Mechanical behavior of a thin nonwoven polyester mat subjected to three-point bend tests

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Within this paper, extended researches have been carried out regarding the mechanical behavior of a 4 mm thick nonwoven polyester mat subjected to three-point bend tests. From a sheet of nonwoven polyester mat impregnated with a thin layer of polyester resin just to be handled after curing, eighteen specimens have been cut according to ISO 14125:1998 – "Fibre-reinforced plastic composites – Determination of flexural properties" and subjected to three-point bend tests on a TEXTURE ANALYSER materials testing machine from Lloyd Instruments. Load-extension, stress-strain as well as other important distributions have been generated using the materials testing machine software NEXYGEN Plus. Some failure modes of the broken specimens have been put into evidence especially in side views. This material presents an outstanding resin absorption capability increasing the general stiffness of a structure.

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1. Introduction

The nonwoven polyester mat can be used as core material in thin sandwich structures to increase their stiffness. Regarding the core materials, there are some major groups of cores namely corrugated, balsa wood, foams and honeycomb [1]. As skins used in sandwich constructions we can commonly encounter fibre-reinforced composite materials like glass fibre-reinforced polyester resins, carbon/aramid fibre-reinforced epoxies or metal sheets. Since composite materials present anisotropies, the micromechanics of these materials are more complex than the metallic ones [2]. To increase the overall stiffness of a composite laminate, following procedure can be approached [3]:

- In the hand lay-up process, a layer of gelcoat is applied on the mold surface;
- Tailored reinforcement material as first layer is then placed over the gelcoat layer;
- The first layer of reinforcement material is impregnated with proper resin;
- All voids and air trapped in the impregnated reinforcement are removed with a suitable procedure;
- Then, the nonwoven polyester mat is placed over the impregnated reinforcement material;
- The nonwoven polyester mat is then impregnated with suitable resin;
- Tailored reinforcement material as second layer is then placed over the impregnated nonwoven polyester mat;
- The second layer of reinforcement material is then impregnated with proper resin;
- The whole stack of layers is cured with a suitable process.

The nonwoven polyester mat can be seen as a multiphase composite material. Very small glass microspheres represent one of the constituents. To predict its elastic properties, homogenization techniques as well as averaging methods can be used. Some methods are given for instance in the reference [4] where a 27% fibre volume fraction Sheet Molding Compound has been taken into account for method's demonstration. Another three-phase polymer matrix composite laminate formed from chopped strand mat impregnated with polyester resin and ceramic particles as filler, has been chosen to be tested at cyclic loadings. The laminate has been subjected to static cyclic tension-compression loadings until break occurs. Various test speeds and loading limits have been used during the whole procedure. Hysteresis effect has been put into evidence in all these tests. Up to 10 mm/min test speed, the hysteresis presented an increased distribution, after this value the hysteresis presents a decreasing tendency [5], [6].

In the case of unidirectional fibre-reinforced composite laminates subjected to off-axis loading systems, the Young's modulus presents interesting distributions on different fibres disposal angles. The stiffness of some composite laminates presents a constant distribution with the variation of the fibres disposal angle [7]. Some composite laminates reinforced with biaxial glass fabrics of type RT have been theoretically analyzed using the finite element method. The laminates cut from warp and weft directions have been subjected to three-point bend tests [8]. Even coefficients of thermal expansion have been experimentally determined on a thin sandwich structure with nonwoven polyester mat as core [9]. Statistic results for the Young's modulus, tensile strength and load at break determined in tensile tests have also been determined. In three-point bend tests, following statistic results have been computed on this sandwich structure:

- Young's modulus of bending;
- Flexural rigidity;
- Stiffness;
- Load at break.

