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## Analysis of Scale Effects on the Behavior of Composite Structures: Case of Automotive Body

By Wel-Doret Djonglibet, Tikri Bianzeubé, Djeumako Bonaventure,  
Danwe Raidandi & Guy Edgar Ntamack

*University of Ngaoundere*

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# Analysis of Scale Effects on the Behavior of Composite Structures: Case of Automotive Body

Wel-Doret Djonglibet<sup>α</sup>, Tikri Bianzeubé<sup>σ</sup>, Djeumako Bonaventure<sup>ρ</sup>, Danwe Raidandi<sup>ω</sup>  
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## Nomenclature

$E_i$ : Young's modulus in the longitudinal direction of the material,  
 $\nu_{ij}$ : Poisson coefficients in the corresponding plane,  
 $G_{ij}$ : Shear modulus in the corresponding plane,  
 with:  
 NASA: National Aeronautics and Space Administration  
 UN: Un-Notch  
 FN: Four-Notch  
 HN: Half-Notch  
 SE: Stacking sequence  
 ES: Static test  
 $\beta$ : Scale factor

## I. INTRODUCTION

Automotive structures integrate the many years since the composite materials for increased performance [AGI01]. A continuing need to increase the capacity leads to develop technological prowess with these materials. The complexity results from various sources: The elementary components, which interact by associating on their respective

Author  $\alpha$ : Group Mechanics and Materials, GMM, Department of Physics, Faculty of Science, University of Ngaoundere, P. O. Box: 454 Ngaoundere, Cameroon.

Author  $\sigma$ : Resistance Laboratory of Materials and Mechanical Construction, LRMCM, Polytechnic University Institute of Mongo, P.O.Box:4377, Ndjamena, Chad. e-mail: bitikri@gmail.com

characteristics; methods of manufacture and the complexity of the geometry, seen point create a significant history within the material as regards their behavior. Designers are constantly in search of new methodologies, experimental approaches and digital tools to facilitate the structural optimization tasks. But experimental studies handicaps and view digital in the automotive sector is the large size of structures and therefore adequate means of testing.

The main objective of this work is to analyze the influence of the dimensions of the behavior of multilayer structures to form plaque, notched and un-notched, carbon / epoxy for body applications, static compression solicited by the similarity of technical. Abaqus software has enabled us to certain assumptions to determine the reactions to the build level based on the number of interface, maximum efforts and energies absorbed by the structures according to slits.

## II. MATERIALS AND METHODS

### a) Materials

Considering the results of laminated composites of elastic moduli (Table 1) of stacking sequence, carbon/epoxy for conducting our [YCH01] studies. The material is orthotropic. Technical elastic moduli are given in the table below.

Table 1: Composite techniques elasticity Study Modulus.

Modulus of elasticity	$E_1$ ( $MP_a$ )	$E_2$ ( $MP_a$ )	$E_3$ ( $MP_a$ )
Values	16700	16700	11000
Modulus of elasticity	$\nu_{23}$ (-)	$\nu_{12}$ (-)	$\nu_{13}$ (-)
Values	0.178	0.69	0.178
Modulus of elasticity	$G_{23}$ ( $MP_a$ )	$G_{13}$ ( $MP_a$ )	$G_{12}$ ( $MP_a$ )
Values	3300	3300	2450

i. *Presentation of test specimens and assumptions*

## ▪ Presentation of the Specimens

Consider three types of specimens and will be named according to the type of notch:

- UN for UN-Notched, corresponding to the non-notched specimens. The size of notch is 0;
- FN for Four-Notched, corresponding to test pieces with a small notch, notch size is 0.25 times the thickness;
- HN for Half-Notched, corresponding to test pieces with a large gash. The size of notch is 0.5 times the thickness. These test pieces are shown in Figure 1.

