Mechanical Properties and Damage Development in GlassFiber Epoxy Laminates Subjected to Tensile Loading at Sub-zero Temperatures

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ABSTRACT

The study focuses on mechanical behavior of glass fiber (GF) composite laminates at different temperatures (room and sub-zero). The laminates are subjected to loading-unloading tensile tests. The degradation of stiffness during the loading due to the micro-damage accumulation is observed. The purpose of this work is to identify the most suitable epoxy system for use in low-temperature environment.

INTRODUCTION

GF/Epoxy composites show promising performance for cryogenic applications but complex thermomechanical loads can cause premature damage initiation and accelerate accumulation of micro-cracks due to brittleness of matrix as well as high thermal stresses in different layers of the laminate [1,2]. This damage can have severe consequences, such as decrease of stiffness but also leaks in pressure vessels and possible premature failure of structures. Thus, delaying the development of the damage is highly desirable.

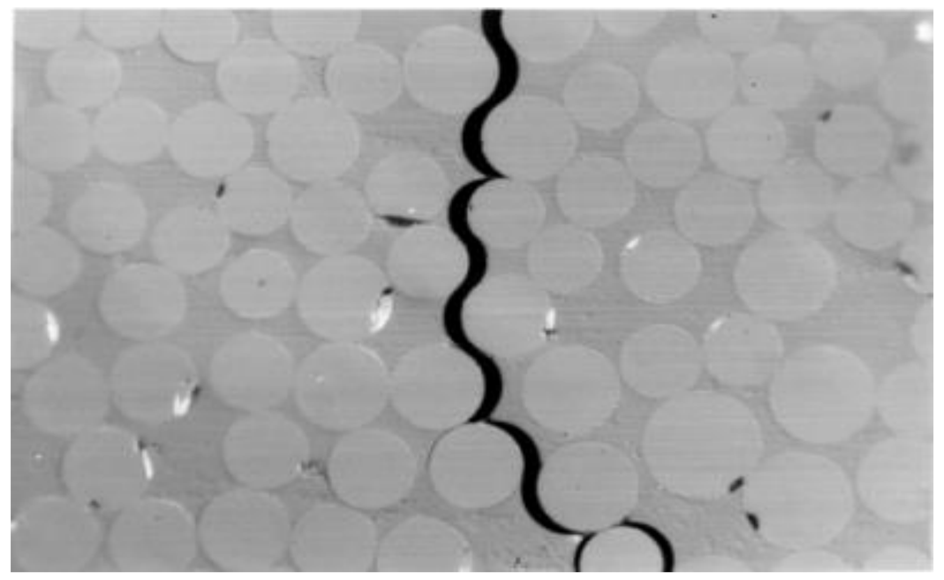


Figure 1. Example of micro-cracks in GF composites (average fiber diameter ≈24μm).

EXPERIMENTAL

- The composite laminates were made out of E-glass plain weave fabric. The fiber volume fraction in composite is around 55% and laminate lay-up is $[0°/90°]_8$. Two types of epoxy resins were used: YD-128 from Aditya Birla Chemicals and YDPN 638A80 from Kukdo. These resins were enhanced with DDS, DICY, and Nowolak P hardeners for improved cryogenic properties.
- Tests were conducted on an Instron 3366 universal testing machine equipped with a 10 kN load cell, mechanical grips and an environmental chamber. Strains were measured by a standard Instron clip-on extensometer.
- Cyclic loading-unloading tests were performed on standard rectangular specimens with step-wise increasing applied strain from 0.25% to failure.
- In displacement-controlled mode, the maximum strain for the samples was 1.2% at a loading rate of 2 mm/min. Small loading-unloading ramp in between high strain steps was done for measurements of Young's modulus (see schematic loading history below).
- The modulus was determined from the linear part of the stress-strain curves within the strain range of 0.05% - 0.20%.
- For sub-zero temperature, samples were held at -50°C for about 30 min before starting test to ensure thermal saturation of the samples.

