ANALYTICAL AND NUMERICAL METHODS TO ACCESS THE MECHANICAL ELASTIC PROPERTIES OF A DEFORMED WOVEN REINFORCED COMPOSITE MATERIAL

A. Lebrun[a]*, S. Joannès[a], J. Renard[a]

[a]*Centre des Matériaux, Mines ParisTech, CNRS UMR 7633 BP 87, 91003 Evry Cedex, France*
**adrien.lebrun@mines-paristech.fr*

Keywords: numerical simulation, analytical method, mechanical characterization, multi-scale, deformation of the reinforcement.

Abstract:

The mechanical properties of a woven reinforced composite material are dependent on the type of weaving as well as the fibre volume fraction. Due to the forming process, the fabric is deformed thus modifie the mechanical behavior once again. The present contribution deals with the characterization of such deformed structures. Nevertheless, for reasons of cost and feasibility, experimental characterization is very difficult. It is thus necessary to use another method to obtain a closest behaviour of the composite. New analytical and numerical approaches are proposed to obtain the mechanical properties of the sheared states of the woven composite. It is indeed extremely difficult to represent individual realistic cells for composite materials with a high fibre volume fraction of more than 50% with software presently available. Numerous analytical methods can be found in literature but these are most often dedicated to (but these can usually only be used on) specific fabrics and cannot easily be generalized.

1. Issues of the mechanical characterization taking into account the defects forming

Composites are interesting for their mechanical properties because they confer for an equivalent mass, a much better performance than most of other families of materials. The majority of composites are an assembly of two immiscible materials with a high adhesion capacity towards each other. This assembly results in properties far superior to those of just one of the materials. This improvement in properties leads to an increasing use of these "new" materials in the industrial world and particularly in the transport industry (cars, planes, trains…) or portable products.

As seen previously, the composite materials are generally composed of reinforcement, also known as “armour”, and a binder commonly called “matrix”. The former provides the mechanical strength while the latter ensures the cohesion and load transmission to the fibers. In a large majority of cases, the armor is composed of short or long fibres and the matrix consists of a thermoplastic or thermosetting material. In the remainder of this paper, the focus will only be on the long fibres. It should be noted, however that all three major of families of composites are found in long fibres: unidirectional (UD), woven or knitted. The following methods are suitable for woven or even knitted composites but not for UD.

The main objective of the use of a composite is for a weight reduction. However, for an optimal weight for a given structure, it is necessary to understand the material behavior perfectly. The more precisely the behavior of the composite can be measured, the more the safety factor can be reduced. That's the reason why experimental tests become more widespread over recent years. It is now possible to find a large number of tests in standards such as ISO and ASTM. In order to optimize more precisely the mechanical law, the following question on experimental tests must be mentioned: "Are they representative of the material within a structure?".

Unfortunately, there is not one single for answer to this question. It mainly depends on such parameters as the manufacturing process, the shaping of the structure and also the geometry of the part. For example, in the context of a thermoforming, we find some common defects such as inter-fiber shearing [1] due to the passage from plate to 3d geometric shapes. It is not possible to do this without causing such defects.

An example of a component from LYCOS (Lightweight hYbrid COmposite Structures) project by Faurecia is shown in Figure 1. In this kind of area, it would be very expensive to test experimentally the behavior of the material as it would require the creation of a large number of laboratory specimens disoriented.

Figure 1: Thermoformed parts in the project LYCOS

For all these reasons, a particular focus will be on its flaws. The method presented in figure 2 was set up to allow, from a thermoformed part, a numerical calculation for its response to mechanical stress. For this purpose an analytical method was developed and a numerical method implemented. These will be detailed later in this paper and a comparison of these two techniques will be established with experimental tests.