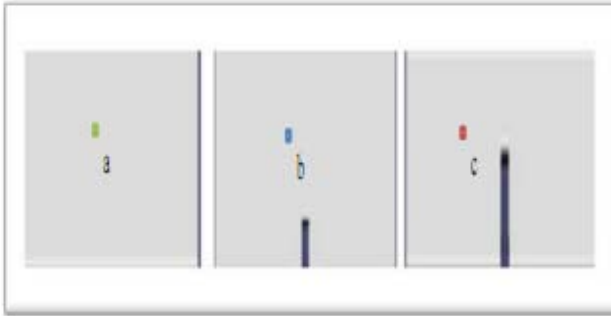


Fig. 1: Geometry of the specimens tested for the construction of a basic digital data studies.

The dimensions of its test pieces are given in Table 2 below. Whose thicknesses are generally those used for the manufacture of composite structures for automotive bodies.

Table 2: Dimensions of test specimens.

Ladders	1/4	1/2	1
Length (mm)	50	100	200
Width (mm)	30	60	120
Thickness (mm)	2.4	4.8	9.6
Number of folds	4	8	16
Approximation of the mesh	0.75	1.5	3

## ▪ Test Hypothesis

- The specimens are homogeneous, isotropic and homothetic.
- The specimens undergo amplitude load 2.5 tons, dependent on the integration period of the elements imposed 30s at the right end and will be fitted to the left end.
- The interactions between the layers and temperature effects will be negligible.

b) *Downscaling Methods*

This is the direct application some of Vaschy-Buckingham theorem. In our study, we will use the geometric similarity Cauchy coupled with reordering techniques ply notched and not notched plate structures form.

This technique is based on several assumptions:

- The prototype and model are made of the same material;
- The model is a copy of the prototype,
- The number of Cauchy remains constant,

A factor called scale factor allows the passage of the prototype model. The table below (tab.3) summarizes the mechanical quantities depending on the model of Cauchy.

Table 3: Mechanical Quantities Cauchy [DDO03].

Variables	Prototype	Model
Shifting	$\delta$	$\beta\delta$
linear dimension	$L$	$\beta L$
Stress	$\sigma$	$\sigma$
Strain	$\epsilon$	$\epsilon$
Energy/Work of a Force	$W$	$\beta^3 W$
Force	$F$	$\beta^2 F$

i. *Arrangement techniques ply Laminate composite structures*

The field of study of scale effects is very large, therefore, the literature is full of articles and theses on one or more parameters such as geometry, monitoring of cracking, fiber dimensions, in depending on the size of the specimens. The appearance of the initial cracks, because of damage to the laminated sheets due to the change in the number of pleats was investigated by Lavoie [DDO03]. The latter uses the reordering technique called folds "ply Level". There are two other techniques proposed in a report NASA by Jackson [DDO03], for work carried out on laminates. We will adapt these techniques presented by Jackson to our problem, particularly the "ply Level" and technology "sub laminate" and the technique of "reducing neutral report".

As a reminder, these similarities techniques involve reorganizing the folds for the passage between the prototype and model. There are two main techniques:

- First, it was the "ply Level" (fig. a), which is to move from a stack to , the transition from  $n$  to  $2n$  fold is by doubling each ply of the laminate. The importance of this similarity is characterized by the consistent scaling of the various moduli of the plan (tension-compression) and flexural modulus.
- The second method called "Sub Laminate" (Fig. b) changes a Laminate stack to the same final as last, the increase is achieved in a balanced form here twice the initial sequence folds. This method allows better scaling plans modules except the flexural modulus.

Note that there are also two other possible techniques:

- The third technique (Fig. c) consists in obtaining from the prototype to reduce the thickness of plies by the reduction factor. This technique is the source

of all searches because it is impossible to apply to manufacturing problems.

- The last way is to mirror the basic stack (fig. d).

The figure below (Fig.2) this reordering techniques folds [DDO03].

