Hysteresis effect in a three-phase polymer matrix composite subjected to static cyclic loadings

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The paper presents hysteresis behaviours of three-phase randomly oriented glass fibre-ceramic particles-reinforced polyester resin composite material subjected to static cyclic tension-compression loadings. Various cyclic tests with different test speeds, load limits and number of cycles have been accomplished on a Lloyd Instruments LS100Plus materials testing machine with STGA/50/50 E85454 extensometer. Among over forty-five mechanical properties determined in extended experimental researches, maximum hysteresis data as well as stiffness distributions of specimens that exhibit maximum hysteresis have been presented. The difference between first and last cycle extension in every single test has been computed to determine maximum hysteresis effect reported at 10 mm/min test speed with a decreasing tendency once test speed is increased.

(Received February 25, 2011; accepted March 16, 2011)

Keywords: Hysteresis effect, Polymer matrix composites, Static cyclic loadings, Load limits, Stiffness

1. Introduction

Static cyclically tension-compression tests are for a significant importance to put into evidence time dependent structural changes inside a material [1-2]. One of the most important problems in a static cyclic tension-compression test of any composite material and especially in thin polymer matrix composite laminates is the gripping of the specimen without introducing unacceptable stress concentrations in its structure [3-4]. For instance, grips are clamped into the specimen ends, transferring the applied cyclic tension-compression loads at the specimen's surface into tensile-compression stresses within the specimen and therefore the clamping forces are significant [5-7]. To avoid high clamping forces it is necessary to manufacture specimens as thin as practically possible or to ensure longer grip lengths so that the clamping forces can be distributed over a larger area [8]. Setiadi *et al.*, have been accomplished tensile and fatigue tests on both polyester and polyurethane-based fibre-reinforced polymer matrix composites as well as studies concerning the damage development in randomly disposed E-glass fibre-reinforced polymers under fatigue loadings up to 10^5 cycles [9]. To estimate the failure and cyclic life, Tan and Dharan have determined cyclic hysteresis experimental data, for instance, on notched [0/90] E-glass/epoxy laminates [10]. Vlase *et al.* [11], Motoc [12], Teodorescu and Vlase [13], present theoretical approaches regarding the prediction of elastic properties of unidirectional or randomly fibre-reinforced polymer matrix composites with and without the particles phase.

In general, a randomly disposed chopped strand mat presents 25.4 mm or 50 mm glass fibres lengths. This type of reinforcement is manufactured from E-glass continuous fibres, bound with powder binder, compatible with synthetic resins and used in naval constructions, sport articles, garden furniture and playgrounds for children, tanks, and products for bathrooms, plain and corrugated plates. It is usually used for the hand lay-up technique and for parts that do not require high strength. Chopped strand mats present good solubility in styrene, very easy impregnation, in general is silane sized and is suitable for polyester resin systems reinforcement. Main characteristics of these kinds of reinforcement, depending on the manufacturer, are: specific weights: 150; 225; 300; 375; 450 and 600 ± 8% [g/m^2]; widths: 1000; 1250 ± 2 [mm]; moisture content: max. 0.2%; size content: 2.5 – 7%. For instance, a typical stress-strain behaviour of chopped strand mat CSM 600 reinforced polyester resin laminates of about 4 mm thickness determined in a simple tensile test on a LS100Plus Lloyd Instruments materials testing machine, shows an approximately 100 MPa ultimate tensile strength (UTS) and 0.035 – 0.04 strains. It has been noticed that the common failure mode is the inter-fibre break that begins at a strain of 0.012 as well as fibres break.

2. Materials and experimental procedure

The composite material used in static cyclic tension-compression loadings is a three-phase one:

- Chopped strand mat CSM 600 (up to 60% E-glass fibres volume fraction);
- Al_2O_3 ceramic particles (up to 10% volume fraction);
- Polyester resin.

A 5 mm thick composite plate has been manufactured from which specimens (dimensions: 5 x 15 x 150 mm) have been cut. The composite specimens have been subjected to different cycles static tension-compression loadings at various test speeds and cycle limits on a Lloyd Instruments LS100Plus (up to 100 kN force range) materials testing machine with a STGA/50/50 E85454-type extensometer (Epsilon Technology Corp.). All experimental data have been procesed using a Nexygen Plus materials testing software. Specimens and tests features are presented in Table 1.

Table 1. Test speeds, cycle limits, number of cycles and specimens features used in cyclic tests.

