An experimental and numerical investigation on the viscous behavior of FRP materials

Luigi Ascione, Valentino Paolo Berardi, Anna D'Aponte
Department of Civil Engineering, University of Salerno, Italy
E-mail: l.ascione@unisa.it, berardi@unisa.it, adaponte@unisa.it

Keywords: FRP viscosity , structural retrofitting, constitutive laws.

SUMMARY. The present paper shows the results of the creep test program on several GFRP laminates and constituent phases, subject to different stress values, under constant environmental conditions. The tests are currently being carried out at the Testing Laboratory of Material and Structures of the Department of Civil Engineering of the University of Salerno.

1 INTRODUCTION

The rheological behavior of materials has an important role in the field of Civil Engineering. One aspect that is particularly relevant is represented by creep phenomenon, in that the continually increasing strain can compromise the durability of structural elements.
The viscous effects result particularly marked in the case of fibre reinforced composite materials (FRP – Fibre Reinforced Polymer), due to the presence of the polymeric matrix, with it being sensitive to viscous phenomena.

The problem has been studied by many authors both from theoretical and experimental points of view [1-9]. Current literature does not provide final conclusions on this important topic. Studies developed in the fields of aeronautic and naval engineering on the creep properties of FRPs cannot be directly applied to Civil Engineering applications, primarily due to the different processing techniques of these materials.

From a practical point of view, the international guide lines on structural retrofitting with FRP, including the recent CNR-DT 200/2004 [10-12], indirectly take into account the viscous phenomena by introducing suitable coefficients, which further reduce FRP design stress.

Within the context, the authors have recently formulated, in the field of linear viscoelasticity, a mechanical model capable of predicting the viscous properties of a FRP laminate starting from those of the single phase (matrix and fibre).
This model assumes basically the perfect adhesion between the components, fibres and matrix and the linear viscoelastic behavior of the components. Its validation has been developed by comparing the theoretical data with the experimental ones available in literature, related to creep tests on both the composite as well as the single phases. A good agreement has been observed [13-19].

The limited amount of both theoretical and experimental data on the subject has motivated the interest to study in further detail the phenomena, with reference to the experimental characterization of the rheological properties of several different types of GRFP laminates and constituent phases, widely used in the field of Civil Engineering. In addition, the data obtained from the tests will be used to further validate the proposed mechanical model.

The present paper shows the first results of the creep test program on several GFRP laminates and constituent phases, subject to different stress values, under constant environmental conditions.
The tests are currently being carried out at the Testing Laboratory of Material and Structures of the Department of Civil Engineering of the University of Salerno.

2. EXPERIMENTAL SET-UP

In order to characterize the rheological behavior of GFRP laminates and the single phases, a creep test program has been set up.

The experiments have been performed at room temperature (20°C), using three steel loading systems.

The experimental equipment includes:

- three testing devices capable of applying constant dead loads;
- two data acquisition systems.

2.1 *Resin samples*

Tables 1 and 2 summarize, respectively, the mechanical and geometrical properties of the polyester resin samples, characterized by a circular cross section.

Table 1: Polyester resin certified mechanical properties.

E_m [N/mm^2]	f_{mk} [N/mm^2]	ε_{mu} [%]
3000.00	67.00	2.03

Table 2: Geometrical properties of polyester resin sample.

Sample	l_m [mm]	d_m [mm]	A_m [mm^2]
1	40.0	20.0	314.2
2	40.0	25.0	490.9

The symbols introduced in these tables indicate, respectively, E_m the longitudinal Young modulus, f_{mk} the tensile strength, ε_{mu} the ultimate strain, l_m the length, d_m the diameter and A_m the area of the polyester resin specimens.

2.2 *Glass fibre samples*

Tables 3 and 4 summarize, respectively, the mechanical and geometrical properties of the glass fibre samples.

Table 3: Glass fibre certified mechanical properties.

E_f [N/mm^2]	f_{fk} [N/mm^2]	ε_{fu} [%]
72500.00	2500.00	6.57

Table 4: Geometrical properties of glass fibre samples.

Sample	Number Roving	A_f [mm^2]
Bottom	4.00	7.52
Middle	6.00	11.28
Top	10.00	18.80

The symbols introduced in these tables indicate, respectively, E_f the longitudinal Young modulus, f_{fk} the tensile strength, ε_{fu} the ultimate strain and A_f the area of the glass fibre samples.

