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Finite element method analysis of some fibre-reinforced composite laminates

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Within this paper, behaviour simulations of various polymer matrix composite laminates subjected to three and four-point bending using the finite element method have been carried out. The models have been designed and analyzed with MSC Patran and MSC Nastran. Four types of composite laminates have been developed based especially on epoxy resin reinforced with Chopped Strand Mats of various specific weights and RT800 glass fabrics, namely four layers 4 x CSM450, four layers 4 x RT800-warp, four layers 4 x RT800-weft, eight layers 2 x CSM600/4 x RT800-warp/2 x CSM450 and eight layers 2 x CSM600/4 x RT800-weft/2 x CSM450 composite laminates. Using the finite element method, strain distributions of these four laminates subjected to three and four-point bending have been determined. The theoretical approach has been compared with experimental data obtained on LR5KPlus Lloyd Instruments materials testing machine. The comparison shows close values between both approaches.

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Keywords: Finite Element Method, Chopped strand mat, Roving, Young's modulus, Composite laminate

1. Introduction

To choose a material for a specific application is quite a challenging task. The user should consult the supplier for detailed mechanical property data on current materials, together with wider databases required for other property data (e.g. electrical, thermal, fire properties, surface finish, etc.), process information (e.g. gel time, working life, curing temperature, cure time, mold release temperature, etc.), as well as material or process costs. For composite applications, most design procedures, whether simple or sophisticated, will be based initially on stiffness data and will often relate to strain or deflection limits design. Consequently, Young's modulus values are normally required for the main in-plane directions of a composite laminate using orthogonal axes. Young's modulus is an important feature of any kind of material since represents its stiffness [1]. In addition, many applications of composites are based on thin-walled structures (e.g. thin pultruded profiles, skins of sandwich structures, etc.). The Young's modulus is also important in controlling the ultimate load for the commonly observed buckling failures. For a two phase composite material (e.g. matrix and fibres), Young's modulus as well as shear modulus can be determined using the well known rule of mixture. For multiphase composite materials, formed basically from matrix, fibres and filler, to predict their elastic properties, some homogenization methods can be used. Three averaging methods including arithmetic, harmonic and geometric means have been used to determine the elastic properties of three phase pre-impregnated composites such as Sheet Molding Compunds (SMCs). These elastic properties (Young's modulus as well as shear modulus) have been computed, for instance, for a 27% fibres volume fraction SMC prepreg. The theoretical approaches are very close to the experimental data obtained on these composite materials [2], [3]. Such approaches can be accomplished on other prepregs like Bulk and Dough Molding Compounds too. Besides tension and compression tests, static cyclic tension-compression tests with different test speeds as well as upper and lower cycle limits have been performed on three phase composite materials (e.g. unsaturated polyester resin, chopped strand mat and ceramic filler). Over forty mechanical properties have been experimentally determined including: stiffness, Young's modulus, load at maximum load, extension at maximum load, work at maximum load, load at maximum extension, extension at maximum extension, work at maximum extension, load at first cycle, extension at first cycle, load at last cycle, extension at last cycle, and so on [4]. Another research field is represented by the sandwich composite structures. An interesting sandwich is made from following layers with dissimilar skins: one layer RT500 glass roving fabric, two layers RT800 glass roving fabric, one layer chopped strand mat (CSM450), one layer nonwoven polyester mat as core and again one layer CSM450 Chopped Strand Mat. On this kind of sandwich structure, thermal expansions have been measured using a dilatometer. The coefficients of thermal expansion and the alpha feature have been determined only on the upper skin for two heating process [5].

2. Material and method

There is a wide range of fibre formats which together with the process used provide a useful information of different classes of composite materials. The fibres lengths can vary from discontinuous fibres (milled, short, and long) to continuous fibres in swirled mats, fabrics, no crimped fabrics, and under sectional plies. The major use of glass fibres is still represented by chopped strand mats. In general, a composite structure is manufactured of various plies of discontinuous or unidirectional fibres with different orientations, stacked together to form so called laminates. In this section we outline how such laminates are designed and analyzed. The model will be analyzed by help of MSC Nastran processor but before running the file we need to do some previous checking in order to validate the finite elements model, as follows:

- Determination of the distance between two locations or nodes;
- Determination of the angle between two directions determined by three points, one of them being considered as origin;
- Identification of common points;
- Identification of common lines;
- Identification of common nodes and joining them;
- Identification of nodes belonging to a selected plane, with the possibility of moving to this plane of the nodes from the adjacent area;
- Identification of the common finite elements;
- Determination of a finite element distortions;
- Identification of the normal in a plane finite elements group and comparing them to a given direction;
- Determination of mass properties for the finite elements;
- Checking the geometric boundary conditions;
- Determination of the loading forces sum in a node.