	Values					
Gauge length [mm]	50	50	50	50	50	50
Test speed [mm/min]	1	10	20	40	60	60
Specimens width [mm]	15	15	15	15	15	15
Specimens thickness [mm]	4.86	4.86	4.86	4.86	4.86	4.86
Cycle limit 1 [kN]	3	3	3	3	3.5	3.5
Cycle limit 2 [kN]	0.3	0.3	0.3	-2	-3.5	-3.5
Number of cycles	10	10	10	10	10	100

3. Results

Folowing 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, last cycle work, load at break, stress at break, machine extension at break, extension at break, strain at break, percentage strain at break and work to break. Distributions of tension-compression cycles determined on specimens that exhibit maximum histeresis, at various test speeds, cycle limits and number of cycles are presented in Figs. 1-8.

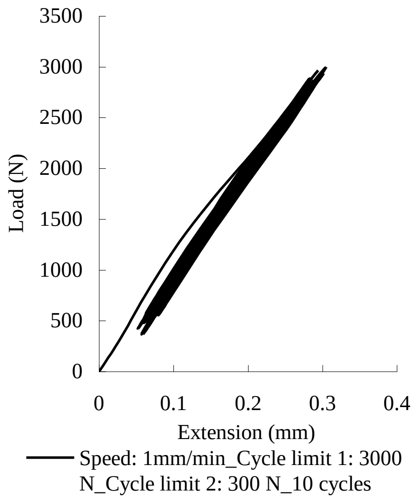

Fig. 1. Tension-compression loadings (1mm/min test speed, 10 cycles). Maximum hysteresis specimen.

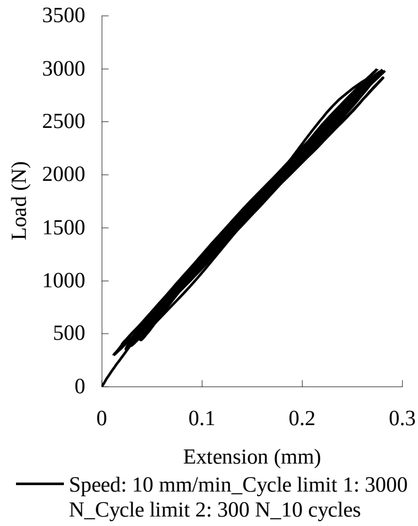

Fig. 2. Tension-compression loadings (10mm/min test speed, 10 cycles). Maximum hysteresis specimen.

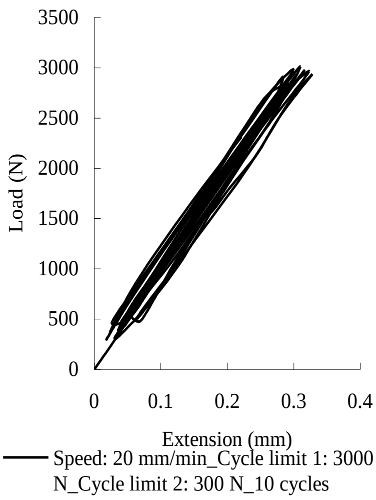

Fig. 3. Tension-compression loadings (20mm/min test speed, 10 cycles). Maximum hysteresis specimen.

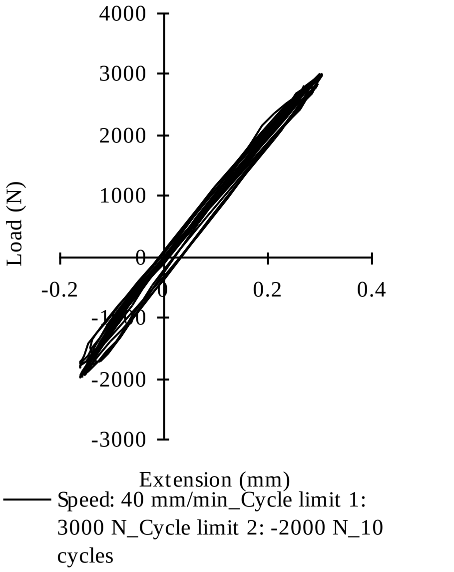

Fig. 4. Tension-compression loadings (40mm/min test speed, 10 cycles). Maximum hysteresis specimen.

