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OPTIMIZATION OF FIBERS ORIENTATION IN A COMPOSITE SPECIMEN

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Summary: *The main purpose of this study was to optimize the fibers orientation in a composite specimen with the objective to minimize the displacement. This composite specimen can be used in aerospace or mechanical structures. The objective function was performed with static analysis by altering the fibers orientation in a finite element solid model, computed using the ANSYS program. A recent method for global optimization GLODS (Global and local optimization using direct search) was used for the optimization process. In the sequence, specimens were manufactured and experimental tested, in o order to validate the numerical results obtained.*

1 INTRODUCTION

Driven by the growth of the use of composite laminates in structural applications, over the last decades, it has been noted a significant effort in the development of techniques of analysis and design of composite structures [1]. The composite structures have a high complexity both in terms of manufacture and maintenance, as well as analysis [2]. The high number of design variables and their complex mechanical behavior increase the complexity of the optimization task, compared to conventional materials [1].

Optimize composite structures, through the classical form of trial and error, quickly was proved to be an expensive exercise that did not bring satisfactory solutions [3]. Later the same mathematical methods employed in the optimization of conventional structures were applied to composite structures. These methods achieved a limited success [4].

Currently there are efficient developed tools looking for to provide answers to the optimization of these structures as, for example, the use of genetic algorithms in the optimization of composite structures in [5]. Also using the application of genetic algorithms, in [6] the stiffness and resistance of composite structures subject to bending and in plane loads were maximized, and also in [2, 7, 8, 9, 10] the lamination sequence using genetic algorithms was optimized. In [1], by the use of multiobjective optimization and genetic algorithms, the weight and the central deflection of a laminated plate was minimized. In [11], response surfaces are applied to structurally optimize composite laminated materials. For the same purpose, in [3] artificial neural networks are applied.

This paper aims to optimize the fibers orientation of specimens in composite materials in order to minimize the displacement. The optimization of the specimens is achieved computationally through the interaction of ANSYS finite element program in loop with GLODS optimization program. The specimens are produced and experimentally tested in order to validate the optimization process.

2 MATERIALS AND METHODS

Previously, it was produced a specimen without an optimized fibers orientation (P1). Subsequently, it was performed a computational optimization of the specimen using the interaction in cycle ANSYS/GLODS. The optimized solution found (P2) was produced and tested experimentally.

2.1 Materials

The specimens were produced using the T300 carbon epoxy unidirectional prepreg with modified epoxy matrix resin, REM.

The number and orientation layers of the non-optimized specimen, P1, are presented in Table 1.

Table 1 – Number and orientation of specimen layers.

Specimen	Number of layers	Layers orientation [º]
P1	8	[0/0/90/90]s

One of the main difficulties encountered in the computation simulation of composite materials was the proper characterization of the material behaviour. It was possible to obtain computationally the elastic properties for each specimen layer, using the numerical method proposed and developed by A. Melro [12,13].

To determine the elastic properties of the specimen layers were created 5 random fiber distributions according to the proposed algorithm in [13]. For each distribution, the following properties were estimated: E_11, E_22, ν_12, ν_23, G_12, and G_13 G_23 (Table 2).

Table 2 – Elastic properties output for the 5 random layers distributions.

	Dist.1	Dist.2	Dist.3	Dist.4	Dist.5	Mean
E_{11} [MPa]	126025	127750	130420	127130	128010	127870
E_{22} [MPa]	8492	8511	8420	8458	8434	8463
ν_{12}	0.244	0.249	0.256	0.247	0.249	0.249
ν_{23}	0.333	0.331	0.338	0.336	0.337	0.335

G_{12} [MPa]	4292	4401	4421	4455	4417	4397
G_{13} [MPa]	4498	4401	4315	4433	4378	4405
G_{23} [MPa]	3186	3197	3146	3166	3153	3170

2.2 Experimental Methods

Experimental tests were conducted in an elastic multiaxial loading to promote a complex optimization study. The grips system used was the typically used in Edge Crack Torsion modified tests - MECT [14].

The specimen is sideways leaning to three guide pins to ensure the perfect alignment. A symmetrical load was applied using a constant rate of 5 mm/min.