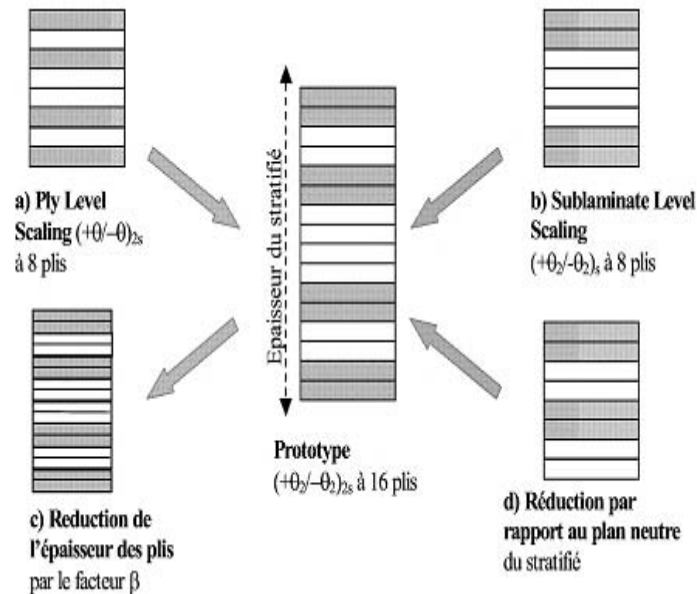


Fig. 2: Technics rearrangement the folds [DDO03].

- ii. *Wide passage Method 1/4 scale 1/2 and 1/2 scales on scale 1.*

The method of crossing is one used by Dany Dormegnien [DDO03]. It consists:

- to move from a model 1/4, 4 ply and orientation three model stratifications 1/2, 8 ply, 2,4 and 6 interfaces, oriented respectively ,and et (fig. 3).

- to move from a model 1/2, 8 plies, interface 2, 4, 6 and respective guidance  $(+2/-2)S$  , and , to six stratification interface 2, 4, 6, 8 , 12, and 14 (fig. 4).

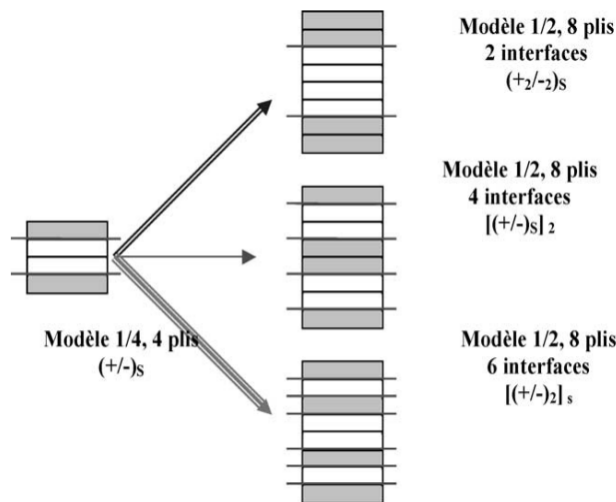


Fig. 3: Scale of Passage 1/4 to 1/2 scale.

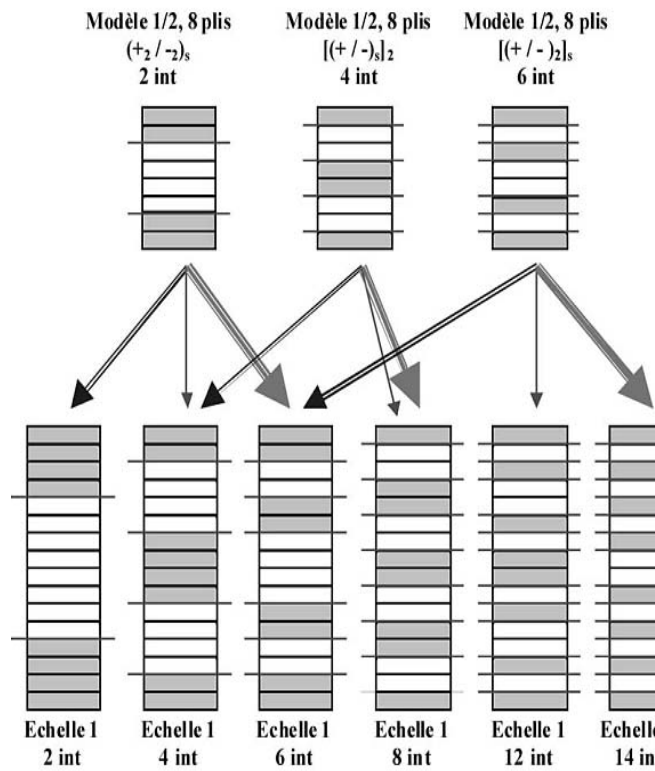


Fig. 4: Methods for determination the stacks of the 1/2 to 1 scale.

