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Behavior of multiphase fiber-reinforced polymers under short time cyclic loading

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The paper presents the most important results regarding mechanical properties of three-phase chopped strand mat-Al_2O_3 particles-SYNOLITE 8388 P2 polyester resin laminates subjected to short time static cyclic tension-compression loadings. Distributions of 10 cycles' tension-compression loadings at various test speeds and cycle limits have been determined on a Lloyd Instruments LS100Plus materials testing machine. Maximum hysteresis data as well as stiffness distributions of specimens that exhibit maximum hysteresis have been presented. Extended researches regarding the behavior of these laminates subjected to short time static cyclic loadings have been accomplished, quantified in determination of over forty-five mechanical properties. Hysteresis data determined as a difference between first and last cycle extension have been reported at 10 mm/min test speed with a decreasing tendency once test speed is increased.

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Keywords: Polymer matrix composites, Chopped strand mat, Cyclic loading, Hysteresis

1. Introduction

It is well known that a simple tensile test is the most basic of all mechanical tests. It tells us how strong and stiff a material is. Generally, the strongest material from its class is usually the most difficult to test for tensile properties [1-3]. Composite materials are no exception and for instance, the axial loading of a unidirectional composite presents the greatest challenge. However, static cyclically tension-compression tests are for a great importance to put into evidence the time dependent structural changes inside a material. One of the most important problems in a cyclic tension-compression test of any composite material is the gripping of the specimen without introducing unacceptable stress concentrations. In general, grips are clamped into the specimen ends, transferring the applied cyclic loads at the specimen surface into tensile/compression stresses within the specimen [4-6]. We assume that composite materials can be strong and therefore the clamping forces are significant. To avoid high clamping forces it is possible to make the specimen as thin as practically possible or to make the grip length longer so that the clamping force can be distributed over a larger area [7-8]. In order to estimate the failure and cyclic life, Tan and Dharan have obtained cyclic hysteresis experimental data, for instance, on notched [0/90] E-glass/epoxy laminates [9]. Tensile as well as fatigue tests both on polyester and polyurethane-based fiber-reinforced polymers as well as studies concerning the damage development in randomly disposed E-glass fibers-reinforced polymers under fatigue loading (until 10^5 cycles) have been accomplished by Setiadi *et al.* [10]. To estimate the elastic properties of randomly fiber-reinforced polymer matrix composites, Vlase et al. [11] and Motoc [12] present interesting approaches.

2. Composite samples and experimental procedure

The multiphase composite samples used in the short time static cyclic tension-compression tests have been manufactured as having random fibers and particles embedded in different volume fractions into a polymeric matrix. The matrix material is known as SYNOLITE 8388 P2 from DSM Composite Resins, Switzerland, a polyester resin type. Particles inclusions considered were ceramic materials with a high content of Al_2O_3, made from a natural stone, characterized as having a relatively high purity and provided by Alpha Calcite, Germany under the ALFRIMAL registered trade-mark, mixed within the polyester resin mass in 5% and 10% volume fractions, respectively. The 3rd phase chosen were E-glass type random fibers, available under MultiStratTM Mat ES 33-0-25 trade name, from Johns Manville, USA, mixed as having a 65% volume fraction in the overall composite volume. A reference sample has been made without any particle content and used for comparison purpose. The samples have been conditioned within a temperature-controlled oven to an extreme environmental regime, 7 days, 24 hours/day, at temperature range from -10 °C to 40 °C. The humidity levels, temperatures and hours corresponding to a single day thermal cycle, used as input data for the oven programming, are given in Table 1.

Table 1. Conditioning features of the composite samples.

Temperature [^{0}C]	Relative humidity level [%]	Time [h]
-10	45	8
0	50	1
10	50	1
20	55	1
30	60	1
40	65	8

The composite samples have been subjected to 10 cycles static tension-compression loading at various test speeds and cycle limits on a Lloyd Instruments LS100Plus materials testing machine. Some specimens and test features are presented in Table 2.

Table 2. Test speeds, cycle limits and specimens features used in short time cyclic loading.