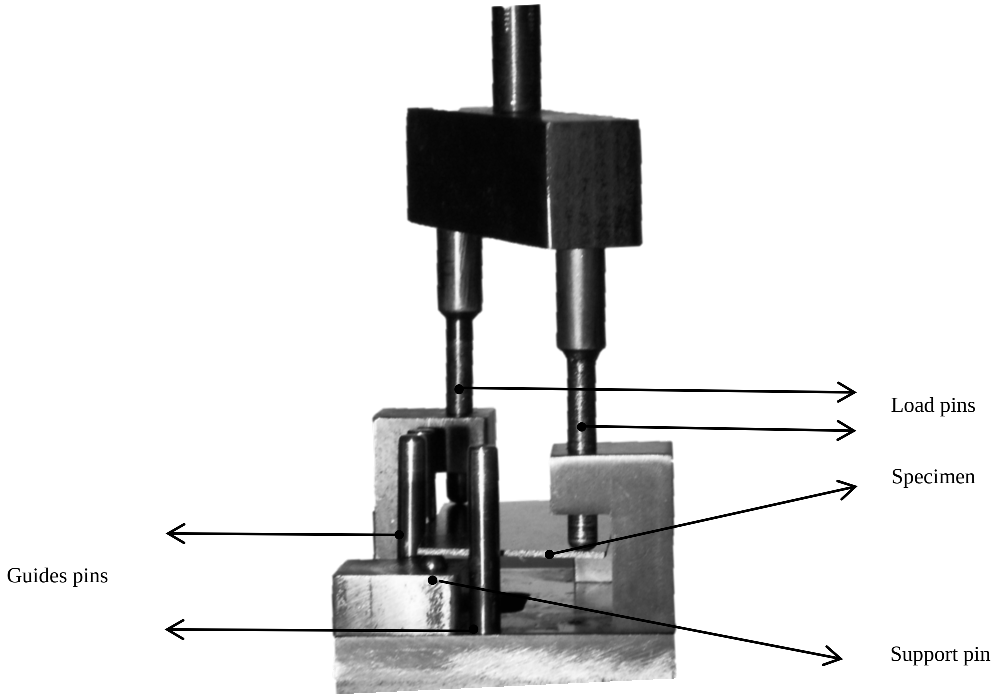


Figure 1 – Experimental test MECT.

Elastic displacement was measured using a digital image correlation tool, DIC. DIC system assesses changes in the specimen surface during the displacement period when successive pictures are capture [15].

2.3 Computacional Method

A constrained nonlinear optimization problem can be mathematically formulated as:

Find n design variables:

$$x = (x_1, x_2, ..., x_n)^T \quad (1)$$

which minimize:

$$\min_{s.t.\ x\in\Omega} f(x) \tag{2}$$

where $f:\Omega\subseteq\mathbb{R}^n \to \mathbb{R}\cup\{+\infty\}$ represents a real-extended value function and $\Omega\subseteq\mathbb{R}^n$ a compact set, defining the problem feasible region. GLODS [17] is a new algorithm for single optimization, suited for bound constrained, derivative-free and global optimization. Using direct search of directional type, the method alternates between a search step, where potentially good regions are located, and a poll step where the previously located regions are explored. This exploitation is made through the launching of several pattern search methods, one in each of the regions of interest. Differently from a multistart strategy, the several pattern search methods will merge when sufficiently close to each other. The goal of GLODS is to end with as many active pattern searches as the number of local minimizers, which would allow to easily locating the possible global extreme value.

On this work the objective function is minimize the maximum displacement in a composite specimen made with 8 layers and the design variables are the fibers orientation for each one of these layers. The fiber orientation is assumed to vary in discrete steps of constant 5º increments, from -85º to 90º. The evaluation of objective function is made with a finite element analysis (FEA) software, ANSYS.

The simulation used the SOLID186 element considering a laminate structural option and a pure formulation of displacement, available in the ANSYS software [16].

The boundary conditions were configured so that both experimental and simulation set-up have similar movement restrictions. The horizontal displacements of the vertical line of the guides pins 1 and 2 were constrained in X direction, as well as the horizontal displacements of the nodes located in the vertical line of guide pin 3 in Y direction (Figure 2).

In order to impose the support pins restrictions the Z displacement were constrained.

The load was applied at one point in the Z axle, in the nodes located at the load pins.