### III. RESULTS AND DISCUSSION

#### a) Results

The results were obtained through finite element method under the Abaqus software. This method was developed by L. Penazzi and al. and in 2003 and in 2010 by MIREN EGAÑA [LPE03, MEG10].

##### i. Presentation of samples tested at the scale $1/4$

The fig 5 below respectively show the Strain of the specimens UN, FN and HN at  $1/4$  scale. While figs 6 provide strain measurements of the specimens UN, FN and HN at 1 scale.

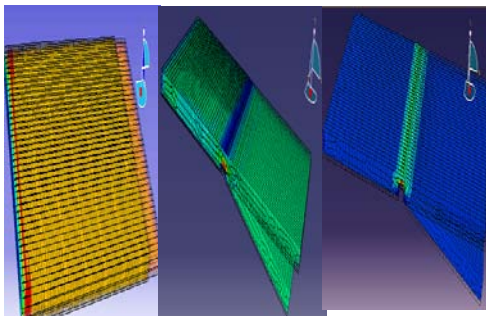


Fig. 5: Specimens UN, FN et HN tested at  $1/4$  scale  $[+45/-45]_S$

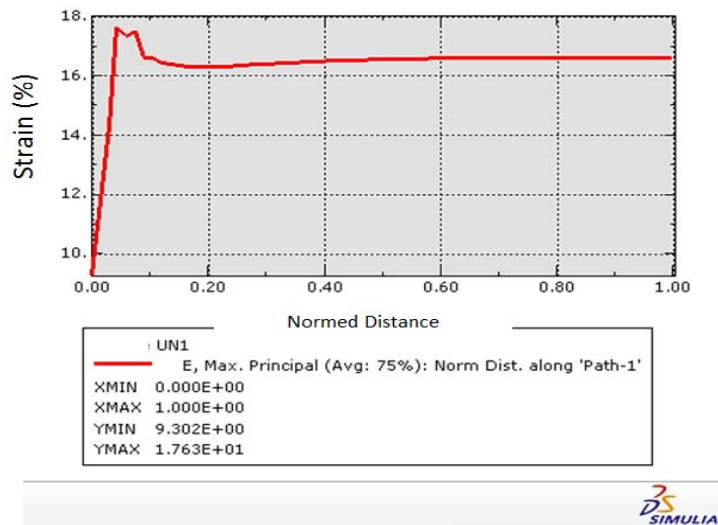


Fig. 6: Strain the prototypes UN1.

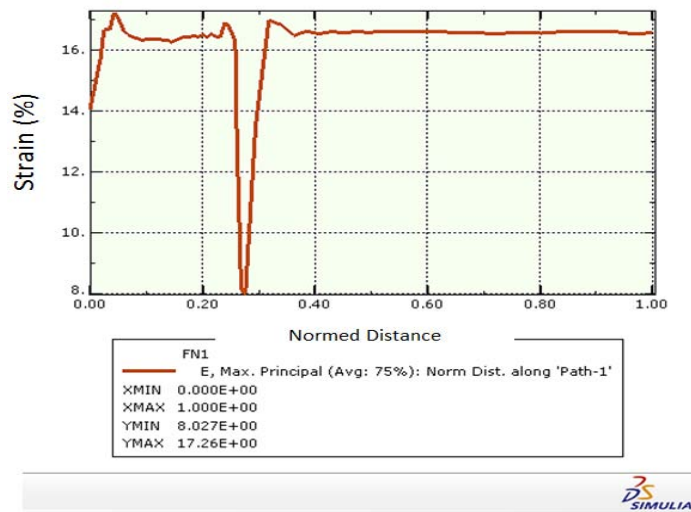


Fig. 7: Strain the Prototypes FN1.