Test and specimens features	Values				
Gauge length [mm]	50	50	50	50	50
Test speed [mm/min]	1	10	20	40	40
Specimens width [mm]	15	15	15	15	15
Specimens thickness [mm]	4.86	4.86	4.86	4.86	4.86
Cycle limit 1 [N]	3000	3000	3000	3000	3000
Cycle limit 2 [N]	300	300	300	0	- 2000

3. Results

The following mechanical properties have been determined: stiffness, Young's modulus, load at maximum load, stress at maximum load, machine extension at maximum load, extension at maximum load, strain at maximum load, percentage strain at maximum load, work to maximum load, load at maximum extension, stress at maximum extension, machine extension at maximum extension, extension at maximum extension, strain at maximum extension, percentage strain at maximum extension, work to maximum extension, load at minimum load, stress at minimum load, machine extension at minimum load, extension at minimum load, strain at minimum load, percentage strain at minimum load, work to minimum load, load at minimum extension, stress at minimum extension, machine extension at minimum extension, extension at minimum extension, strain at minimum extension, percentage strain at minimum extension, work to minimum extension, load at first cycle, stress at first cycle, machine extension at first cycle, extension at first cycle, strain at first cycle, percentage strain at first cycle, first cycle work, load at last cycle, stress at last cycle, machine extension at last cycle, extension at last cycle, strain at last cycle, percentage strain at last cycle and last cycle work.

Distributions of 10 cycles tension-compression loadings determined on specimens that exhibit maximum histeresis, at various test speeds and cycle limits are presented in Figs. 1-5. More results regarding stiffness, loads at maximum load and extensions at maximum load are shown in Tables 3-6.

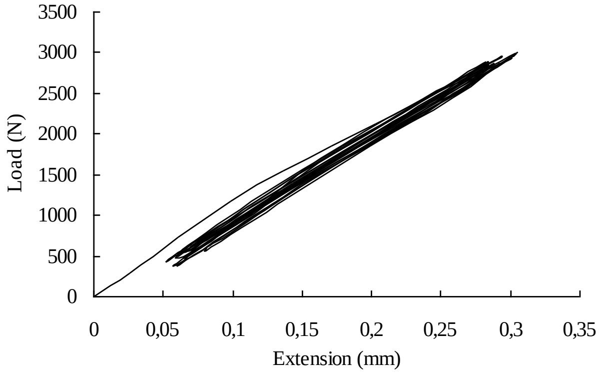

Fig. 1. Distribution of 10 cycles tension-compression loadings. Maximum hysteresis specimen. (Test speed: 1 mm/min; cycle limit 1: 3000 N; cycle limit 2: 300 N)

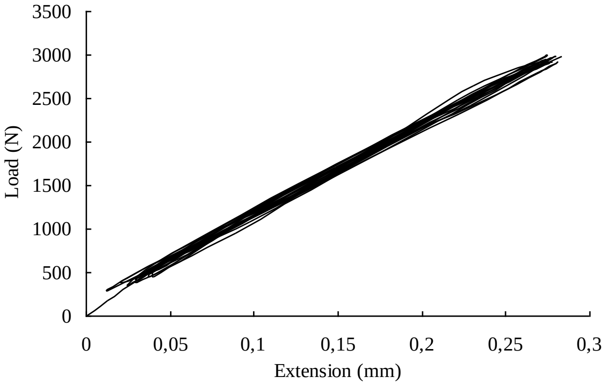

Fig. 2. Distribution of 10 cycles tension-compression loadings. Maximum hysteresis specimen. (Test speed: 10 mm/min; cycle limit 1: 3000 N; cycle limit 2: 300 N).

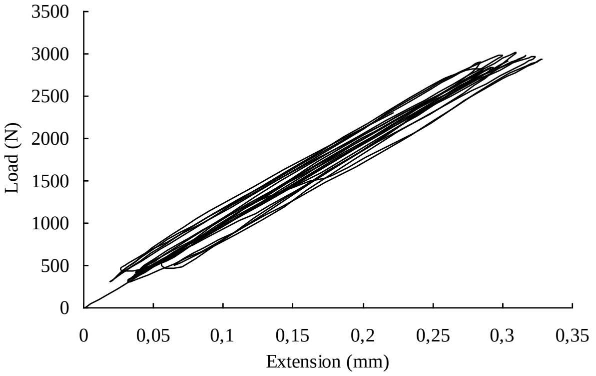

Fig. 3. Distribution of 10 cycles tension-compression loadings. Maximum hysteresis specimen. (Test speed: 20 mm/min; cycle limit 1: 3000 N; cycle limit 2: 300 N).