2.3 *Laminate samples*

Tables 5 and 6 summarize, respectively, the mechanical and geometrical properties of the GFRP laminates.

Table 5: GFRP certified mechanical properties.

E_{FRP} [N/mm^2]	f_{FRPk} [N/mm^2]	ε_{FRPu} [%]
48972.00	994.28	2.03

Table 6: GFRP geometrical properties.

Sample	b_{FRP} [mm]	t_{FRP} [mm]	A_{FRP} [mm^2]
Bottom	20.00	1.60	32.00
Middle	30.00	1.60	48.00
Top	50.00	1.60	80.00

The symbols introduced in these tables indicate, respectively, E_{FRP} the longitudinal Young modulus, f_{FRPk} the tensile strength, ε_{FRPu} the ultimate strain, b_{FRP} the width, t_{FRP} the thickness and A_{FRP} the area of the GFRP laminates.

2.4 *Testing mechanical devices*

In order to ensure the correct execution of the creep tests, the values of the applied loads must be constant for the duration of the whole test.

Two analogous metallic structures were used, one for the tests on glass fibres (Device 1), another for the GFRP laminates (Device 2), capable of applying axial strain to the test samples, through the use of a lever arm. The device was designed and set up through a series of tests aimed at analyzing the rheological behavior of CFRP laminates, carried out by the authors over the last few years.

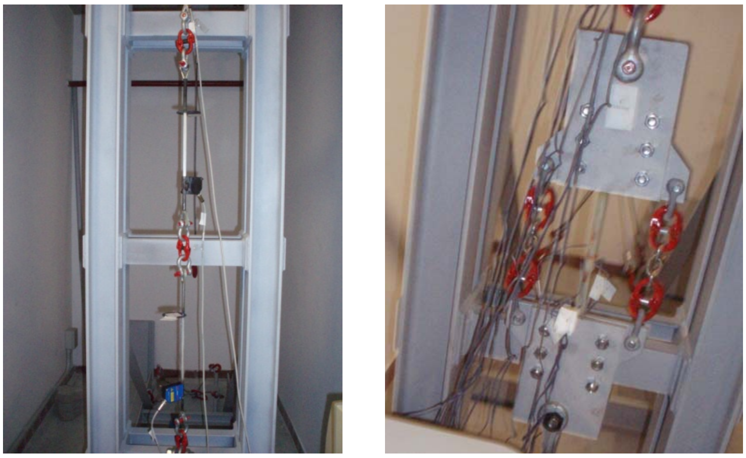
The aforementioned test devices being mechanical guarantee the absence of dissipative phenomena over time, which could have occurred had hydraulic jacks been used.

In detail, each test device is made up of a horizontal beam, acting as the lever arm, with a set of samples and the necessary weight, required to generate the axial dead load, attached to the respective extremities (Figure 1). This beam is welded to a circular section tree, which is hinged at the extremities with roller bearings, connected through bolted plates to the four columns of the equipment.

The set of samples is also constrained at its lower extremity, in correspondence to the base, by a horizontal contrast beam.

a) b)

Figure 1**:** Mechanical system for load application:
a) Device 1 (for GFRP samples); b) Device 2 (for Laminate samples).



a) b)

Figure 2: Samples links:
a) Device 1 (for GFRP samples); b) Device 2 (for Laminate samples).

The running system requires an efficacious load transfer from the end of the lever arm to all the composite specimens. With this aim, the GFRP specimen anchorages are made up of two suitable steel plates glued to the laminates and then bolted to each other. The link between the two

specimens in succession is composed of chains and hooks (Figure 2a).
Whereas, the links of the fibre samples are ensured through chains (Figure 2b).

In order to guarantee the continuation of the test in the case of failure of one of the GFPP samples, a by-pass system between the anchoring plates of the general sample was also set up, using further chains and hooks.

Due to the negligible weight of the anchorage plates and the clips compared to the dead load, each laminate sample is subject to the same strain value. In addition, after defining the geometry of the plane cross section of the samples, it has been possible to apply a normal constant stress to each sample, which was however different for each specimen.

Table 7 shows, for both test devices, the axial force values, N, applied to the sets of samples, the tensile strength, f_k, of each sample and the subsequent stress values, σ.

Table 7: Experimental stress values (Devices 1 and 2).