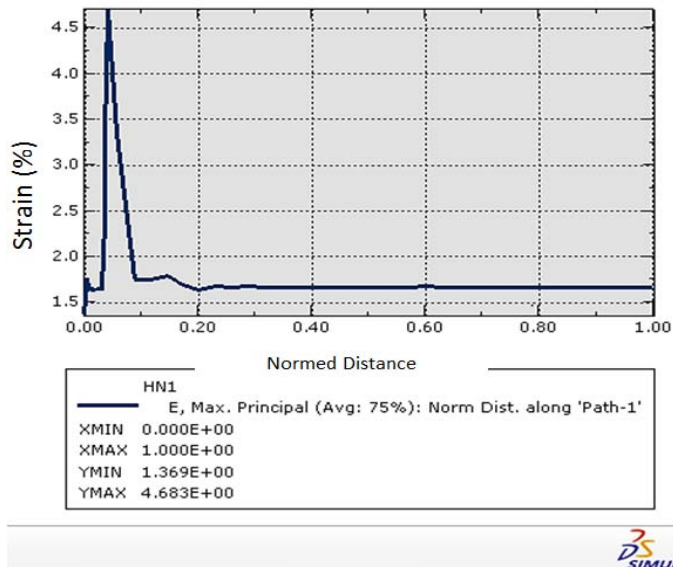


Fig. 8: Strain the Prototypes HN1

ii. Comparison reactions underrun

The above fig.7 presents the results of the reactions at the recessed portion of the specimens study test. These results will be presented according to the type of taps and the number of interfaces in order to highlight the effect of tiller and the number of interfaces on the behavior of structures.

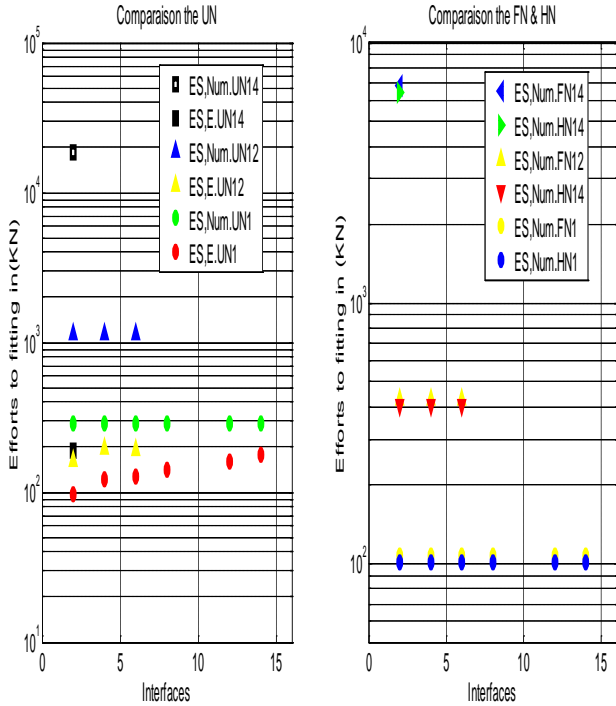


Fig. 9: Maximal responses in the recess as a function of notches and the number of interfaces

iii. Comparison of Efforts

The graphs below show the effort peaks in test tubes UN, FN and HN plate to scale 1/4, 1/2 and 1 depending on the notches.

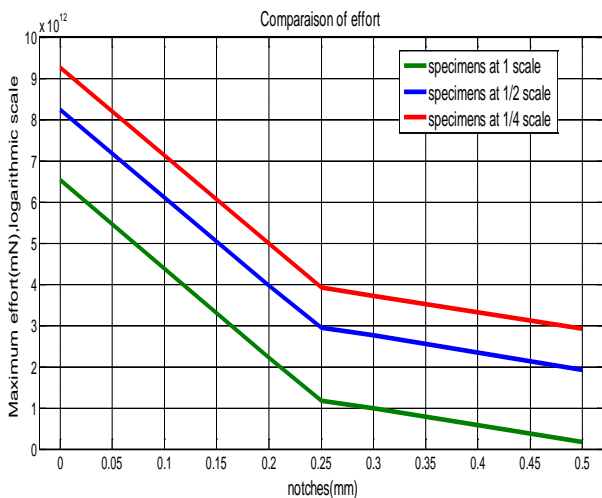


Fig.10: To maximize efforts in terms of cuts

iv. Comparison of Energy

The graphs below show the work effort of the specimens UN, FN and HN plate to 1/4, 1/2 and 1 scale depending on the notches.