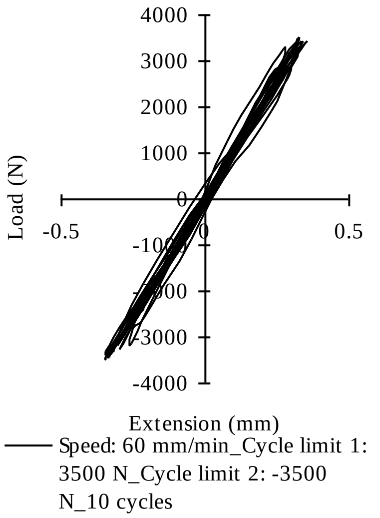

Fig. 5. Tension-compression loadings (60mm/min test speed, 10 cycles). Maximum hysteresis specimen.

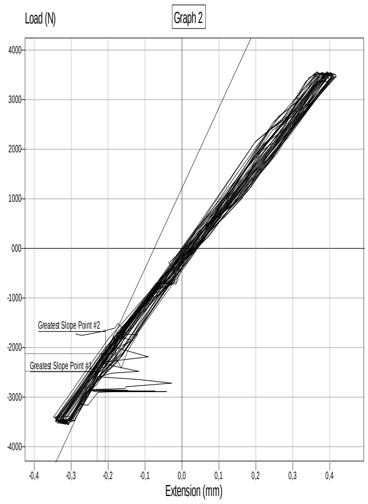

Fig. 6. Tension-compression loadings (60mm/min test speed, 20 cycles, cycle limits: 3500 N; -3500 N).

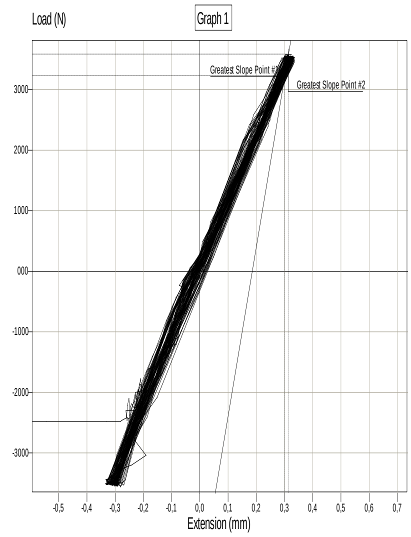

Fig. 7. Tension-compression loadings (60 mm/min test speed, 50 cycles, cycle limits: 3500 N; -3500 N).

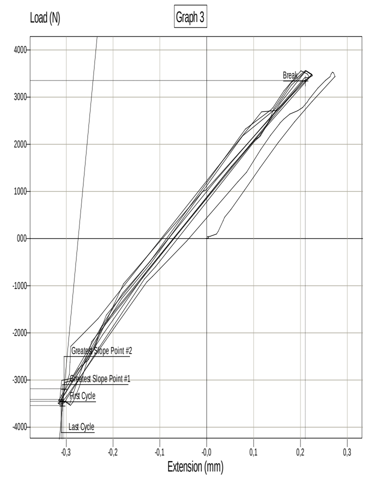

Fig. 8. Tension-compression loadings before break on specimen number 3 (60 mm/min test speed, 5 cycles).

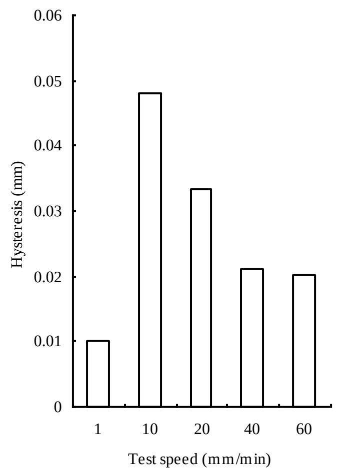

Fig. 9. Maximum hysteresis (10 cycles) at different test speeds and cycle limits.

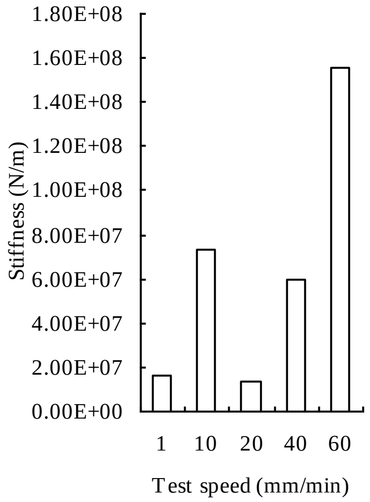

Fig. 10. Stiffness distribution (10 cycles) of maximum hysteresis specimens at various test speeds.