The model was developed using MSC Patran and MSC Nastran. In this paper we will present the study of composite samples made of chopped strand mat, roving and combination of chopped strand mat and roving subjected to three-point and four-point bending. Following composite materials have been used both in the theoretical and experimental approaches:

1. Four layers Epoxy/Chopped Strand Mat CSM450 (450 g/m^2 specific weight), 3.2-3.6 mm thick laminate (Fig. 1);
2. Four layers Epoxy/RT800 glass fabric (800 g/m^2 specific weight), 3.2-3.6 mm thick laminate, samples on warp direction (Fig. 2);
3. Four layers Epoxy/RT800 glass fabric (800 g/m^2 specific weight), 3.2-3.6 mm thick laminate, samples on weft direction (Fig. 3);
4. Two layers Epoxy/CSM600 (2-2.6 mm thick) – four layers Epoxy/RT800 on warp (3.2-3.6 mm thick) – two layers Epoxy/CSM450 (1.6-2 mm thick) (Fig. 4);
5. Two layers Epoxy/CSM600 (2-2.6 mm thick) – four layers Epoxy/RT800 on weft (3.2-3.6 mm thick) – two layers Epoxy/CSM450 (1.6-2 mm thick).

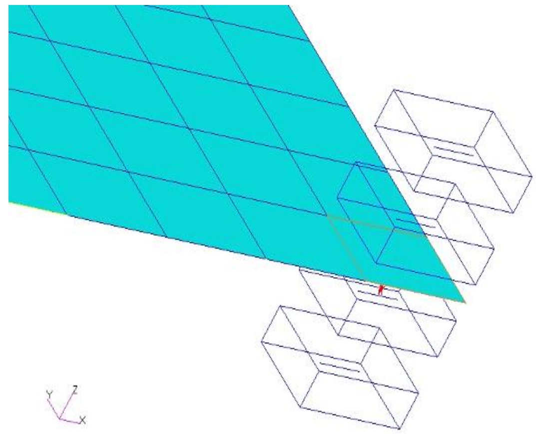

Fig. 1. Composite sample of Epoxy/Chopped Strand Mat type CSM450.

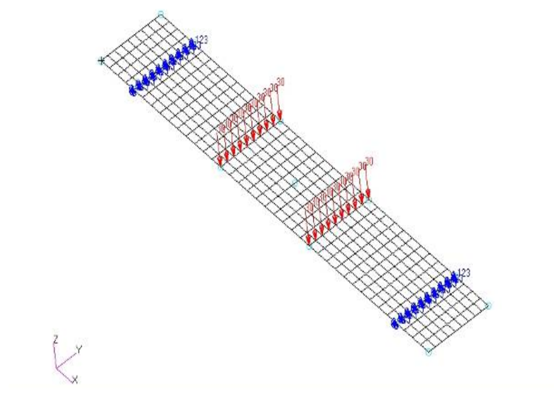

Fig. 2. Four layers Epoxy/RT800 – warp, subjected to four-point bending, 600 N.

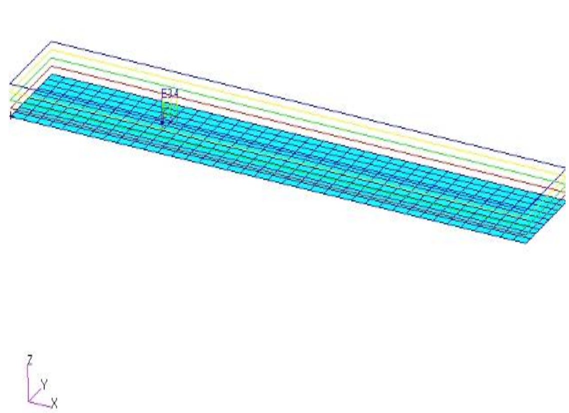

Fig. 3. Discretized specimen and arrangement of layers for four layers Epoxy/RT800 – weft.

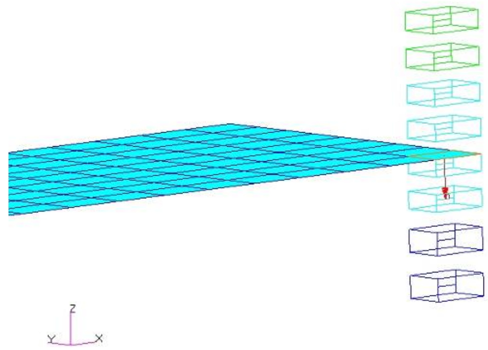

Fig. 4. Epoxy/CSM450/RT800 – warp/CSM600 composite laminate.