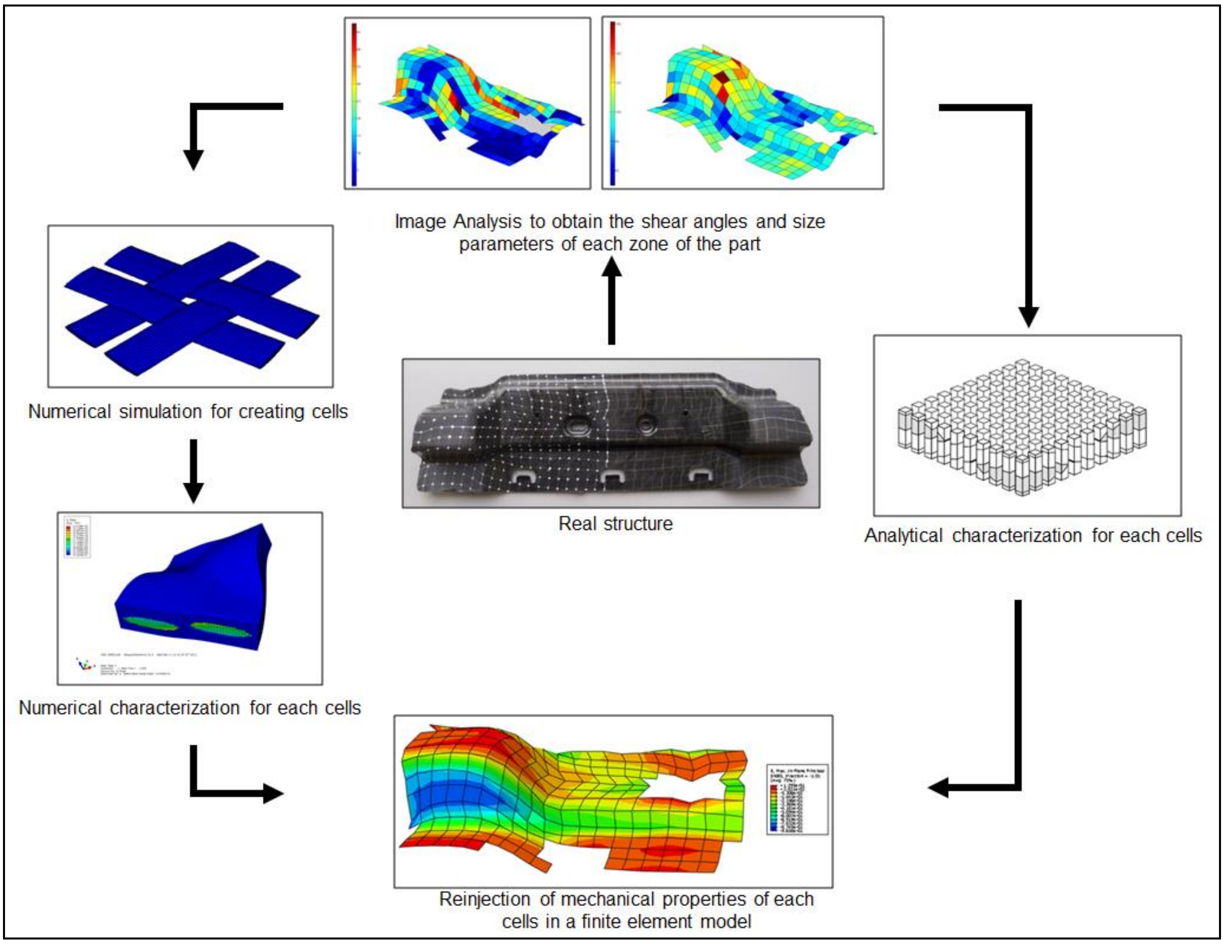

Figure 2: Calculation of the mechanical strength of a real structure

2. Characterization at the meso-scale numerically

Many of the mechanical properties of composite woven reinforcements, sewn or braided are directly dependent on the type of weaving as well and as the rate of fiber. Nowadays, there are a large number of methods and software (WiseTex [2], TexGen [3]), to obtain the reinforcement material geometry or mesh with varying degrees of accuracy. Even with these methods, creating geometry for weaving composite with high volume fractions is always problematic. This is why it was decided to search for a new method that can be generalized to any composite made with woven or knitted reinforcement. The result of the thought was the use of finite element methods.

The main objective of this numerical method is to reproduce realistic cells with a simulation of the weaving. However, displacements or loads to set up the simulation are very difficult to obtain and simulate. For that reason, the focus will be on a basic model and will not represent the reality during the ‘shaping’ in terms of stress or strain. Nevertheless, it will reproduce a final geometry very close to that observed in actual cases.

The important steps of shaping digitally can be described in three or four steps present in the figure 3 for a simple geometry with two strands. However, it should be noted that a fifth step of calculation will be necessary after re-meshing for guidance elements within locks. All steps are summarized below and then described in detail:

- Creation of geometry : consists of creating a simple mesh of undistorted warp and weft;
- Formatting weaving: is to shape the strands in an exaggerated way;
- Spring back: allows the fiber into place using spring back;
- Compaction: is to represent the phase of compacting during the forming with presses.