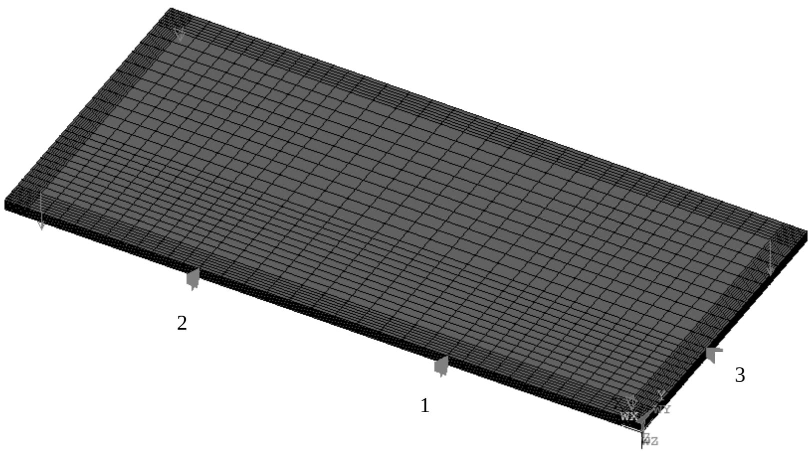
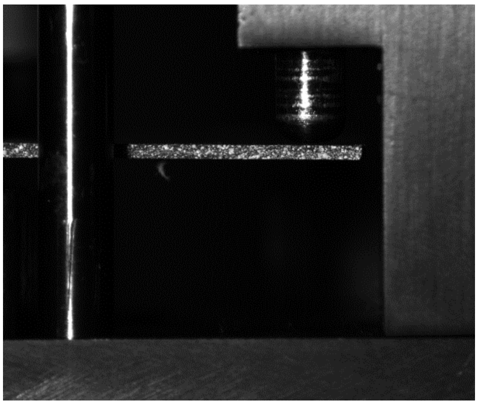


Figure 2 – FE model in ANSYS® of MECT test.

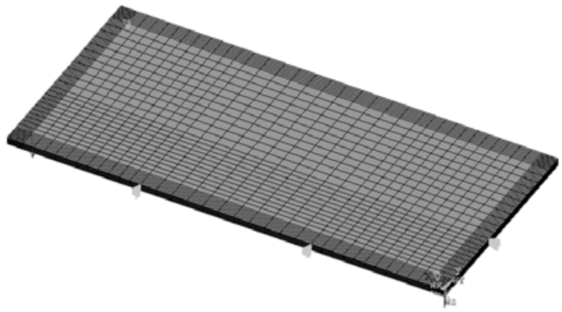
3 RESULTS AND DISCUSSION

3.1 Non-optimized specimen P1

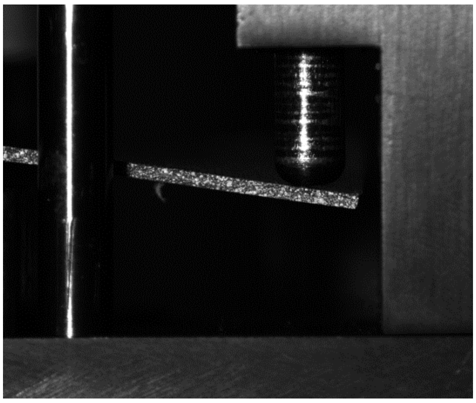
The study area is the zone closest to the specimen apex where the displacement is higher. Figure 4 presents the computationally and experimentally images obtained before and after the load application.



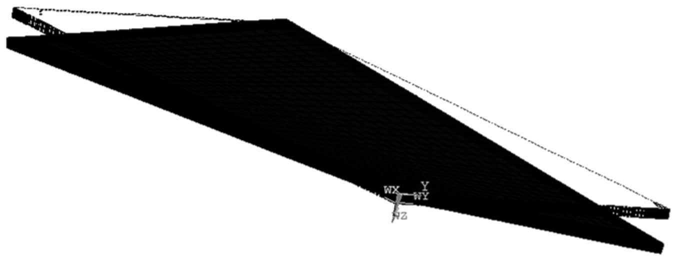
(a) Experimental test before the load application.



(b) ANSYS model before the load application.



(c) Experimental test after the load application.



(d) ANSYS model after the load application.

Figure 4 – Comparison between the experimental test and ANSYS model, before and after the load application.

The experimental and numerical results for the maximum position in thickness of P1 specimen are presented in Table 4. The last two columns record the absolute and relative difference between the experimental and numerical displacement results.

Table 4 – Displacement results for the maximum position in thickness obtained experimentally and numerically for specimen P1.

	Displacement DIC [mm]	**Displacement ANSYS [mm]**	**Absolute difference [mm]**	**Relative difference [%]**
	(A)	**(B)**	**|A-B|**	**|A-B|/A**
P1	4.34	8.14	3.80	87.46

3.2 Computational Optimization

In the optimization process performed by GLODS were analysed two nodes, each corresponding to two opposite corners of the specimen with the greatest displacement.