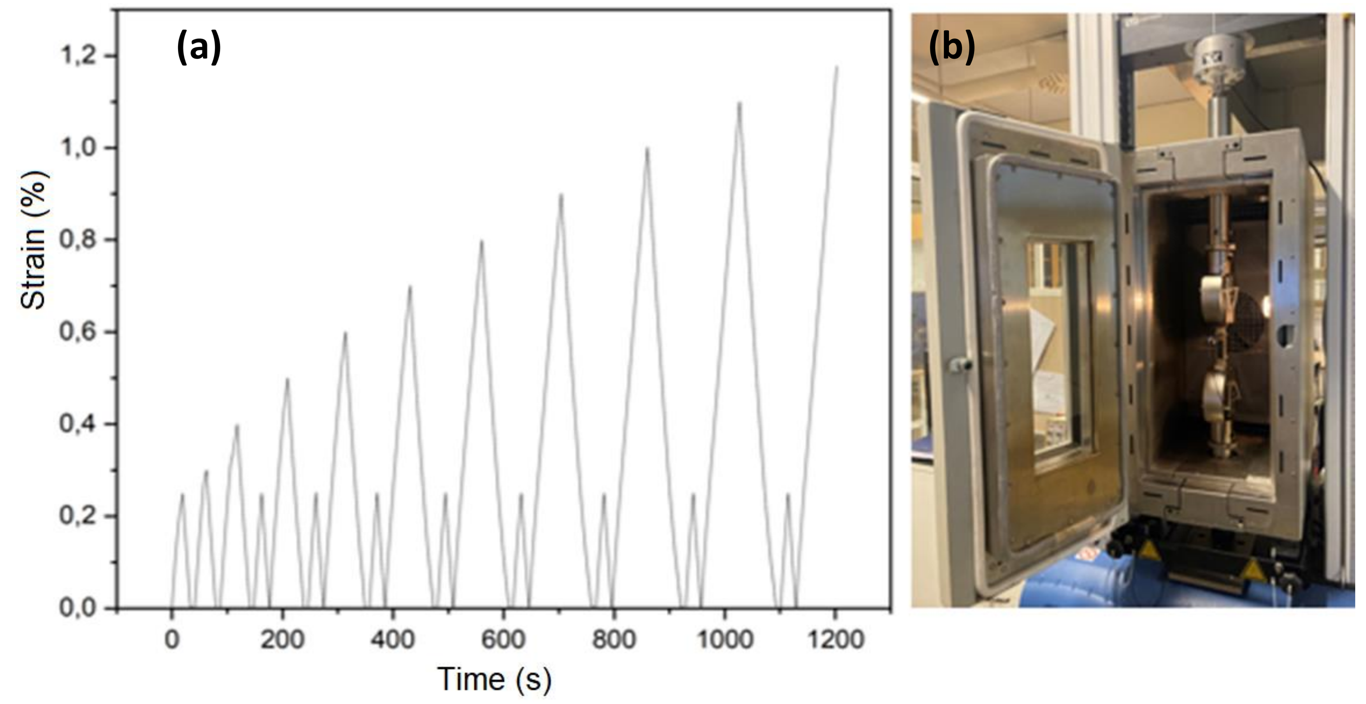


Figure 2. Schematic representation of load application in loading-unloading test (a) and specimen in the environmental chamber (b).