3. Results

The strain distributions of various composite laminates of different layers are presented in Figs. 5-9.

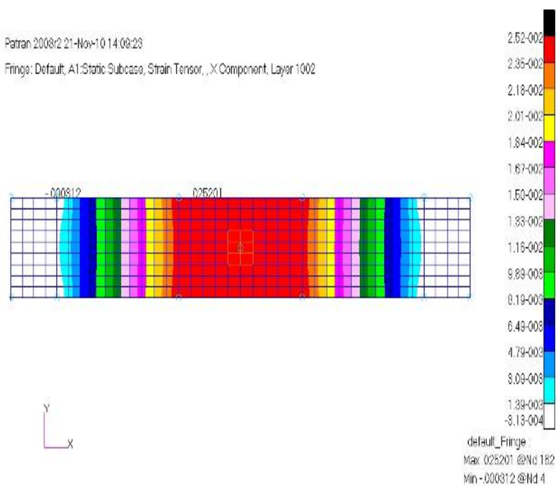

Fig. 5. Three-point bending. Strain distributions of Epoxy/CSM450 laminate (layer 2).

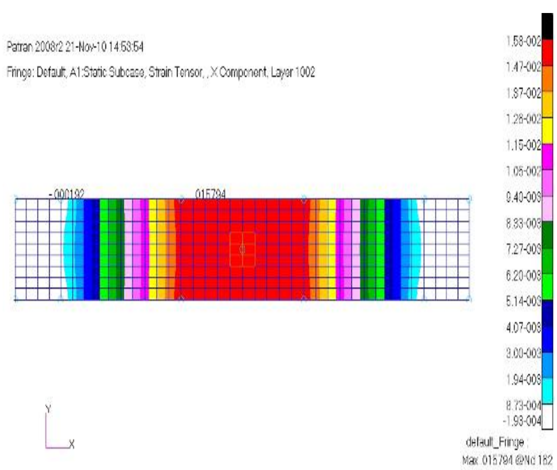

Fig. 6. Three-point bending. Strain distributions of Epoxy/RT800 – warp (layer 2).

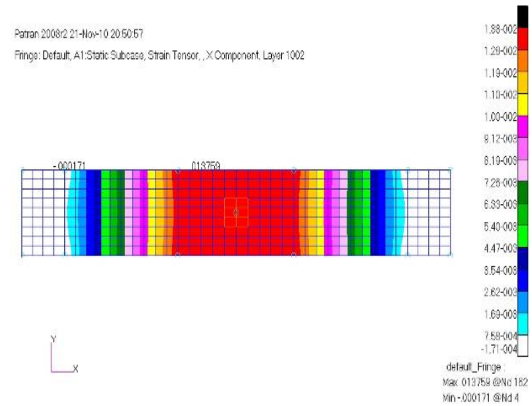

Fig. 7. Three-point bending. Strain distributions of Epoxy/RT800 – weft (layer 1).

For both composite laminates with eight layers combination between chopped strand mats and roving, the strain distributions are shown in Figs. 8-9.

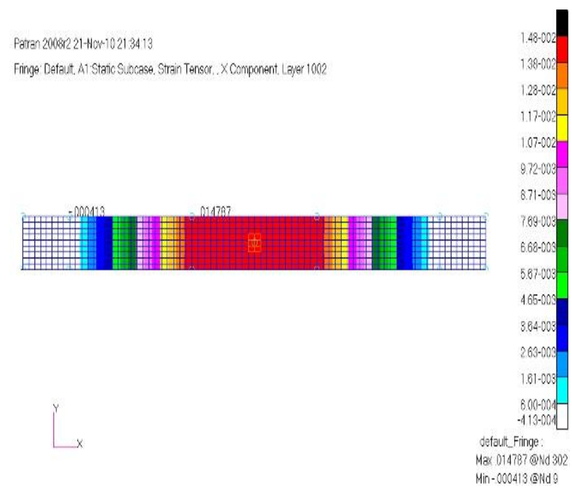

Fig. 8. Three-point bending. Strain distributions of Epoxy/CSM450/RT800–warp/CSM600 (layer 2).

