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"INTELLIGENT" OPTIMAL DESIGN OF WOVEN COMPOSITES

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ABSTRACT

By the coupling of the existing knowledge of experts, the numerical results and the experimental data with the help of some special automatic learning and optimization techniques, it is now possible to propose a very simple tool to design materials. The purpose of this paper is to show its particular application to the very difficult design of woven composites where it is necessary to adjust the mechanical properties, the electromagnetic properties and taking care of the price too.

INTRODUCTION

Composites are continuing to gain enormous uses in the mechanical engineering, the civil engineering, the automotive, the aeronautical and the naval industries. It is necessary to reduce their acquisition cost while improving the life cycle and safety of the structures.

Over several decades, many general contributions have been made to understand the physics and to develop models for the mechanical, electromagnetic global properties of aggregates during this modeling called homogenization. Several general papers on simplified models, simple bounds of the properties or and even sophisticated theories ... were produced. Books such as *Micromechanics: overall properties of heterogeneous materials*, (North-Holland) by Nemat-Nasser et al (1999), gave a general view of the state of the art in this fundamental area.

In the case of the woven composites, idealized geometry and even numerical finite element methods due to the complex geometry, were also done. The simulated results are sometimes

near from the real experimental ones, but very often they do not give sufficient elements to be used into the real design.

The challenge is thus the following one: how to design the optimal woven composite (i.e. to give the composition and the process) for any special application when, only a few tests are available (due to the cost in money and time) and when the simulated predictions are not reliable.

Textile composite materials with woven, braided or knitted fabrics have efficient properties. The description of the process is rather difficult: fibers are used to make bundles or yarns which are then intertwined according several types.

Here, we consider only a special hybrid woven composite where in one bundle one or two fibers are used and where one or two bundles are used for the warp and the fill in one layer. We follow the geometrical description of the University of Technology of Compiègne for the layer. All the fabrics are made with 16 layers.

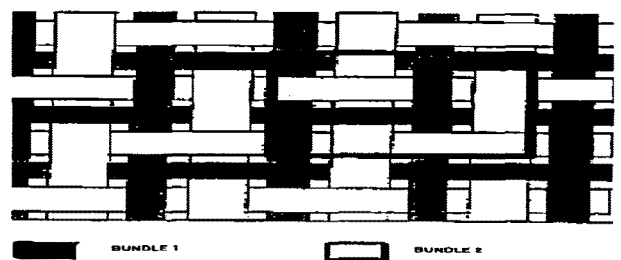


Figure 1: Relative position of the bundles in the fabric

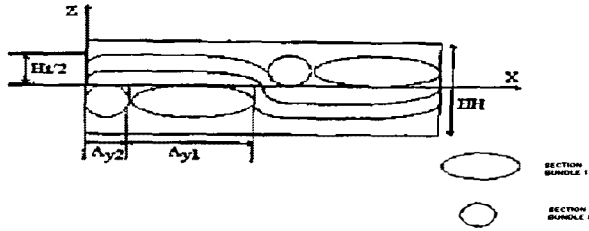


Figure 2: Definition of microscopic parameters

BUILDING THE DATA BASE

Eleven different fibers are available. Each fiber is fully characterized from a data base of materials. Only one resin is used and characterized.

Primitive description of the data base:

The composite materials are all equilibrated fabrics with a constant step of 2: i.e. the two bundles in the warp and the fill are the same. Usually, the fabric is characterized by the macroscopic parameters:

- Porosity (x%)
- Nature of fibers (Glass, Peek..among the eleven fibers)
- Total_weight of fibers per unit surface in one layer (zzz gr)
- Hybridation_massic_ratio for the two bundles (Tx1 Glass Tx2 Peek)

$$Tx1 = \frac{\text{mass (fiber 1)}}{\text{mass (fiber 1)} + \text{mass (fiber 2)}}$$

$$Tx2 = \frac{\text{mass (fiber 2)}}{\text{mass (fiber 1)} + \text{mass (fiber 2)}}$$

- Thickness of the fabric
- Nature of the resin (here only one).