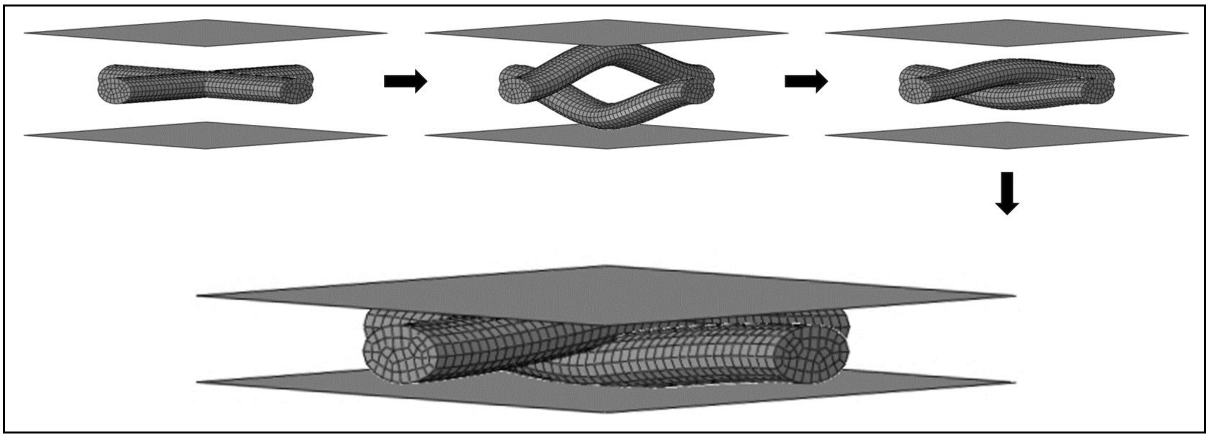

Figure 3: Principe of the numerical method

The proposed numerical approach can be applied to a wide range of composite: from low to high fibre volume fractions and from an un-deformed to a distorted fabric. A second conventional calculation is then used to obtain the mechanical properties of the composite cells.

3. Development of an analytical model

The motivation to develop an analytical method that is felt in order to have a quick idea about the mechanical properties of a composite unlike the numerical simulation which is quite heavy in terms of CPU time. There are a number of analytical methods, but none is directly suitable for fabric deformation due to thermoforming. It was therefore decided for reasons of simplicity to start from a so-called undulation method.

This analytical model initially developed by Ishikawa and Chou [3] and resumed by Shembekar and Naik ([4], [5]) has been modified. Those modifications consist to describe the fibre undulations with an analytical expression which depend only of six geometrical factors: warp and weft height/width and the separation between each warp and weft.

For the shear deformation due to the forming, we have observed on a real structure incorporating a homogeneous grid that the local geometry surfaces do not have the same area before and after the forming (see Figure 4 and 5). Furthermore, the relation between the area of the surface and shear angle appear to be not obvious. For this reason, it was decided to include two other parameters: the shear angle and an area factor.

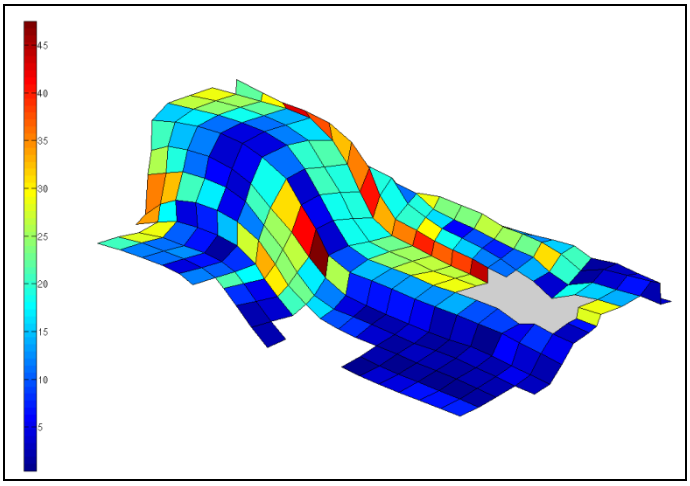

Figure 4: Shear angle on the grid (°)

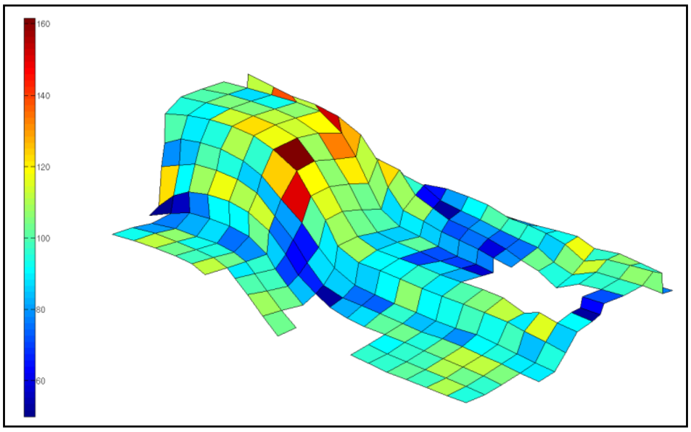

Figure 5: Size of each Grid (mm^2)

For the mechanical resolution, the same approach as Ishikawa and Chou or Naik has been applied with a Classical Laminate Theory. It is simple to implement and economical in term of CPU with an interesting result. However, the sum of elements in parallel or in series (iso-deformation or iso-stress) does not give a single value but two landmarks (see figure 6).