2. Experimental setup

A 4 mm thick sheet of nonwoven polyester mat has been chosen to be impregnated with a thin layer of polyester resin in order to achieve a certain stiffness through curing. From the cured nonwoven polyester mat plate, eighteen specimens have been cut according to SR EN ISO 14125:1998 and subjected to three-point bend tests. The plate has been manufactured at Compozite Ltd., Brasov and tested in the Materials Testing Laboratory within Transilvania University of Brasov, Romania. The materials testing machine used in three-point bend tests is a TEXTURE ANALYSER type TA Plus, produced by Lloyd Instruments, UK, with following characteristics (Fig. 1):

- Force range: up to 1 kN;
- Test speed accuracy: < 0.2 %;
- Load resolution: < 0.01 % from the force cell;
- Extension resolution: < 0.1 microns;
- Type of force cell: XLC-1K-A1;
- Extensometer: type Epsilon Technology;
- Analysis software: NEXYGEN Plus.

Following main features have been determined in three-point bend tests:

- Stiffness (N/m);
- Young's modulus of bending (MPa);
- Flexural rigidity (Nm^2);
- Maximum bending stress/strain at maximum load (MPa);
- Maximum bending stress/strain at maximum extension (MPa);
- Maximum bending stress/strain at minimum load (MPa);
- Maximum bending stress/strain at minimum extension (MPa);
- Load/stress/strain at maximum load;
- Load/stress/strain at maximum extension;
- Load/stress/strain at minimum load;
- Load/stress/strain at minimum extension;
- Load/stress at break;
- Work to maximum load/extension;
- Work to minimum load/extension;
- Machine extension at maximum load.

Three-point test and specimens features are:

- Span: 50 mm;
- Test speed: 1 mm/min;
- Median specimens width: 10.05 mm;
- Median specimens thickness: 4 mm.

The materials testing machine allows determination of experimental results in electronic format by help of the NEXYGEN Plus software.

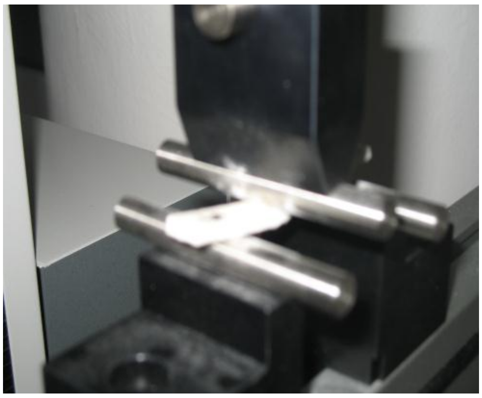

Fig. 1. TA Plus materials testing machine in a three-point bend test.

3. Three-point bend tests results

Basic mechanical properties determined in three-point bend tests are presented in table 1 as well as other features are shown in Figs. 2-9.

Table 1. Basic mean mechanical properties of 4 mm thick nonwoven polyester mat obtained in three-point bend tests.

Feature	Value
Stiffness (N/m)	20908
Young's modulus of bending (MPa)	1085
Flexural rigidity (Nm^2)	0.054
Load at maximum load (kN)	0.017
Maximum bending stress at maximum load (MPa)	8.510
Extension at maximum load (mm)	1.526
Maximum bending strain at maximum load (-)	0.014
Work to maximum load (Nmm)	16
Maximum bending stress at maximum extension (MPa)	0.399
Extension at maximum extension (mm)	7.544
Maximum bending strain at maximum extension (-)	0.070
Work to maximum extension (Nmm)	48
Load at minimum load (kN)	-0.00010
Extension at minimum load (mm)	1.137
Maximum bending stress at minimum load (MPa)	-0.048
Maximum bending strain at minimum load (-)	0.010
Work to minimum load (Nmm)	7
Load at minimum extension (kN)	-0,0000035
Maximum banding stress at minimum extension (MPa)	-0.0018
Extension at minimum extension (mm)	0.0000013
Maximum banding strain at minimum extension (-)	1.3447E-08

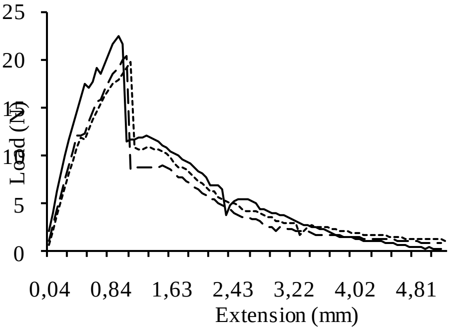

Fig. 2. Three-point bend test. Specimens 1-3.