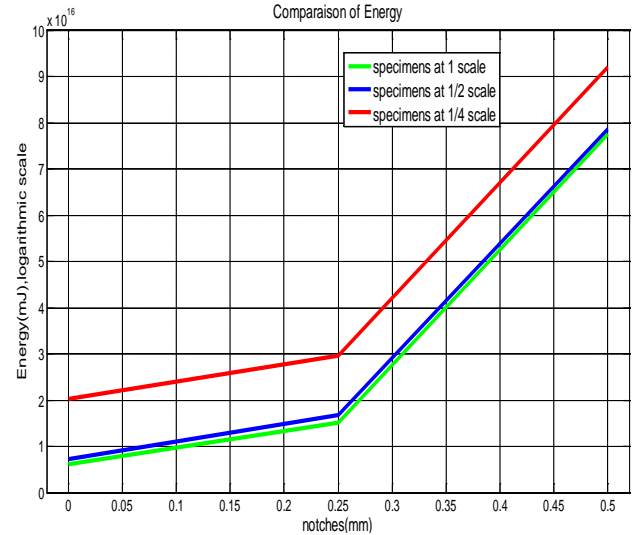


Fig.11: Energy absorbed depending notches

IV. DISCUSSION

The fig. 6, fig. 7 and fig.8 show that the deformations are delayed. UN14 the samples show growth of deformation around the recess. This change is certainly due to the existence of embedding reactions that oppose the compressive force. It decreases gradually between  $0.020 \cdot L$  and  $0.05 \cdot L$ . appears to be constant for values greater than  $0.200 \cdot L$ . The peak of the deformation of 1.7630 to 2.500 mm and the minimum is 0.9304, about 10mm in length. As for FN14 and HN14 samples tested the maximum deformations of 17,560 and 12.34 respectively. To compare the efforts and energies between different scales we use the following steps:

- The values for each stratification in the lower scale are determined from those of the scale 1 and the crushing.
- Efforts to embedding (or level of effort) are determined by the same method as before.
- The highest energies are calculated by the relationship  $W \cdot \delta$ .

With  $w$ : the peaks efforts and  $\delta$ : the maximum displacement.

The Cauchy relations of the three parameters: the reactions to the installation, the peaks efforts and energies on one scale are compared to those of the lower scales. The solutions obtained depend on the dispersion of the fillers in the structure. Fig.9 shows that maximum efforts at embedding remain virtually constant for all number of interfaces between deferred orientations folds (vary little 1%). This confirms our first

hypothesis static loading (imposed). We clearly observe that efforts to embedding are more important for all types of specimens of small dimensions. These efforts to bearings UN plated structures are more important than those structures in omega unlike crashed. This difference is from more to the fiber properties, the specimen geometry and boundary conditions. While for slotted structures, efforts bearing believe with sizes of notches. We cannot say that in this case there's notch effect. However it can be concluded that the plate's structures in carbon / epoxy more resistant to shocks than structures omega-E glass / epoxy and one has to do to a size effect. The maximum forces (fig.10) in the test specimens linearly uncross when the size of test specimens and the notch size become important. This confirms our last two assumptions of the size effect on the behavior of composite structures [BZP84, BZP04, and WWE39]. The specimens to 1 and 1/2 scale are less resistant to compression than the specimens in 1/4 scale [DDO03] because the presences of notches are obstacles to the uniform redistribution of efforts in test tubes and are considered of initial defects. The energy of curves in Fig.11 believes exponentially. These growths energy are mainly due to the presence of notch, the delamination and the friction between the pleats. There is a similarity in relation to all the parameters presented in scale 1 and 1/2.

## V. CONCLUSIONS

This work highlights the scale effects on the behavior of multilayer composite structures in carbon / epoxy notched and un-notched. It shows that the plates 1/4 scale absorb a significant amount of energy that the scale plates 1/2 and 1. The results show that there is no difference in behavior between the technical "ply Level", the "sub Laminat" technique and the technique of "reducing neutral report". We can conclude that, for static compression uses the FN or HN plates are solicited.

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