4. Discussion

Distributions of maximum hysteresis as well as stiffness at various test speeds and cycle limits determined at 10 cycles are presented in Figs. 9-10. The maximum hysteresis values have been determined as a difference between maximum extension at first cycle and maximum extension at last cycle. At 1 mm/min test speed the composite material presents a 0.29 mm extension at maximum load while at 10 mm/min test speed, the extension at maximum load exhibits 0.28 mm. The decreasing tendency maintains until 40 mm/min test speed when the extension at maximum load presents the median value of 0.26 mm. With the test speed of 60 mm/min, this extension at maximum load increases quickly at a median value of 0.31 mm (Fig. 11).

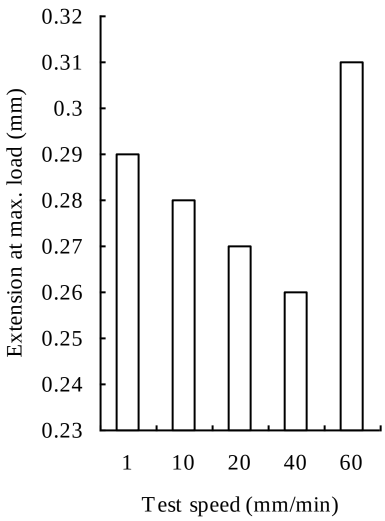

Fig. 11. Extension at maximum load distribution at various test speeds.

Unlike the decreasing tendency of this extension, the load at maximum load presents an increasing tendency once the test speed is increased (from 3.005 kN median value at 1 mm/min test speed to 3.542 kN median value at 60 mm/min test speed). The stiffness of the composite material presents an increased tendency with the increase of test speed. This increase is up to 10 times at 60 mm/min test speed. Between 300 N and 3000 N cycle limits, the load at first cycle presents an increased distribution from a median value of 0.308 kN at 1 mm/min test speed to 0.33 kN at 20 mm/min test speed. The extension at last cycle distribution presents a decreased tendency while the load at last cycle presents an increasing tendency (Figs. 12-13).

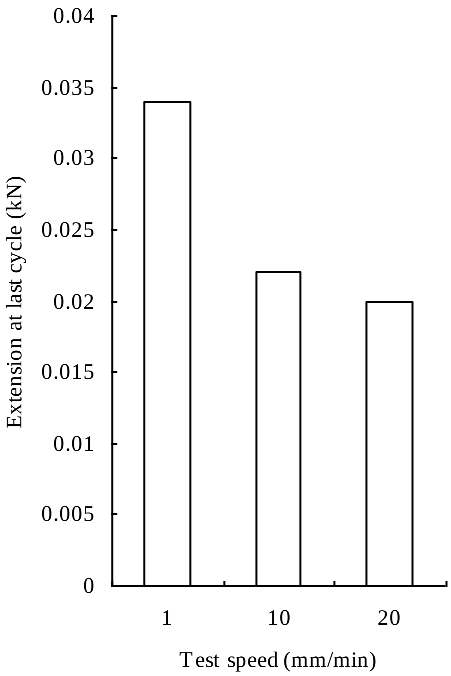

Fig. 12. Extension at last cycle distribution at various test speeds.

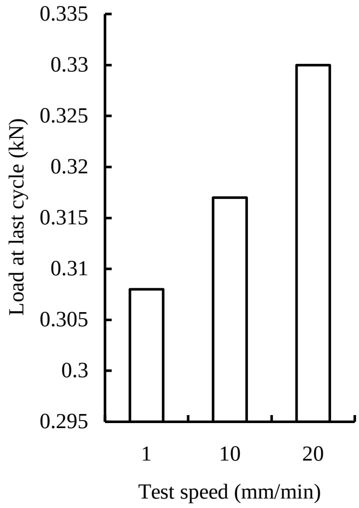

Fig. 13. Load at last cycle distribution at various test speeds.

5. 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 test speed with a decreasing tendency once the test speed increases. Maximum stiffness has been determined at 60 mm/min tests speed, the general tendency is the increase of this stiffness. With the increase of cycle limits, the maximum hysteresis presents a decreasing tendency while the stiffness distribution increases. The same specimens have been subjected to increased loading conditions; this means increased cycle limits, test speeds and number of cycles. The break detector reported breaking of the composite material after 115 static cyclic tension-compression loadings. All the experimental data have been processed statistically. For instance, some statistics for maximum hysteresis results are presented below:

- 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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