For this special problem, there are 49 active design parameters (twice {22 for each fiber: 0 or 1 selected or not, the concentration, with the number of fibers in the bundle}) + 5 for the process.

A Design of Experiments is impossible. Indeed, only sixteen woven composite materials were ordered. At the AIA/CP, they were then mechanically characterized according the classical normalized tests: the resistance and the elastic modulus in tension, as in compression, flexion, and shearing, are defined and measured; the fabrics are also electromagnetically characterized: the dielectric constant and the loss tangent are measured. Some microscopic parameters are at last measured by cutting the fabric:

- A_{y1}: width of the first bundle
- A_{y2}: width of the second bundle
- H₁: height of one wave of fibers
- HH: height of one layer (the thickness of the fabric is here 16 x HH).

ref_CVR	Hybridation %	Total_wel_fibers	TVF%	TMR%	porosity	Ay1	Ay2	HH	HT
2628	100% Silice (SiO2)	270.00	46.30	35.60	0.00	0.59	0.59	0.29	0.27
2529	100% Glass_E	290.00	54.80	25.40	1.06	1.90	1.90	0.31	0.31
2397	100% Glass_D	260.00	47.60	34.80	0.00	0.96	0.96	0.26	0.26
2407	52% Silice/48% Polyester	180.00	51.70	33.80	5.88	0.58	0.80	0.18	0.18
2414	54.5% Glass_E/45.5% Polyester	253.00	48.00	36.70	5.69	0.58	0.53	0.28	0.25
2412	51.5% Glass_D/48.5% Polyester	273.00	51.10	34.00	1.96	0.57	0.56	0.28	0.27
2408	64% Silice/36% PEHT	254.00	49.30	40.70	13.38	0.63	0.55	0.33	0.30
2416	75.2% Glass_S2/24.8 PEI	248.00	54.30	35.80	2.56	0.62	0.71	0.29	0.29
2419	45% Glass_S2/55 PEHT	262.00	48.90	43.50	3.02	0.63	0.61	0.36	0.33
2420	100% Vectran	270.00	47.00	43.80	6.55	0.92	0.92	0.41	0.37
2475	71.8% Silice/28.2% PEI	266.00	49.10	36.20	7.89	0.62	0.70	0.29	0.27
2470	73.4% Glass_E/30.6% PEEK	260.00	48.30	34.90	6.62	0.74	0.59	0.26	0.24
2471	59% Glass_D/31% PEEK	260.00	50.90	36.10	6.80	0.62	0.55	0.26	0.24
2474	59.7% Silice/40.3% PTFE	253.00	54.60	28.60	9.63	1.00	0.96	0.25	0.25
2478	60% Silice/25% PTFE/15% PEEK	267.00	45.30	38.30	0.00	0.63	0.66	0.26	0.23
2484	65% Glass_D/10.5% Vectran/24.5% PEHT	259.00	48.60	41.10	7.14	0.78	0.56	0.34	0.31

