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To cite this version:

Jean-Noël Périé, Jean-Charles Passieux. FE DIC for strengthening the experiment/simulation dialog: application to composites. 8th International Conference on Structural Analysis of Advanced Materials (ICSAAM 18), Aug 2018, Tarbes, France. hal-01882758

HAL Id: hal-01882758

https://hal.science/hal-01882758v1

Submitted on 8 Feb 2019

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FE DIC for strengthening the experiment/simulation dialog: application to composites

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Abstract

Digital Image Correlation (DIC) nowadays appears as a very convenient counterpart to FE simulation for validation or identification purposes. Nevertheless, DIC strain resolution is high compared to the strains met in composite structures, and classical subset based DIC are not convenient to couple with finite element (FE) simulations. With the emergence of FE-Stéréo DIC (FE-SDIC) approaches, and the use of multiscale measurements, it now becomes possible to make objective and quantitative comparisons between computed and measured displacements. In addition, FE-SDIC also makes it possible to regularize the measurements using part of the model. This makes it easier to assess mechanically consistent boundary conditions. The example of the experiment/simulation dialog proposed structural test perfomed during the ANR VERTEX project is presented.

Keywords: Digital Image Correlation, Finite Element, Structural Test, Composites

1 Limitations of subset based DIC

Because of their multiscale architecture and the manufacturing process, composite structures exhibit very complex mechanical behaviors that are not all well understood and that are hard to incorporate into models. As a

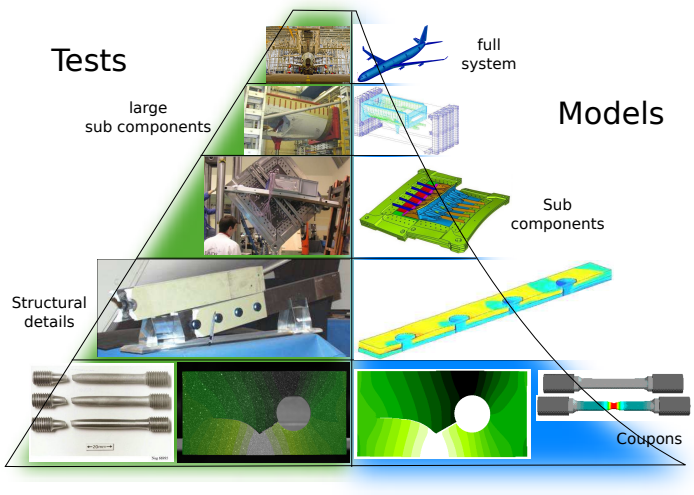

Figure 1: *Test pyramid: experiments and virtual testing*

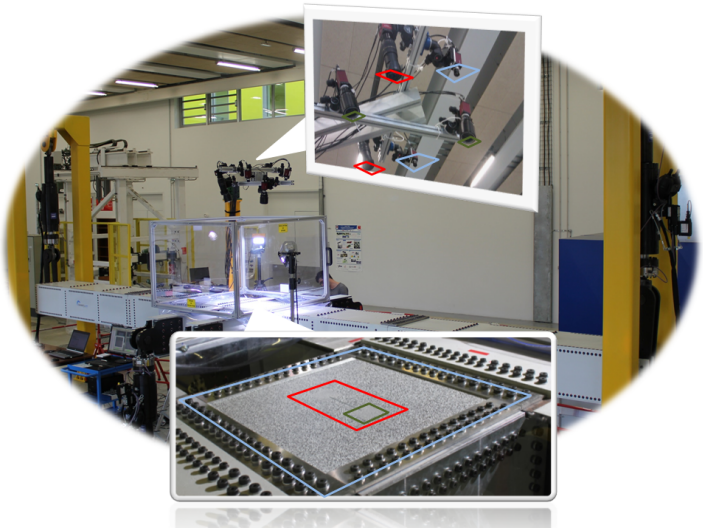

Figure 2: *Vertex bench and its associated instrumentation*

consequence, the certification of aerostructures still rely on the so called test pyramid (cf. Figure 1). In practice, the identification of the constitutive parameters usually rely on experiments performed at the lowest level of the test pyramid, and particularly at the coupon scale. In this case, standard testing and instrumentation (eg gages, extensometers) are resorted to study simple specimens that may not be very representative of the material present in the actual structures. The validation of the modeling is then achieved at higher levels, for instance on sub structures. Very specific specimens and experiments are then used and, up to now, quantitative compaisons between measured and computed strains are only based on a classical instrumentation.