The GLODS program found 14 local minimums. Table 5 shows the layers orientation and nodes displacement obtained from the optimization process. It was produced only one specimen for experimental validation, named P2, which corresponding to the solution 3 founded by GLODS. This solution was chosen because, beside the displacement node value being symmetrical, the displacement is near a possible global extreme value.

Table 5 – Lamination sequence and nodes displacements obtained by optimization process.

Solution	**Layers orientation [º]**	**Displacement Node 1[mm]**	**Displacement Node 2 [mm]**
1	[45/-50/-50/45/45/-50/-50/45]	2.42	3.40
2	[25/-25/-50/60/15/-25/35/-30]	3.60	3.59
3	[40/-70/-20/-85/60/-80/45/-35]	3.37	3.37
4	[40/-50/-30/-65/20/25/-35/-25]	3.46	3.35
5	[40/-15/25/-60/-20/70/45/-55]	3.55	3.40
6	[55/-65/-20/30/-65/-85/40/-50]	3.05	3.50
7	[60/-80/-40/-40/-85/-50/45/-50]	3.45	3.24
8	[65/-40/-70/15/-60/40/20/-45]	3.58	3.53
9	[-50/65/60/-45/-55/40/50/-55]	3.15	3.44
10	[-50/75/65/25/-85/55/-40/35]	3.33	3.22
11	[-45/25/-15/50/-60/-55/-20/50]	3.42	3.15
12	[-35/45/40/80/-40/50/-55/40]	3.17	2.86
13	[-35/45/60/85/55/65/50/-55]	3.45	2.52
14	[-35/-45/55/-85/-40/25/-45/40]	3.52	3.30

3.3 Optimized specimen P2

Table 6 presents the displacement results of specimen P2 considering the same loading condition of specimen P1 (Table 4).

Table 6 – Displacement results for the maximum position in thickness obtained experimentally and numerically for specimen P2.

	Displacement DIC [mm]	**Displacement ANSYS [mm]**	**Absolute difference [mm]**	**Relative difference [%]**
	(A)	**(B)**	**|A-B|**	**|A-B|/A**
P2	1.86	1.86	0.00	0.02

Is visible that for the optimized specimen, the displacement values obtained experimentally and computationally are equal.

4 CONLUSIONS

The aim was to optimize the specimen in terms of minimizing the maximum displacement for a specific load. The design variable was the orientation of the layers, and the restrictions were: fixed number of eight layers, with the guidelines of the layers varying between -85º and 90 º with a 5º increment. The model employed for the optimization was GLODS, proposed by [17]. This model performs a global uni-objective optimization based on direct search, which uses a multistart technique. The orientation of the eight layers that minimizes the maximum displacement was achieved through the interaction, in loop, of GLODS and ANSYS®. One of the 14 solutions found was manufactured and experimentally tested, along with the non-optimized specimen. The experimental displacement values were obtained using the digital image correlation technique.

It is observed that P2 was optimized, because it presents lower displacement values, about 50%, for the same load, when compared to P1 (see Figure 5).

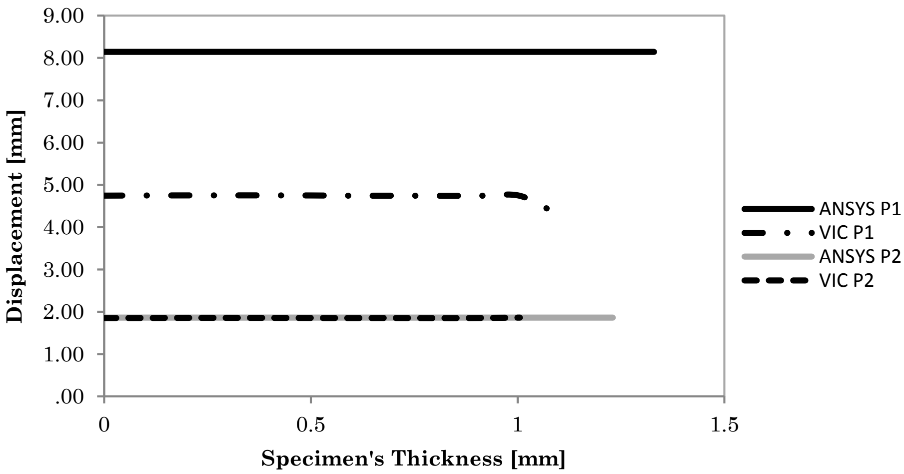


Figure 5 – Comparison of the experimental (DIC) and computational (ANSYS) values obtained for the non-optimized specimen P1 at 50,92N and the optimized specimen P2 at 50,65N.