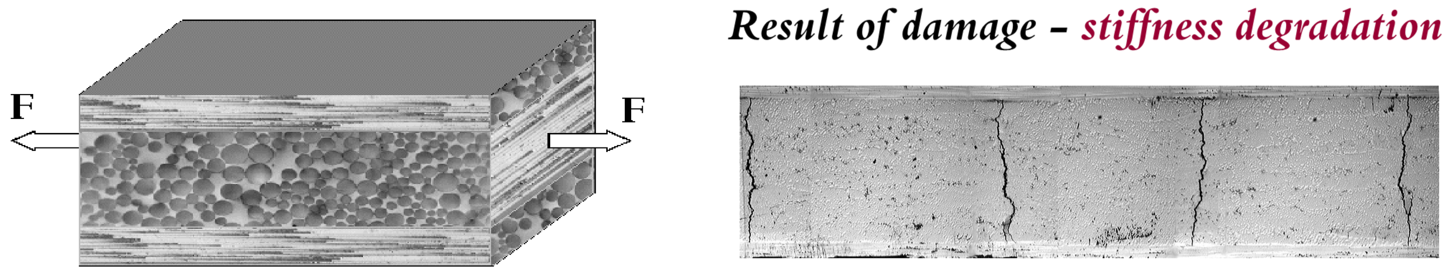
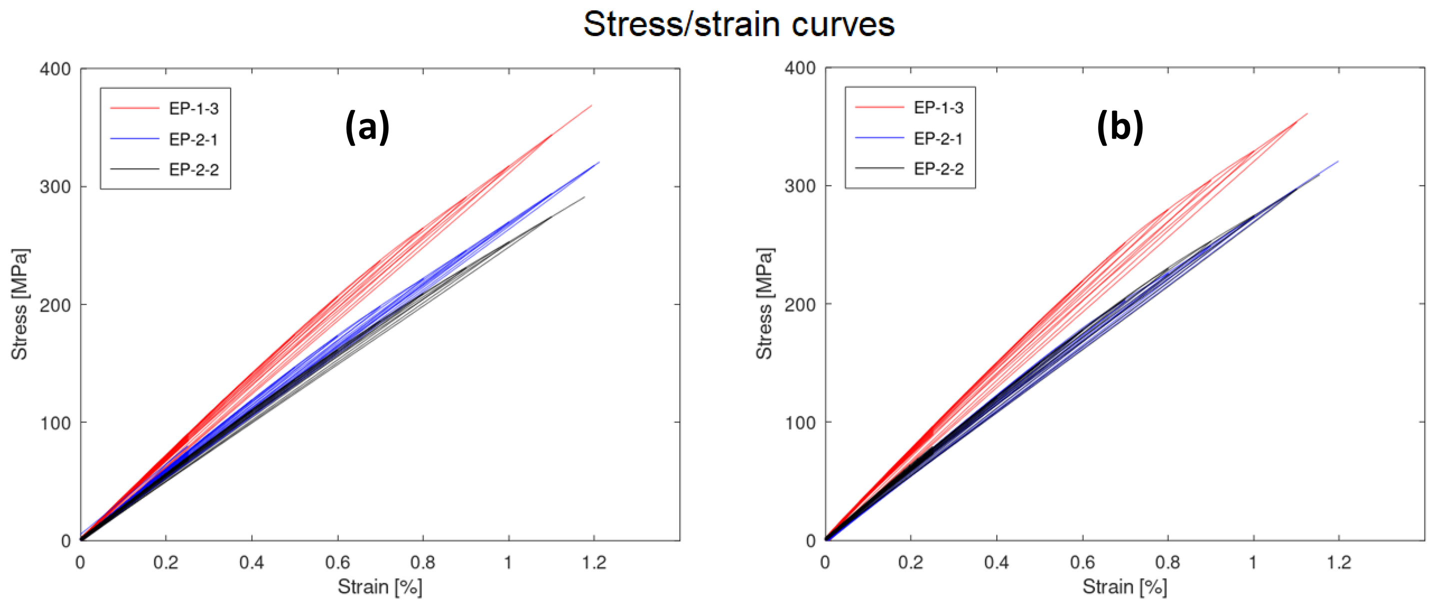


Figure 3. The representation of cross-ply laminate (left) and micrograph of laminate with transverse cracks which cause stiffness degradation.

RESULTS



Symbol	Material composition	E_0 (GPa)	
		RT	LN
EP_1_3	YDPN 638A80 + DDS	35.6	37.7
EP_2_1	YD128 + NOVOLAC	29.8	29.8
EP_2_2	YD128 + DICY	27.7	30.7

Figure 4 . Stress-strain curves of materials at RT (a) and at -50°C (b)