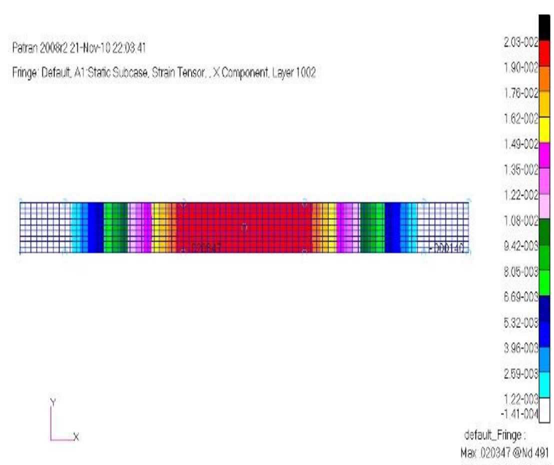

Fig. 9. Three-point bending. Strain distributions of Epoxy/CSM450/RT800–weft/CSM600 (layer 1).

4. Discussion

The first type of composite laminate made of four layers of Epoxy/CSM450, exhibits the maximum experimentally determined strain between –0.033210 and 0.033580, and the analysis with finite element method presents the same feature between –0.025 and 0.025 (Fig. 5). For the second type of composite laminate with four layers sequence of Epoxy/RT800 – warp, the maximum experimentally determined strain was between –0.023369 and 0.025651 unlike the theoretically determined one which was situated between –0.016 and 0.015 (Fig. 6). The errors occur due to the difference in distance from neutral axis to a finite element set. For the third type of composite laminate with four layers sequence of Epoxy/RT800 – weft, the maximum experimentally determined strain was recorded between 0.016164 and 0.017041 unlike the theoretically determined one which was situated between –0.014 and 0.014 (Fig. 7). For the epoxy based composite laminate with eight plies sequence CSM450/RT800–warp/CSM600, the maximum experimentally determined strain has been recorded between –0.02 and 0.02 as well as for the theoretically determined one which exhibits values between –0.020 and 0.021 (Fig. 8). It can be noticed that composite laminates with combination of chopped strand mat and roving present smaller maximum strain values than other studied composite laminates due to greater material's thickness than other ones. For the last type of epoxy based composite laminate with eight plies sequence CSM450/RT800–weft/CSM600, the maximum experimentally determined strain has been recorded between –0.02 and 0.02 as well as for the theoretically determined one which exhibits values between –0.035 and 0.020 (Fig. 9). Some experimental results like distributions of Young's modulus of bending versus maximum bending stress at break for RT800–warp and for CSM450/RT800/CSM600 epoxy based composite laminates are presented in Figs. 10-11 and present close values with the theoretical approach.

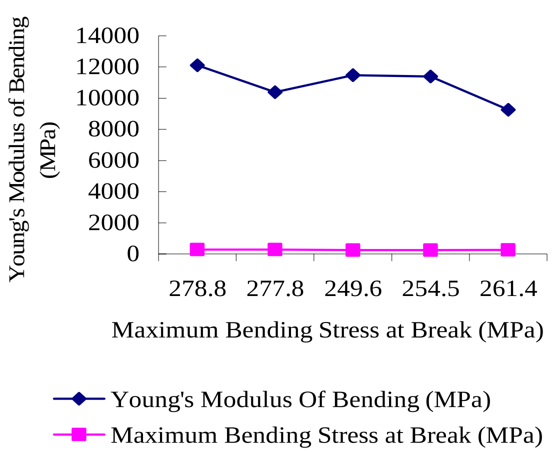

Fig. 10. Distribution of Young's modulus of bending for Epoxy/RT800-warp laminate.

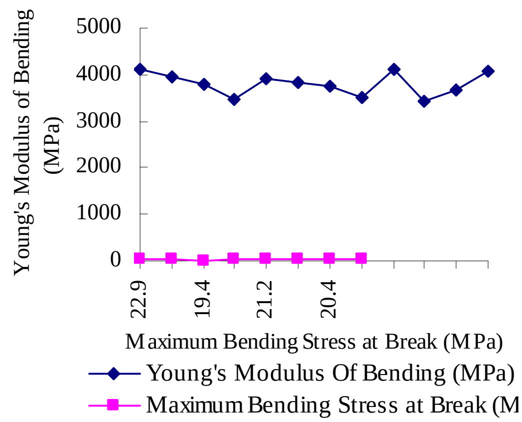

Fig. 11. Distribution of Young's modulus of bending for Epoxy/CSM450/RT800/CSM600 laminate.

5. Conclusions

The finite element method allows to compute a structure in order to determine the bearing capacity of the structure subjected to different types of loads, to track the spread of damages and how the structure behaves under certain loading conditions. Analysis of mechanical systems with the finite element method plays an important role in the modern design and is one of the ways to identify the strain and stress fields of the elements of mechanical systems.

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