It was concluded that the lamination sequence found by GLODS minimized about 50% the displacement compared to the non-optimized specimen.

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REFERENCES

[1] ALMEIDA, F. S.; AWRUCH, A. M. – Optimization of Composite Plates and Shells using a Genetic Algorithm and the Finite Element Method. *Mecánica Computacional*. Asociación Argentina de Mecánica Computacional. Vol. 26, p. 372-385, 2007.

[2] SOREMEKUN, G. A. E. – *Genetic Algorithm for Composite Laminate Design and Optimization*. Virginia: Faculty of the Virginia Polytechnic Institute and State Univertity. Master's Thesis, 1997.

[3] LOPES, P. A. M. – *Otimização de Estruturas de Materiais Compósitos Laminados, Baseada em Confiabilidade, Utilizando Algoritmos Genéticos e Redes Neurais Artificiais*. Porto Alegre: Universidade Federal do Rio Grande Sul. PhD Thesis, 2009.

[4] SOREMEKUN, G. A. E. [et al] – Composite Laminate Design Optimization by Genetic Algorithm with Generalized Elitist Selection. *Computer & Structures*. Vol. 79, p. 131-143, 2001.

[5] ALMEIDA, F. S. – *Otimização de Estruturas de Materiais Compósitos Laminados Utilizando Algoritmos Genéticos*. Porto Alegre: Escola de Engenharia da Universidade Federal do Rio Grande Sul. Master's Thesis, 2006.

[6] CALLAHAN, K. J.; WEEKS, G. E. – Optimum Design of Composite Laminates using Genetic Algorithm. *Composites Engineering*. Vol. 2, nº 3, p. 149-160, 1992.

[7] NAGENDRA, S; HAFTKA, R. T.; GURDAL, Z. - Stacking Sequence Optimization of Simply Supported Laminates with Stability and Strain Constrains. *AIAA Journal*. Vol. 30, nº 8, p.2132-2137, 1992.

[8] LE RICHE, R; HAFTKA, R. T. - Optimization of Laminate Stacking Sequence for Buckling Load Maximization be Genetic Algorithm. *AIAA Journal*, Vol.31, nº 5, p.951-956, 1993.

[9] GURDAL, Z.; HAFTKA, R. T.; NAGENDRA, S. - Genetic Algorithm for the Design of Laminated Composite Panels. *SAMPE Journal*, Vol.30, nº 3, p.29-35, 1994.

[10] LE RICHE, R. - *Optimization of Composite Structures by Genetic Algorithms*. Virginia: Virginia Polytechnic Institute and State University. Master's Thesis, 1994.

[11] FERNANDES, J. T. – *Otimização Estrutural de Materiais Compósitos Laminados Usando Superfície de Resposta e Algoritmos Genéticos*. Curitiba: Universidade Tecnológica Federal do Paraná. Master's Thesis, 2009.

[12] MELRO, A. R. – *Analitical and Numerical Modelling of Damage and Fracture of Advanced Composites*. Porto: Faculdade de Engenharia da Universidade de Porto. PhD Thesis, 2011.

[13] MELRO, A. R.; CAMANHO, P. P.; PINHO, S. T. – Influence of Geometrical Parameters on the Elastic Response of Unidirectional Composite Materials. *Composite*

Structures ELSEVIER. ISSN 0263-8223. Vol. 94, nº11, p. 3223-3231, 2012.

[14] MARAT-MENDES, R. M. M. – *Critérios de Delaminação em Materiais Compósitos Sob Solicitações Multiaxiais*. Lisboa: Instituto Superior Técnico da Universidade Técnica de Lisboa. PhD Thesis, 2009.

[15] Correlated Solutions, Inc. - *Principle of Digital Image Correlation*. Available in: http://www.correlatedsolutions.com/vic-2d. [Consul. July 2014].

[16] ANSYS Element Reference - Solid 186. 2010.

[17] Custodio, A.L. and Madeira, J.F.A.. GLODS: Global and Local Optimization using Direct Search. Journal of Global Optimization, 62(1):1-28, May 2015. Available in: http://dx.doi.org/10.1007/s10898-014-0224-9.