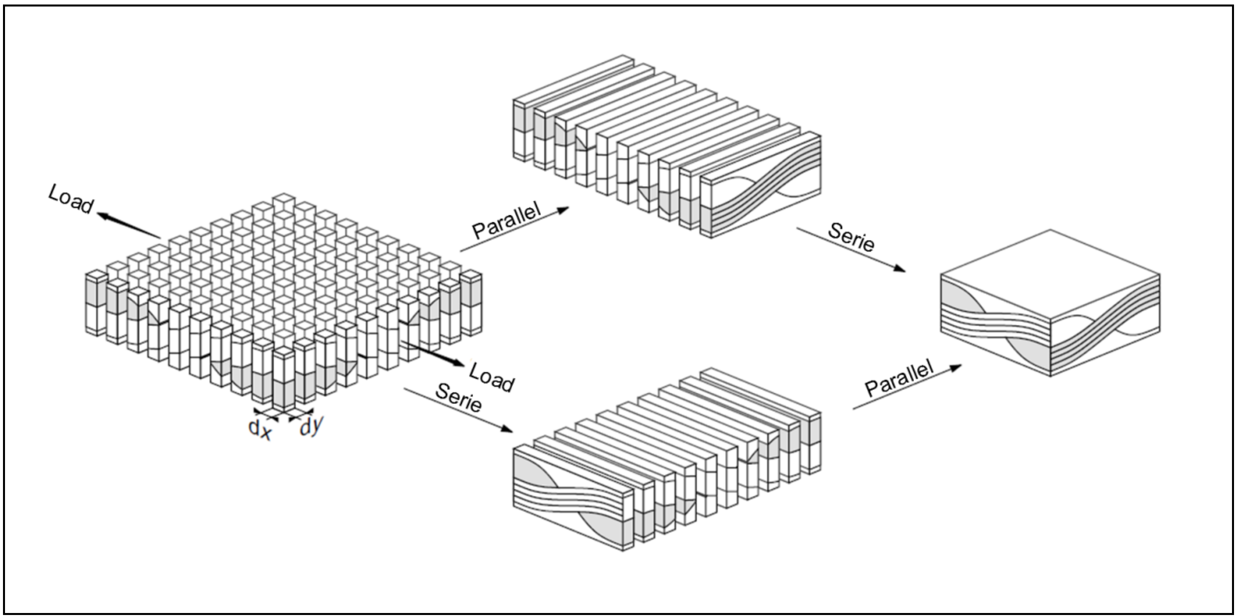

Figure 6 : Series-parallel and parallel-series configurations of the undulation model 2D [7]

To conclude, this analytical method can be quick to predict more or less roughly the mechanical behaviour for most of fabrics designs. It enables us to perform calculations involving the shear deformation due to forming structures with simply parameters.

4. Discuss and Benchmark of analytical/numerical methods and experimental test

Both proposed methods will be compared to experimental results obtained on un-deformed specimens and complex structures. This will show clearly that the numerical method is more accurate than the analytical method. In addition, the numerical method can yield properties such as plasticity or insertion of damage. On other hand, the analytical method is much simpler to implement and much faster than the numerical one. Each method thus has its strengths and weaknesses and should be used according to the needs of precision and time available for calculations / implementation methods.

References:

[1] Boisse, P., Cherouat, P., Gelin, A. J. C., Sabhi, H. Experimental study and finite element simulation of a glass fiber fabric shaping process. *Polymer Composites*, vol. 16 (pp. 83 – 95), 1995.

[2] Lomov, S. V., Verpoest, I. Modelling of the internal structure and deformability of textile reinforcements : Wisetex software. *10th European Conference Composite* Matérials, 2002.

[3] Robitaille, F., Clayton, B. R., Souter, B. J., Rudd, C.D. Geometric modelling of industrial preforms : Woven and braided textiles. *Journal of Materials : Design and Applications*, Proc. Institution of Mechanical Engineers (Part L), vol. 213 (pp. 69 – 84), 1999.

[4] Ishikawa, T., Chou T.W. One-dimensional micromechanical analysis of woven fabric composites. *American Institute of Aeronautics and Astronautics Journal*, vol. 21 (pp. 1714 - 1721), 1983.

[5] Shembekar P.S., Naik N.K. Elastic behavior of woven fabric composites. I. Laminate analysis. *Journal of Composite Materials*, vol. 26 (pp. 2197 - 2225), 1992.

[6] Shembekar P.S., Naik N.K. Elastic behavior of woven fabric composites. II. Laminate analysis. *Journal of Composite Materials*, vol. 26 (pp. 2226 - 2246), 1992.

[7] Dal Maso, F., Mézière, F. Calcul des propriétés élastiques des tissus utilisés dans les matériaux composites. *Revue de l'institut Français du pétrole*, vol. 53, n° 6, 1998.