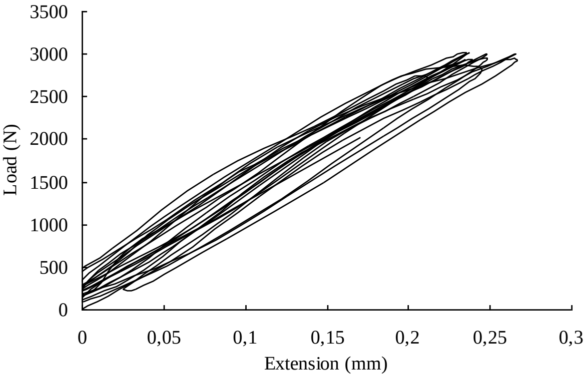

Fig. 4. Distribution of 10 cycles tension-compression loadings. Maximum hysteresis specimen. (Test speed: 40 mm/min; cycle limit 1: 3000 N; cycle limit 2: 0 N).

Table 3. Ten cycles loadings on five specimens. Results at 1 mm/min test speed.

Stiffness [N/m]	Load at Maximum Load [kN]	Extension at Maximum Load [mm]
13475942.4	3.00377393	0.30719793
15132051.5	3.00759271	0.32767069
16549676.8	3.002124	0.29343876
16095991.2	3.00837308	0.30559519
33332739.9	3.00593337	0.25764742

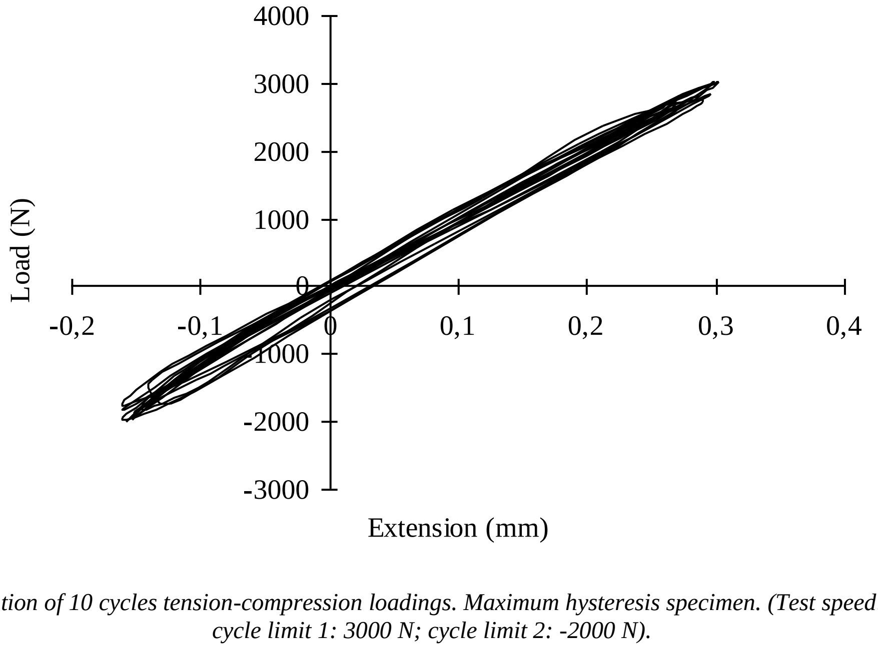

Fig. 5. Distribution of 10 cycles tension-compression loadings. Maximum hysteresis specimen. (Test speed: 40 mm/min; cycle limit 1: 3000 N; cycle limit 2: -2000 N).

Table 4. Ten cycles loadings on five specimens. Results at 10 mm/min test speed.