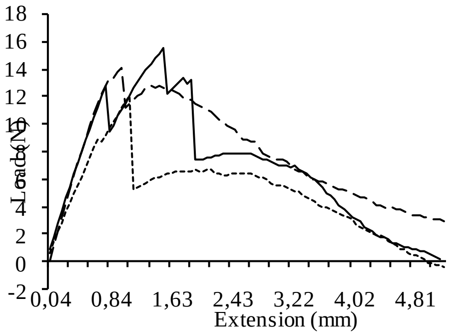

Fig. 3. Three-point bend test. Specimens 4-6.

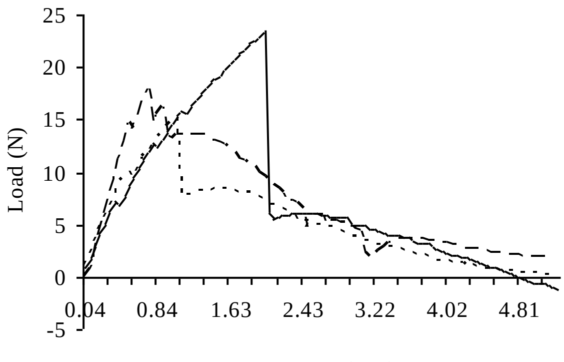

Fig. 4. Three-point bend test. Specimens 7-9.

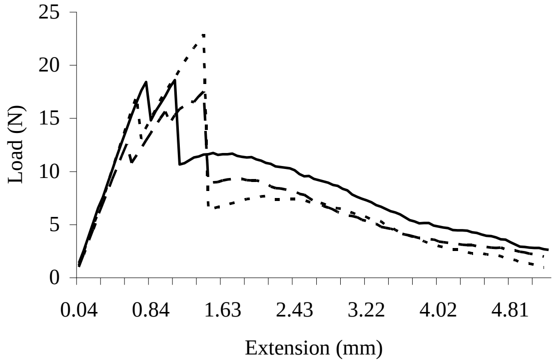

Fig. 5. Three-point bend test. Specimens 10-12.

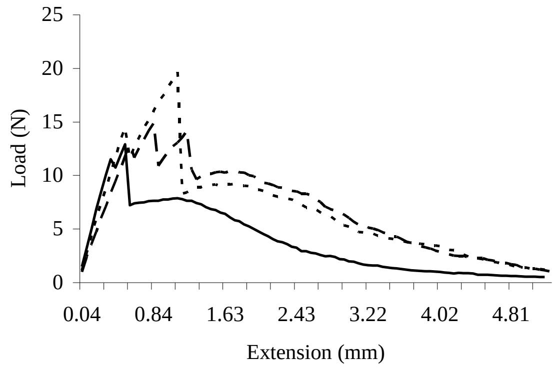

Fig. 6. Three-point bend test. Specimens 13-15.

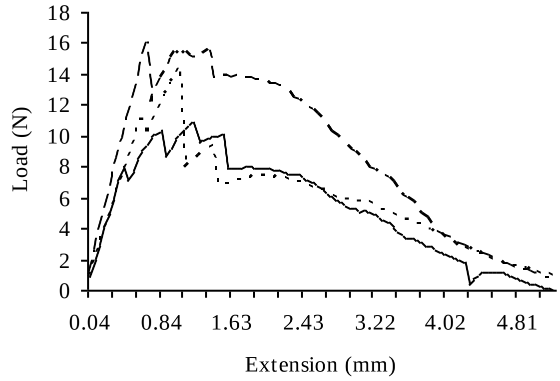

Fig. 7. Three-point bend test. Specimens 16-18.

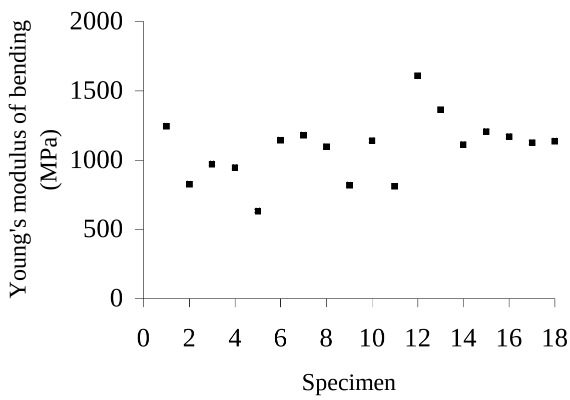

Fig. 8. Young's modulus of bending distribution.