Testing device		1	2
Sample \ N		3000 N	3000 N
Top	σ	159.57 N/mm^2	37.50 N/mm^2
	σ/f_k	6.38%	3.77%
Middle	σ	265.96 N/mm^2	66.50 N/mm^2
	σ/f_k	11.00%	6.28%
Bottom	σ	398.94 N/mm^2	93.75 N/mm^2
	σ/f_k	16.00%	9.42%

The testing device for the load application on resin (Device 3) allows for the execution of creep tests, at a constant temperature, on polyester resins samples subject to different stress values (Table 8).

Table 8: Experimental stress values (Device 3).

Column		1	2
Sample \ N		371 N	371 N
Top	σ	0.75 N/mm^2	1.18 N/mm^2
	σ/f_{mk}	1.13%	1.76%
Bottom	σ	0.75 N/mm^2	1.18 N/mm^2
	σ/f_{mk}	1.13%	1.76%

The system consists of a steel structure and is constituted of a beam, with three sample columns attached inside and subject to fixed axial load (Figures 3).
The link of the prototype samples is realized with chains and hooks (Figure 4).
The metallic elements of the test system are made of Fe360 steel, characterized by a failure stress, f_{ys}, equal to 236 N/mm^2.

Figure 3: Mechanical device for load application to the resin samples.

Figure 4: links between the resin samples.

2.5 *Data acquisition system*

The data acquisition system is made up of:

- strain gages applied to the lateral surface of the GFRP and polyester resins samples;
- lasers probes used for monitoring fibre samples;
- two modular scanners and relative data management software, installed on two computers;
- four thermal-couples.

The adopted scanners guarantee not only an automatic and modulated data acquisition system, but also they carry any corrections in the time of the data acquisition, due to either the loss of the signal or the instantaneous temperature.

Every fibre sample is then equipped with a laser, every polyester resin sample with three strain gages applied close to midspan, and every laminate sample with six strain gages symmetrically set out to the middle plane (three strain gages on every single face of the laminate: two orientated along the load application axis and the other orthogonal to it) in order to compensate for any eventual measuring errors caused by bending deformation.

3 EXPERIMENTAL RESULTS

The tests are started once the devices were set up and the necessary preliminary controls of the data acquisition system were carried out. The test temperature was set and held constant at 20°C.

The increase percentages of the axial deformations for the composites and the phases are reported in Tables 9, 10 and 11.

Table 9: Longitudinal deformations of the fibre samples (Device 1).

Sample	σ/f_{fk} [%]	$\varepsilon(t=0)$ [%]	$\varepsilon(t=40d)$ [%]	$\Delta\varepsilon/\varepsilon(t=0)$ [%]
Top	6.38	1.000	1.000	-
Middle	11.00	2.000	2.000	-
Bottom	16.00	2.220	2.220	-

Table 10: Longitudinal deformations of the GFRP samples (Device 2).

Sample	σ/f_{FRPk} [%]	$\varepsilon(t=0)$ [%]	$\varepsilon(t=45\ d)$ [%]	$\Delta\varepsilon/\varepsilon(t=0)$ [%]
Top	3.77	0.179	0.180	0.616
Middle	6.28	0.213	0.216	1.599
Bottom	9.42	0.284	0.287	1.234

Table 11: Longitudinal deformations of the resin samples (Device 3).

Column	Sample	σ/f_{mk} [%]	$\varepsilon(t=0)$ [%]	$\varepsilon(t=160\ d)$ [%]	$\Delta\varepsilon/\varepsilon(t=0)$ [%]
1	Top	1.13	0.149	0.299	100.671
	Bottom	1.13	0.150	0.433	188.667
2	Top	1.76	0.271	0.795	193.358
	Bottom	1.76	0.287	0.902	214.286

The mean values of the axial deformations recorded over time for the samples of devices 1, 2 and 3 are plotted in Figures 5, 6 and 7.

