Transactions on Engineering Sciences vol 10, © 1996 WIT Press, www.witpress.com, ISSN 1743-3533

Optimum fibre orientation layout of composite sandwich panels for maximum stiffness

W. Boruszewski, M. Kataoka-Filho, L.E. Barbosa
Instituto Nacional de Pesquisas Espaciais, Caixa Postal 515,
12201-970, S.J. Campos, SP, Brazil

Abstract

Composite sandwich panel stiffness as a function of fibre orientation layout of face sheet is examined keeping total mass constant. Two basic layouts are considered: the first using constant fibre orientation and the second having a different fibre angle for each panel quarter. Specimens are tested showing good agreement with the first natural frequencies calculated for their finite element models. Taking fibre angles as design variables both layouts are maximized for the first eigenvalue. Two subsequent partitions are modeled with important stiffness increases achieved.

1 Introduction

The use of sandwich structures has been increasing in recent years as a result of their light weight and high stiffness. They have been used in a variety of applications such as automotive bodywork, marine hulls, aircraft wing skins and satellite bodies and their solar panels. Special attention is devoted to the possibility of improving the performance of those structures by structural optimization of composite face sheets.

In this paper the problem of an optimum fibre layout of symmetric composite sandwich panels is treated. The objective is to maximize the stiffness of composite sandwich panels without increasing their weight. The optimum layout is obtained by subdividing the faces in regions with different fibre orientations. Initially a unidirectional fibre orientation is considered. The optimization is carried out by dividing the face sheet in smaller regions each of them allowed to have a specific fibre orientation.

Transactions on Engineering Sciences vol 10, © 1996 WIT Press, www.witpress.com, ISSN 1743-3533

The normal modes of composite sandwich panels are calculated by the finite element method, using the first eigenvalue as a measure of the stiffness. The fibre orientation that yields the optimum layout is calculated through a two-stage iterative process using Modified Method of Feasible Directions and Golden Section Method, a part of MSC/NASTRAN[1] optimization procedures.

The numerical figures have been compared to modal test results aiming mainly to validate the studies. As a second outcome a two new models were developed bi-partitioning the previous models in both directions.

2 The approach

To examine the effectiveness of subdividing the faces of a sandwich panel and attributing to each one of them optimum fibre orientations one needs reliable computational tools. Having used the MSC/NASTRAN (presently version 68) as the main software for structural analysis in Brazilian space program, it was chosen to be the processor for normal mode and optimization analyses. Pre and post-processing was performed using MSC/XL version 3B.

A first instance of practical optimization is the search of a maximum for predictive analysis success before the fabrication phase. To achieve it a gradual approach was adopted, intercalating finite element modeling, optimization and testing of specimens. Once gotten, better models could be developed.

3 The basic panel

A square sandwich panel with 0.32m sides, identical faces and single fibre orientation was defined. The faces were composed of Carbon T300 fibres in Epoxy DER 331, having a 0.0003m thickness and a 1740.0 kg/m^3 density considering the FM73 adhesive as distributed mass. The honeycomb core was made of Al 5052-3/8-0.0007, with a 0.00955m cell-height and 16.0 kg/m^3 density. Other relevant properties, expressed in the international system of units, are presented in Table 1.

	Young Modulus N/m^2	**Poisson's Ratio**	**Shear 1-Z** N/m^2	**Shear 2-Z** N/m^2
Face	1.15 10^{11}	0.34	5.0 10^9	5.0 10^9
Core	negligible	irrelevant	8.274 10^7	4.287 10^7

Table 1: Basic panel properties

A finite element model was developed for the basic panel, using 64 composite symmetric square (4-node, 3-layer) elements. A set of modal runs for the unconstrained model was performed to identify the fibre orientation with highest resulting panel stiffness.

The results presented in Figure 1, show a global optimum at 45 degrees and an eigenvalue almost 30% higher than that calculated for the layout with fibres parallel to the sides.

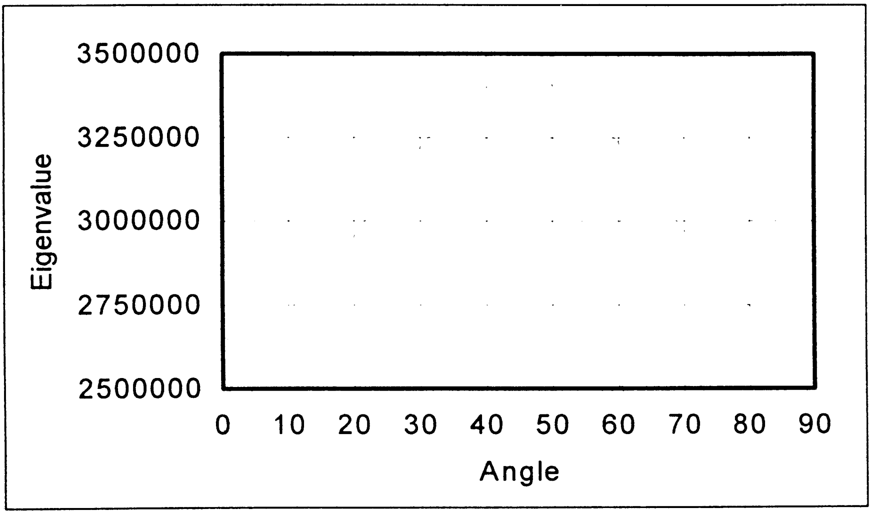

Figure 1. Stiffness of the basic panel as a function of fibre angle

The natural frequency for the unconstrained model and optimum fibre orientation is 294.7 Hz (3.429188 10^6 eigenvalue).