Stiffness [N/m]	Load at Maximum Load [kN]	Extension at Maximum Load [mm]
13967680.9	3.00937169	0.28241922
16661178.1	3.00540243	0.28349737
135859632	3.00931013	0.30639223
73525334.1	3.01062039	0.20652689
60387410.8	3.00700736	0.33509265

Table 5. Ten cycles loadings on five specimens. Results at 20 mm/min test speed.

Stiffness [N/m]	Load at Maximum Load [kN]	Extension at Maximum Load [mm]
17827375	3.00943709	0.28685673
13379229.6	3.01802144	0.31033918
15775800.3	3.01335963	0.25577515
13231534.5	3.01604018	0.2722434
14079242	3.015046	0.2523938

Table 6. Ten cycles loadings on five specimens. Results at 40 mm/min test speed.

Stiffness [N/m]	Load at Maximum Load [kN]	Extension at Maximum Load [mm]
23242274	3.03827211	0.2401018
19543018.2	3.0141013	0.26273534
15370866.1	3.0401521	0.28077099
13525374.8	3.02023364	0.28549097
15314877.1	3.03328912	0.2537304

The distributions of the maximum hysteresis as well as stiffness at various test speeds and cycle limits are presented in Figs. 6-7. The maximum hysteresis values have been determined as a difference between maximum extension at first cycle and maximum extension at last cycle. Some statistics such as coefficient of variance, standard deviation (N) and standard deviation (N-1) have been also determined.

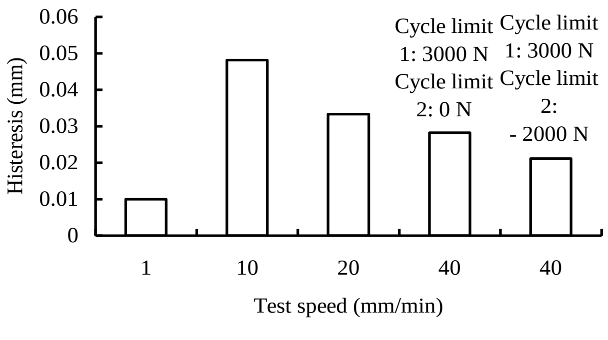

Fig. 6. Maximum hysteresis at various test speeds and cycle limits (up to 20 mm/min test speed, cycle limit 1: 3000 N; cycle limit 2: 300 N).

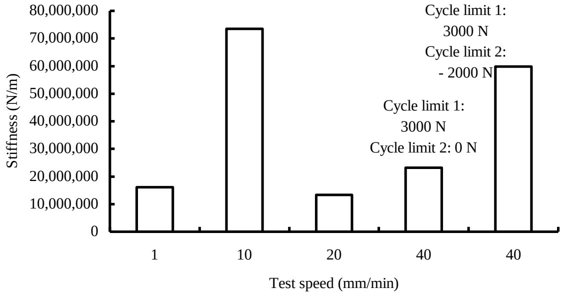

Fig. 7. Stiffness distribution at various test speeds and cycle limits (up to 20 mm/min test speed, cycle limit 1: 3000 N; cycle limit 2: 300 N). Maximum hysteresis specimens.

4. Conclusions

It can be noticed that with the test speed increase, non-linear behavior at unloading phase is more significant. Maximum hysteresis value has been determined at 10 mm/min tests speed and with test speed increase the hysteresis distribution decrease. Maximum stiffness has been reported also at 10 mm/min tests speed with an increase once the test speed is increased. With the increase of cycle limits, the maximum hysteresis presents a decreasing tendency while the stiffness distribution increases. For instance, some statistics for maximum hysteresis are presented as follows:

- Stiffness coefficient of variance: 74.19%;
- Young’s modulus coefficient of variance: 72.14%;
- Load at maximum load coefficient of variance: 0.06%;
- Extension at maximum load coefficient of variance: 15.09%;
- Work to maximum load coefficient of variance: 18.61%;
- Load at maximum extension coefficient of variance: 0.29%;
- Extension at maximum extension coefficient of variance: 7.87%;
- Work to maximum extension coefficient of variance: 16.16%;
- Load at first cycle coefficient of variance: 2.47%;
- Extension at first cycle coefficient of variance: 36.72%;
- Load at last cycle coefficient of variance: 2.37%;
- Extension at last cycle coefficient of variance: 126.82%.

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