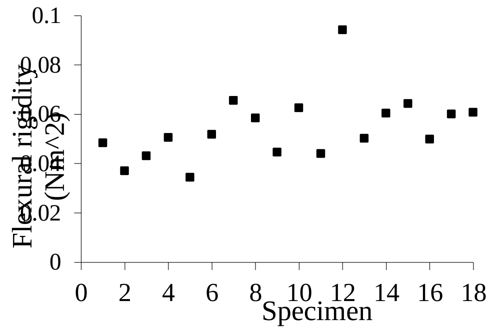

Fig. 9. Flexural rigidity distribution.

4. Discussion

Load-extension distributions of specimens 1-3 present a peak value of 23 N load with a decreased tendency to specimens' number 2 and 3. The extension distributions show an increased tendency from specimen 1 to 3. The load-extension distributions of specimens 4-6 show that the first highest peak load is reached by specimen number 5 followed by specimen 4 and then 6. Specimen 3 presents a rapid load decrease between 0.84 and 1.63 mm extension. Specimens' 7-9 load-extension distributions present an important load decrease of specimen 7 between 1.63 and 2.43 mm extension. At specimens 10-12 load-extension distributions, the highest load value is reached by specimen 12. Same tendency is noticed at specimens' 13-15 load-extension distributions where the highest load value is reached by specimen 15. Specimens' 16-18 load-extension distributions show that the highest load value is reached by specimen number 17 between 0.4 and 0.84 mm extension. Some failure modes in three-point bend tests of the 4 mm thick nonwoven polyester mat are presented as side views in Figs. 10-11.

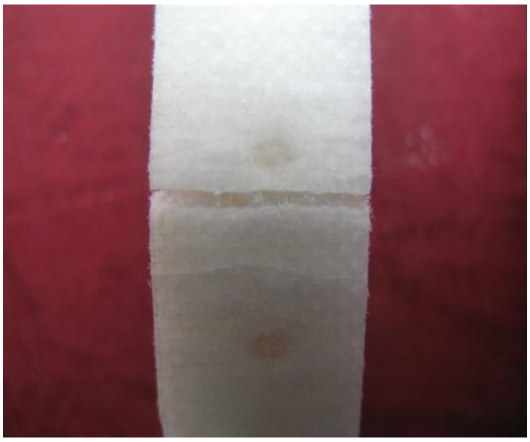

Fig. 10. Break detail of 4 mm thick nonwoven polyester mat subjected to three-point bend test.

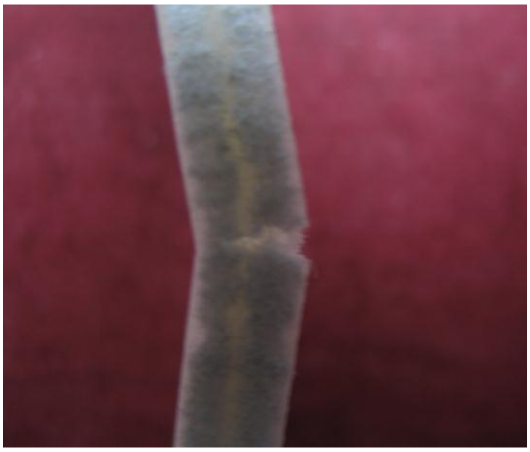

Fig. 11. Side view of 4 mm thick nonwoven polyester mat after break in three-point bend tests.

5. Conclusions

The nonwoven polyester mat represents an excellent choice as core for thin composite laminates. Embedding it in a composite laminate structure, it increases the overall structure's stiffness unlike the stiffness for a composite laminate without this material. An outstanding median stiffness of 20908 N/m has been achieved at light impregnated nonwoven polyester mats. To avoid using ribs in most common composite structures, this material can increase the overall structure's stiffness up to twelve times then its skins without important resin and reinforcement consumption with environmental consequences.

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