4 The basic specimen

A sandwich panel specimen, with optimum fibre orientation, was constructed as a second step of the proposed gradual approach. Its first natural frequencies were determined by modal testing. The measured first natural frequency was 196.2 Hz, for the panel in its testing environment.

An updated finite element model was developed to include the masses of all involved testing hardware and the related constraints. The accelerometers used in the tests, one in the panel center and one near each one of its corners, were considered as concentrated masses and inertias. The testing boundary condi-

Transactions on Engineering Sciences vol 10, © 1996 WIT Press, www.witpress.com, ISSN 1743-3533

tions were represented in the model as constraints in x and y directions (parallel to the panel sides) at test supporting points.

Using that model, the finite element analysis determined a first natural frequency of 198.5 Hz, showing an excellent agreement with the measured one.

5 An improved model

A new model for the sandwich panel was developed, subdividing each face in four square quarters. An optimization run was performed, using the seventh eigenvalue as the objective function, and the fibre angles of each quarter as the design variables. The quarters were numbered counterclockwise from bottom left and fibre angle values of -5, 5, -5 and 5 degrees were used as initial guesses. The optimum was achieved after a clear asymptotic tendency to -45, 45, -45 and 45 degrees for the fibre angles. Figure 2 shows the evolution of the objective function with the cycle number, while Figure 3 presents the first design variable history

When compared with the basic model optimum the achieved objective function value (eigenvalue 5.751479 10^6, frequency 381.7 Hz) shows a growth of about 67.7 %, that for the frequency means a 29.5 % increase.