TVF=Volume fibers

TMR=Resin content in % weight

ref_CVR	Et	sigma_t	Ec	sigma_c	Ef	sigma_f	S13	eps	tg_loss
2628	15.40	347.00	19.40	102.00	15.60	169.00	18.70	2.89	0.003
2529	24.70	443.00	23.40	186.00	21.10	293.00	27.60	4.39	0.011
2397	11.50	245.50	15.50	118.20	12.50	223.20	18.10	3.20	0.006
2407	13.40	324.70	16.50	82.20	11.10	162.30	11.20	3.03	0.004
2414	11.00	225.00	13.60	81.00	11.50	143.00	15.00	3.62	0.010
2412	9.90	196.00	13.80	90.90	12.40	157.00	14.90	3.22	0.005
2408	12.30	342.00	13.90	47.00	11.50	88.80	8.00	2.64	0.002
2418	10.60	283.00	13.30	83.00	12.00	150.00	16.90	3.16	0.012
2419	9.90	351.00	13.00	63.50	14.40	123.00	13.50	2.94	0.015
2420	11.80	417.00	12.50	46.00	14.10	156.00	10.70	2.85	0.003
2475	13.20	342.00	16.80	90.00	13.50	139.00	16.40	2.94	0.003
2470	15.20	260.00	15.20	88.00	13.80	149.00	17.00	3.82	0.009
2471	10.00	162.00	10.00	84.00	9.30	133.00	14.30	3.10	0.007
2474	14.30	325.00	15.10	83.00	12.80	158.00	9.80	2.82	0.005
2478	12.30	303.00	14.00	66.00	14.50	127.00	13.20	2.76	0.006
2483	15.00	305.00	14.80	63.00	13.00	128.00	13.20	3.33	0.010
2484	13.20	218.00	13.20	59.00	13.20	119.00	12.70	2.84	0.004

Figure 3: Experimental data on the fabrics

Intelligent description

It is impossible with classical mathematical tools to represent these results. We need to be able to make the fusion of the different fibers in the bundles and of the different fabric parameters. For that, we use the actual knowledges.

For one bundle i.e. one dimensional composite, analytical approximated models for the elastic and electromagnetic properties are available. It is also the case for layer with straight bundles.

For the woven fabric, there are quasi-analytical models and finite element based models. (the calculations of the elastic properties were made in one internal report of UTC based on the Ishikawa and Chou's works.

For the electromagnetic properties, we use for one fiber, the Bruggeman's model and for two different fibers, the Kingery's model.

AUTOMATIC LEARNINGS

Even if these simulated results are not very well representative of the experimental values on the fabrics, they allow to make the fusion and to help the learnings. For this special problem, we use general regression net or polynomial

net in NeuroShell from Wards systems. They are both based on numerical learnings

Figure 4: Primitive active design parameters

Successively, for each case, described by its active design parameters or primitive descriptors, we have analytically, the mass and the price of the fabric, and the bundles properties.

Then, after learning, we are able to compute the other intelligent descriptors:

for the process

A_{y1} first bundle , A_{y2} second bundle

H_t wave of fibers, HH one layer

for the layers with straight bundles

EXM1, EYM1, NUXYM1, NUYXM1, GXYM1

EXM2, EYM2, NUXYM2, NUYXM2, GXYM2

for the fabric

Eps_{th} , simulated permittivity

Exy_{th} , Poisson $_{th}$ and Gxy_{th} simulated elastic coefficients.

We build these descriptors for all the 16 examples.

Then, we can after learning, give the real measured experimental conclusions or values of the fabric:

F_t , F_{sigmat} , F_c , F_{sigmac} , F_f , F_{sigmaf} , FS13, Eps and t Tg-loss.

OPTIMAL DESIGN OF THE WOVEN FABRIC

Indeed, this approach allows to go much further and to answer to the real problem: we have to design the fabric such that its mechanical end electromagnetic properties satisfy some requirements.

We may assume that, for economical reasons, this fabric must be obtained at the lowest price but any other objective function may be taken.

This optimization problem is very difficult as, here also, there is no convexity of the functions, moreover, even if we have a reasonable representation of the functions this is not the case of their gradient. Only particular algorithms may be used. However, as all our functions are represented analytically (polynomial functions), and do not imply any new finite element analysis or test, the time to evaluate them is very short even within the program EXCEL. We use the add-inn Genehunter of Wards Systems to have the total integration of the Optimal Design of the Woven Fabric. It is elementary to

introduce any new constraint on the design variables or on the conclusions or between the conclusions by referencing the particular cells.

Figure 5: Example of an intelligent optimal design tool

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Within a special department, a consultants company, CADLM, trains and helps Engineers in their own problems.

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