Kinematic full-field measurements now allow to take a new insight at the mechanics of such structures. Due to its simplicity of use, its wide range of applications (shape and displacement measurements, large deformations, dynamics, etc.) and its unique ability to exploit different imaging modalities (microscopy, tomography, etc.), Digital Image Correlation (DIC) has become the reference full field measurement method. It has been widely used for validating FE simulations, although the comparisons often remain qualitative. The technique has even been used for identification purposes [1]. In this context, it seems appealing to exploit experiments performed on demonstrators (simpler to produce/reproduce than sub-structures, but still more representative than coupons) in situations more representative of their use (structural tests, multiaxial tests, etc.) to identify constitutive parameters.

The subset-based approach initiated in the 1980s remains the most common DIC technique. This approach is easy to handle and use, but it exibits several limitations. For example, even if he has a very low number of parameters to tune, the user has always to face a difficult compromise between spatial resolution and measurement resolution. By the way, the achievable strain resolution is limited in comparison with the strain observed in composite structures. In addition, this approach to DIC does not make interfacing DIC measurements and FE models easy. For instance, the strain spatial resolutions of both techniques are usually not comparable, the coordinate systems are different and no DIC information can be retrieved on the edges. Finally, such an approach can not take advantage of any relevant mechanical information.

2 FE-SDIC and structural testing

In the course of the 2000s, new formulations of the DIC (so-called global) were proposed. The displacement field is then interpolated in the whole Region Of Interest (instead than in subsets). Global DIC makes it possible to integrate a more or less important *a priori*, in particular on the mechanical behaviour. For example, the FE-DIC makes it possible to use a Finite Element description of the displacement field [2]. It is therefore possible, in theory, to exploit the optimized FE mesh built for simulation purposes. This provides the opportunity to avoid reprojection issues when comparing simulations and experiments [3], to integrate the model into the measurement in order to regularize it, or even to identify constitutive parameters directly from images (Integrated DIC).

It will be shown how these tools could help to couple strongly measurements and simulations in the context

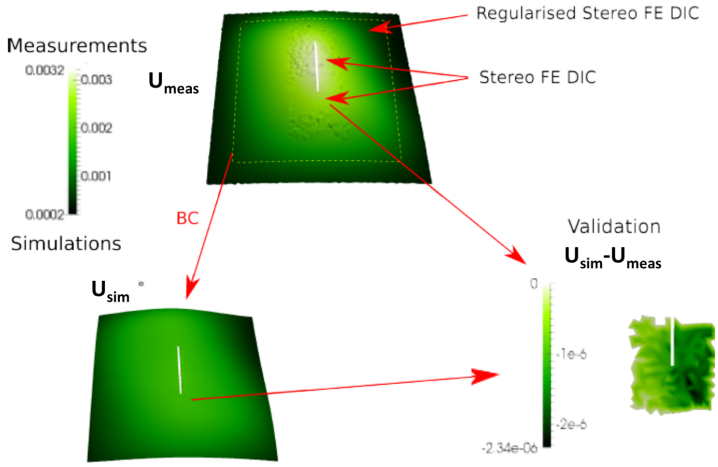

Figure 3: *Experiment/simulation dialog established by using a FE approach to stereo DIC*

of structural testing. For instance, the interest of a "multi-scale" instrumentation in the context of identification [3] will be demonstrated in a simple 2D case. A far field view allows estimating boundary conditions, while the addition of a near field view allows reducing drastically the measurement uncertainties for a given simulation mesh. The case of structural tests performed during the ANR VERTEX project will then specifically be detailed [4]. A large notched laminate panel is subjected to a complex biaxial loading thanks to a specific bench (cf. Figure 2). An original FE-SDIC method has been developped to treat such a 3D case [5]. A part of the specimen, outside of the damaged region, is assumed to remain elastic and is considerd as a test specimen ("load cell"). By using far field images, a regularised FE-SDIC gives access to mechanically consistent boudary conditions (cf. Figure 3) for the simulation. In the same time, near field images allow retrieving well resolved displacements while using the "fine" simulation mesh near the notch-tips (cf. Figure 3).

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