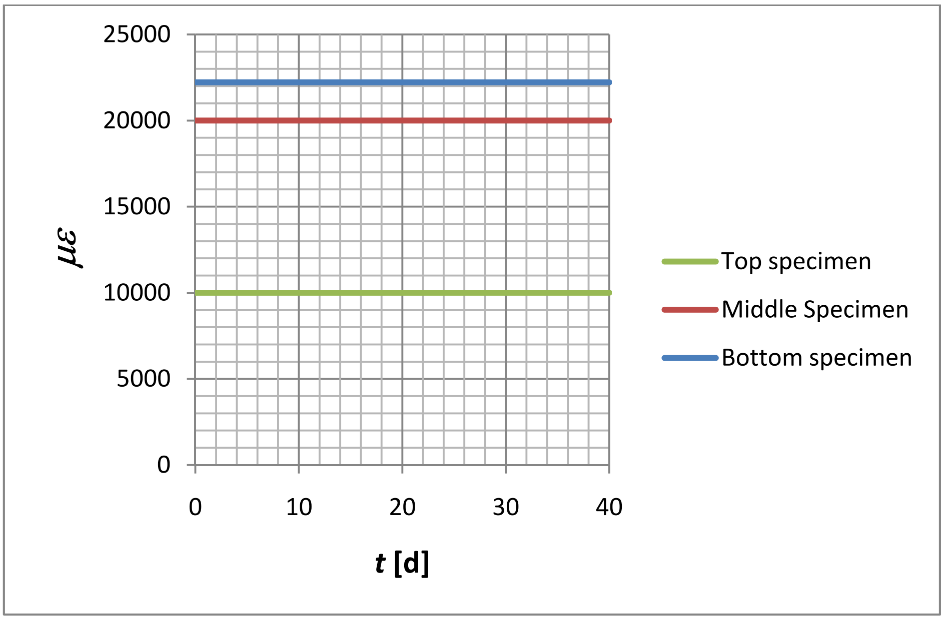


Figure 5: Deformations of the glass fibres.

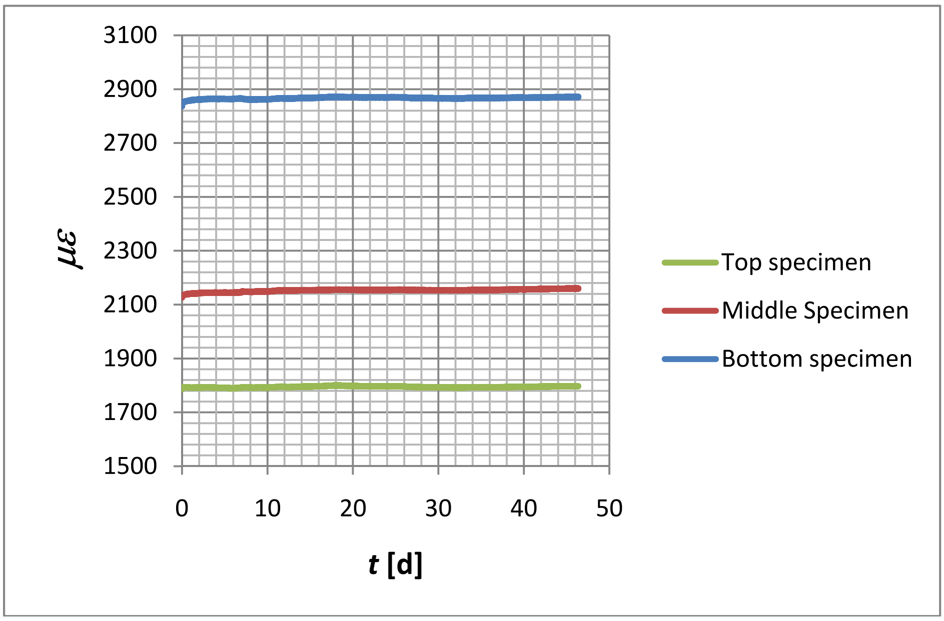


Figure 6: Deformations of the GFRP samples.