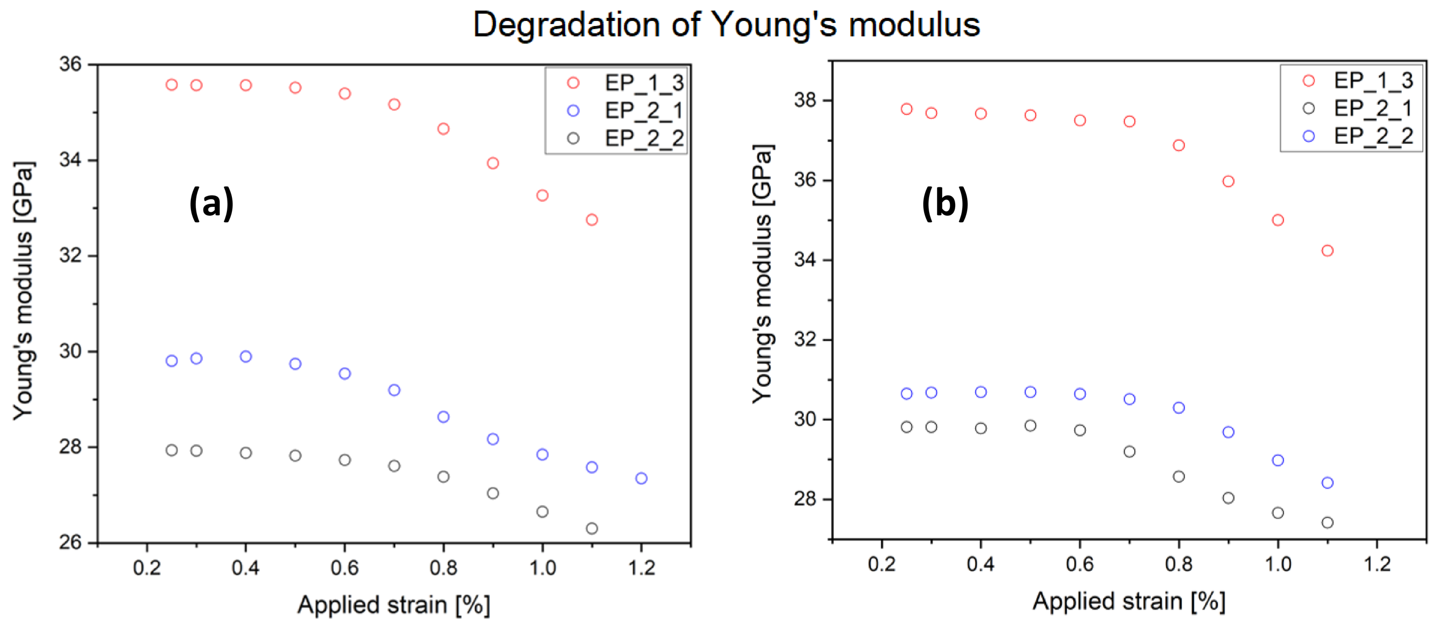


Figure 5. Degradation of Young's modulus of GF/EP laminates with increase of applied strain at RT (a) and at -50°C (b)

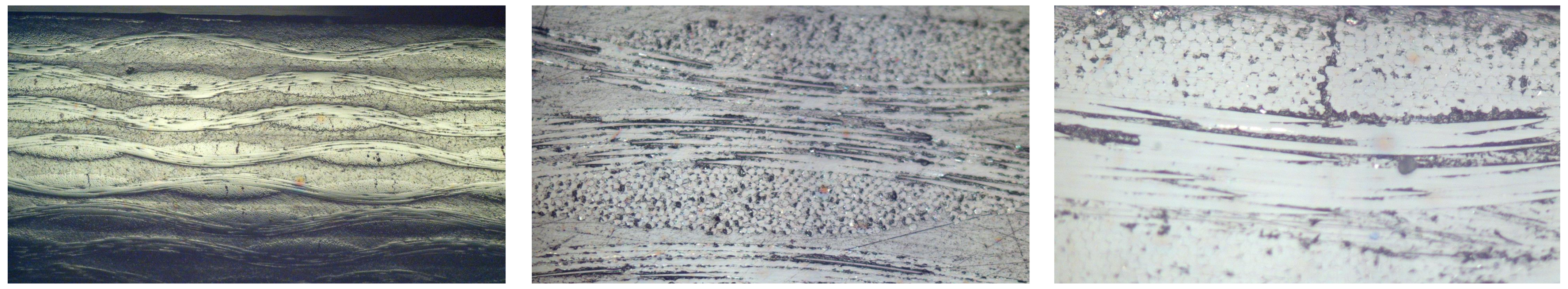


Figure 6. Optical micrographs showing composite micro-structure and micro-cracks in transverse bundle.

CONCLUSION

- The stiffness degradation was observed in tested laminates (≈10%). This indicates that there may be rather significant amount of damage. Materials with different epoxy matrix show some differences in initial stiffness but not so much in degradation of it during the loading. The laminates tested at -50°C showed somewhat higher initial stiffness of the laminates compare to RT but only slightly larger (and more rapid) decrease of stiffness.
- The EP_2_1 (YD128 +NOVOLAC) exhibits greater stability both at RT and -50°C compared to other materials.
- Due to the complex micro-structure of laminates as well as challenging test conditions it was not possible at this stage to quantify amount of damage (number of cracks). This part of the study should be carried out in the future.

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