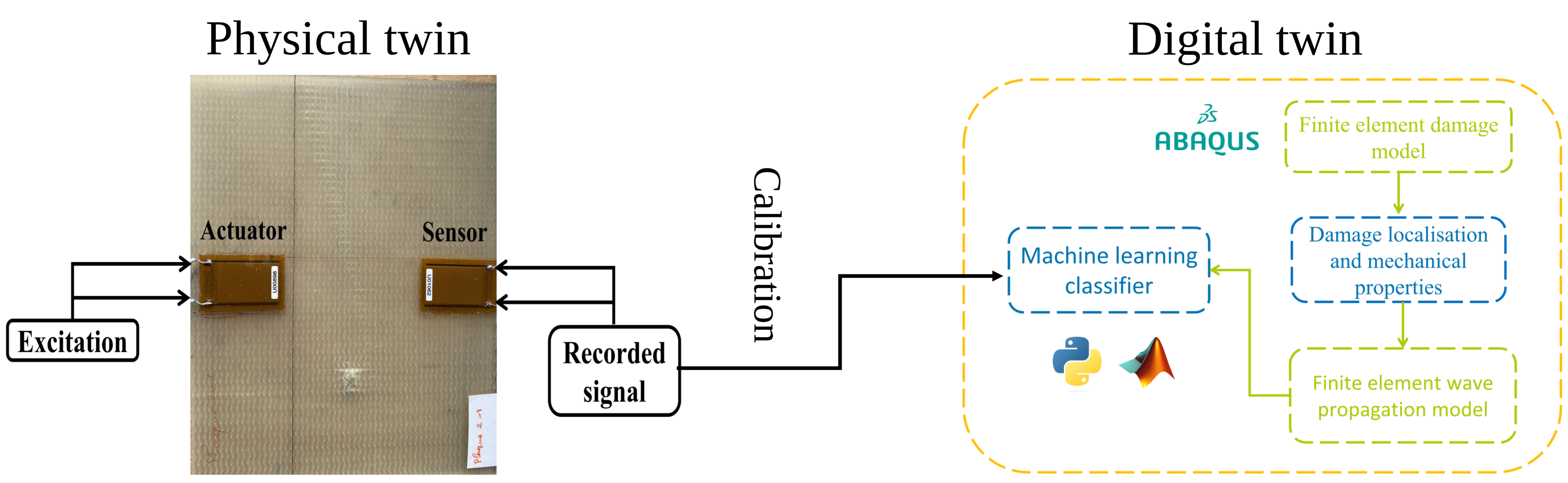
## Approach

The digital twin approach is based on two numerical models. The first one is a damage model allowing for generating multiple damage scenarios. The location of the damage and the mechanical properties of the damaged zone are then used as inputs for the wave propagation model to simulate the signature of each damage present in the structure. The physical model is a smart composite that enables real-time excitation of the component to collect data using sensors. These data are subsequently linked to the machine learning classifier to identify the presence of a defect and evaluate its remaining useful life.

## Material & Experimental setup




## Methodology



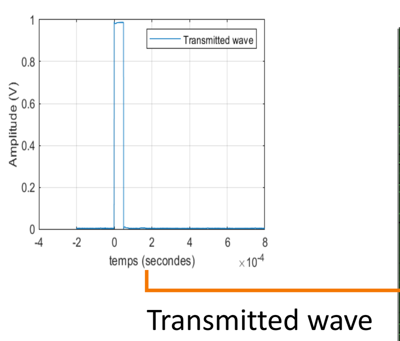

## Results

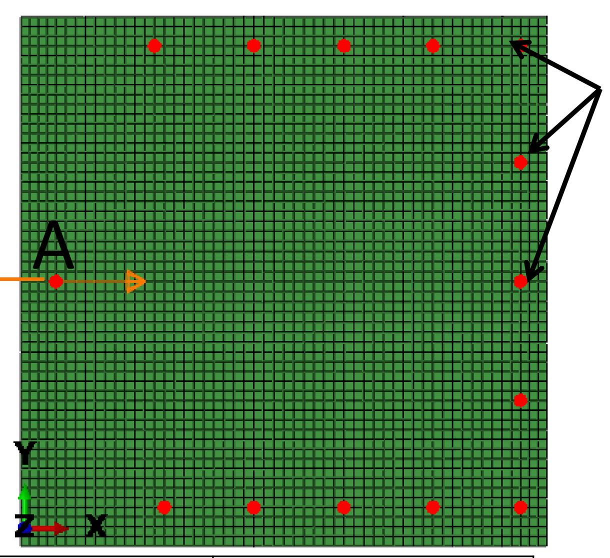
### Damage parametrization

In this work, the assumption considers that the damage becomes apparent at a larger scale as a localized decrease in stiffness. To take into account this assumption, the components of the stiffness matrix are calculated according to the damage factor d∈ [0,1]. Then the mechanical properties are updated after damage.

$$C=\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{12} & C_{22} & C_{11} \\ C_{13} & C_{11} & C_{33} \end{bmatrix} \Longrightarrow C(d)=d*\begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{12} & C_{22} & C_{11} \\ C_{13} & C_{11} & C_{33} \end{bmatrix}$$

### Finite element wave propagation model




The dimensions of the plate are:

- Length : 150 mm
- Width : 150 mm
- Thickness : 2.5 mm

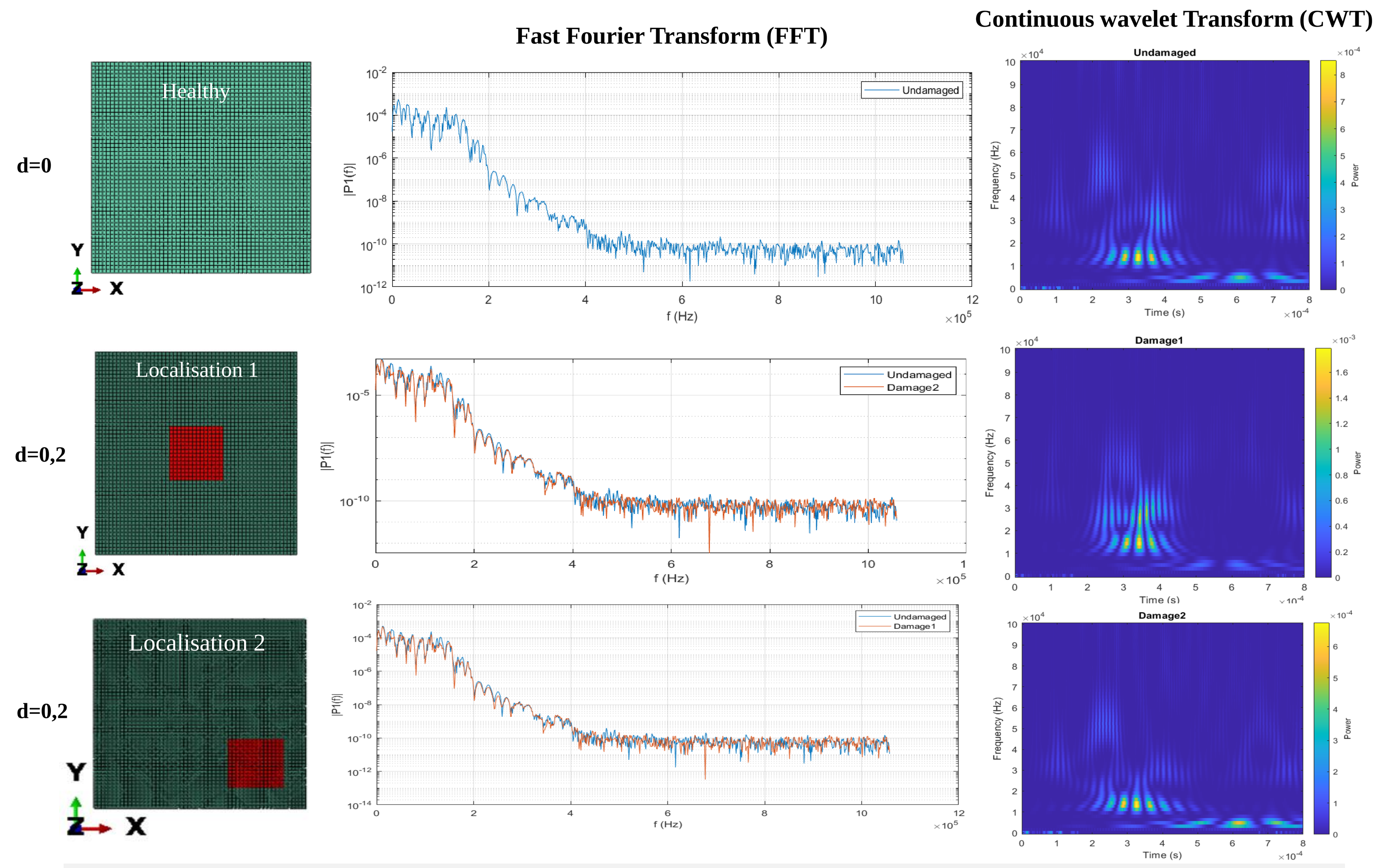
| Solver | Element type | Element number |
|---|---|---|
| Abaqus Explicit | C3D8R | 2916 |

Data for machine learning classifier

Sensors

| | Healthy | Location-min | Location-max |
|---|---|---|---|
| Healthy | Reference | - | - |
| dmin | - | FFT and CWT | FFT and CWT |
| dmax | - | FFT and CWT | FFT and CWT |

Damage factor : d∈ [0,1]
X-location: [width-min, width-max]
Y-location: [length -min, length -max]




The CWT function is used to perform a continuous wavelet transform to localize the signal components in time and frequency. This method concentrates the energy of the signal in specific frequency intervals, which helps to clearly specify the different frequency components of the signal and provides more accurate information about its distribution.

## Conclusions & Perspectives

In this paper, a damage scenario generation algorithm has been developed for a simple structure in order to validate the numerical damage signature detection method. A finite element model of wave propagation is used with the Abaqus Explicit solver to export the received wave signal in a structure under different conditions. A healthy structure is characterized by d=0 and hence its FFT and CWT provide a reference to identify damaged structure in the frequency band of interest. Future work will focus on the development of a numerical twin based on a machine learning classifier for the structure by changing the mechanical properties locally. Then, a damage model based on the Hashin criterion will be integrated into the numerical method in order to estimate the damage ratio after impact using a VUMAT user subroutine. Experimental tests will also be performed to validate the numerical models.

## References


[1] R.S.C. Coenen "A hybrid approach to implement the Digital Twin concept into a damage evolution prediction for composite structures". MASTER OF SCIENCE THESIS, the Delft University of Technology, 2021.
[2] T.G. Ritto, F.A. Rochinha "Digital twin, physicsbased model, and machine learning applied to damage detection in structures" Electrical Engineering and Systems Science, 2020.
[3] D. Jones, and al, Characterising the digital twin: A systematic literature review, CIRP Journal of Manufacturing Science and Technology in press (2020).
[4] D. Wagg, and al, Digital twins: State-ofthe-art and future directions for modelling and simulation in engineering dynamics applications, ASME in press (2020).