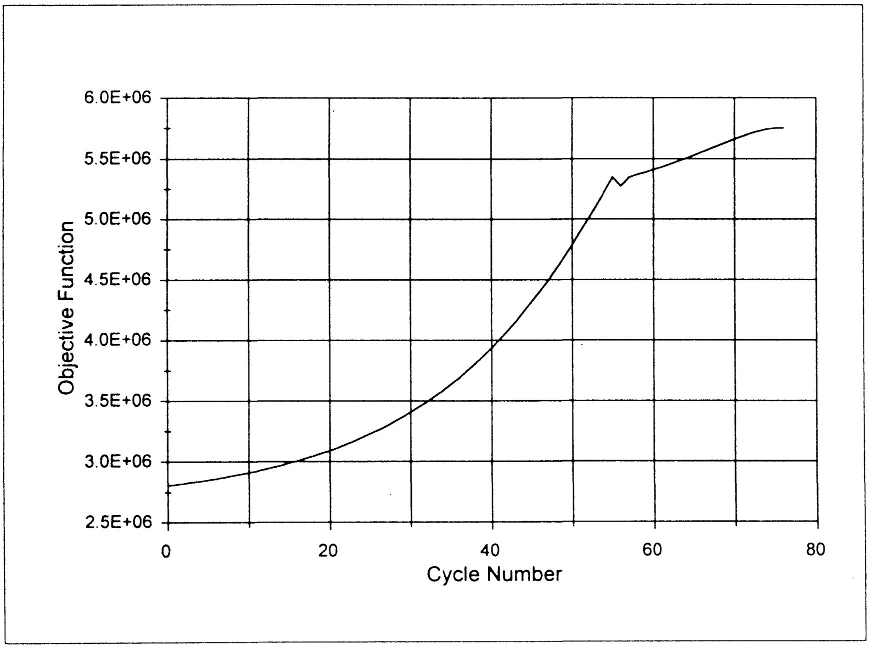

Figure 2. Stiffness history for 2x2 layout

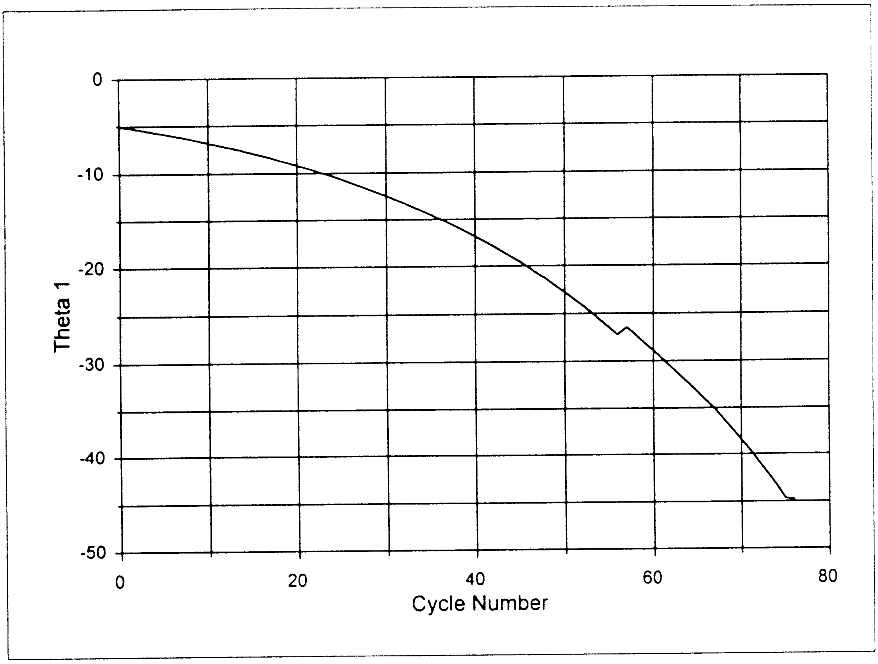

Figure 3. Fibre angle history at bottom left quarter of the 2x2 layout

6 The improved specimen

Based in the interesting results obtained by finite element analysis, a second specimen was built following the achieved optimum directions. Practical feasibility was attained by means of eight 0.01m width orthogonal strips having fibre orientations perpendicular to their longitudinal axes. A schematic drawing of the panel face is shown in Figure 4.

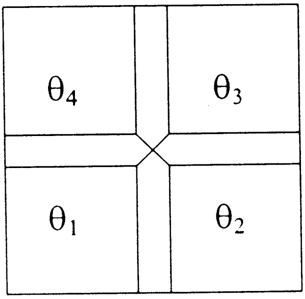

Figure 4. Schematic improved panel

The first natural frequency measured for that specimen was 231.1 Hz, again in its testing environment. That means an increase of 17.8% with respect to the basic specimen.

7 The improved model

A more detailed finite element model was developed taking into account the modifications included for feasibility of the improved specimen. It had 1225 nodes, 1152 quadrilateral 4-node elements and 8 triangular 3-node elements.

Its first natural frequency was found to be 234.4 Hz showing again an excellent level of agreement with the measured value.

8 Some advances

Having therefore a good level of confidence in the numerical procedures new advances were found following the partitioning procedure previously shown.

The third step was to subdivide the basic model in 16 equal square regions. Following the numerical approach used for previous finite element model optimization a new significant increase was obtained in the first eigenvalue that attained 6.675460 10^6, corresponding to a frequency of 411.2 Hz. The set of the sixteen fibre angles is presented in Figure 5.

50.918	34.075	-33.359	-44.471
48.523	48.344	-52.727	-47.679
-48.523	-48.344	52.727	47.679
-50.918	-34.075	33.359	44.471

Figure 5. Set of fibre angles for a 4x4 partition

The final improvement was obtained by means of an 8x8 subdivision attaining still a small gain in the eigenvalue calculated to be 6.795800 10^6 or 414.9 Hz, being its set of optimum fibre angles is presented in Figure 6.

44.072	44.072	33.060	35.105	-38.076	-38.076	-50.462	-50.462
44.072	44.072	35.105	35.105	-40.432	-38.076	-50.462	-50.462
47.252	47.252	49.210	70.542	-47.911	-47.911	-48.088	-48.088
44.499	44.499	55.487	79.539	-47.911	-47.911	-48.088	-48.088
-48.088	-48.088	-47.911	-47.911	79.539	55.487	44.499	44.499
-48.088	-48.088	-47.911	-47.911	70.542	49.210	47.252	47.252
-50.462	-50.462	-38.076	-40.432	35.105	35.105	44.072	44.072
-50.462	-50.462	-38.076	-38.076	35.105	33.060	44.072	44.072

Figure 6. Set of fibre angles for an 8x8 partition

9 Conclusions

The achieved finite element results are summarized in Table 2 showing each calculated frequency and also the corresponding partial and accumulated increases.

Transactions on Engineering Sciences vol 10, © 1996 WIT Press, www.witpress.com, ISSN 1743-3533

Layout	**Frequency** Hz	**Increase over previous layout** %	**Accumulated increase** %
1x1 0°	259.1	-	-
1x1 45°	294.7	13.7	13.7
2x2	381.7	29.5	47.3
4x4	411.7	7.9	58.9
8x8	414.9	0.8	60.1

Table 2. Summary of finite element results

The obtained improvements, encourage the continuation of research and development of composite panels with such an approach.

References

1. Moore, G. J. *MSC/NASTRAN Design sensitivity and optimization, User's Guide, v68,* The MacNeal-Schwendler Corporation, USA, May, 1984