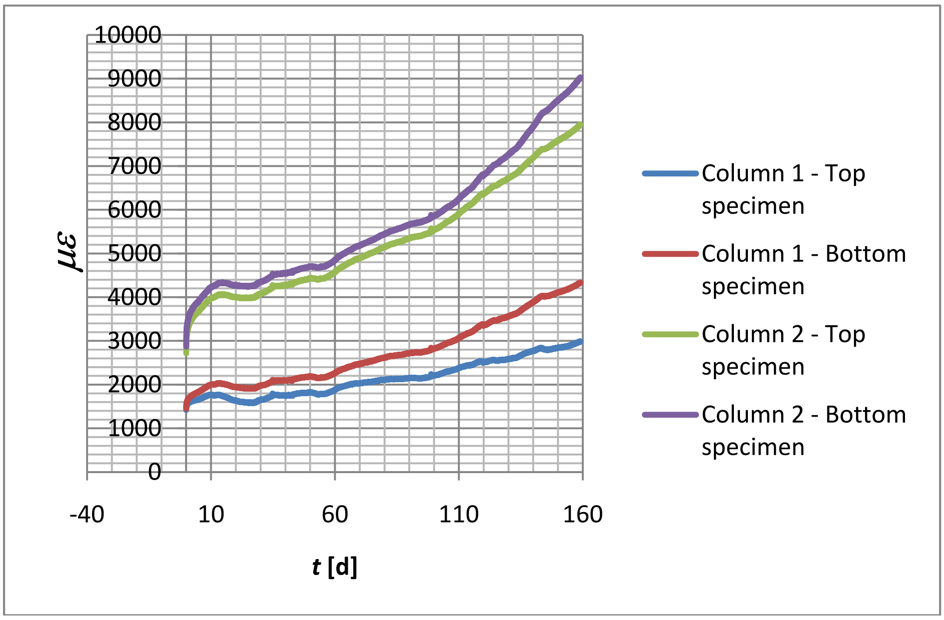


Figure 7: Deformations of the resins samples.

4 CONCLUSIONS

In this paper an experimental study on the creep behavior of GFRP pultruded laminates and their phases is presented. In particular several creep tests are being performed for different stress values at a constant temperature.

From the analysis of the experimental data, a significant increase of the longitudinal deformations, exhibited by the samples of polyester resin over time, has been remarked, from the early hours of observation.

Whereas, no strain increase has been recorded with regard to the glass fibres; a limited one (less than 2%), related essentially to primary creep, has been observed with reference to the GFRP specimens.

From a theoretical point of view, the long term behavior of the tested GFRP laminates can be justified starting from that of their phases.

More specifically, the different rheological properties of the phases have led to a stress migration from the matrix towards the fibres. Due to the negligible viscous behavior of the fibres, the matrix stresses have tended to zero and the axial strains of the composites have assumed a constant value over time.

The experimental results referred to the resin are in good agreement with that available in literature, as well as with the expected ones.

On the contrary, the outcomes of the creep tests, performed both on the GFRP laminates as well as the glass fibres, have shown a better rheological behavior than that expected in literature.

Such a discrepancy, however, can be explained by taking into account the different type of tested materials: composites mainly used in the aeronautical and naval fields, within the theoretical and experimental studies available in literature; laminates specifically designed for civil applications with reference to the investigation here presented.

The tests are still being continued in order to obtain experimental data, which allow further validating the mechanical model formulated by the authors, able to predict the long term behavior of FRP laminates, once viscous behavior of phases is known.

References

[1] Barbero E., Harris J.S., “Prediction of creep properties from matrix creep data”, *Journal of Reinforced Plastics and Composites*, 17(4), (1998).

[2] Dutta K., Hui D., “Integrating fire-tolerant design and fabrication of composite ship structures”. *Interim report University of New Orleans,* (1997).

[3] Maksimov R.D., Plume E., “Long-Term creep of hybrid aramid/glass fiber-reinforced plastics”, *Mechanics of Composite Materials,* 37(4), (2001).

[4] Pang F., Wang C.H., Baghgate R.G., “Creep response of woven composites and effect of stitching”, *Journal of composites science and technology*, 57, (1997).

[5] Petermann J., Schulte K., “The effects of creep and fatigue stress ratio on the long-term behavior of angle-ply CFRP”, *Composite Structures,* 57, pagg. 205-210, (2002).

[6] Scott D., Zureick A., “Compression creep of a pultruded e-glass/vinylester composite”, *Composites Science and Technology*, 85, pagg.1361-1369, (1998).

[7] Yamaguchi T., Kato Y., Nishimura T., Uomoto T., “Creep rupture of FRP rods made of aramidic, carbon and glass fibres”, *Non-Metallic (FRP) Reinforcement for Concrete Strucutres*, Proceeding of the third Symposium, 2, (1997).

[8] Ascione L., Berardi V.P., “Gli effetti reologici nel placcaggio strutturale di elementi in c.a. con laminati fibrorinforzati”, *XVI Congresso AIMETA*, CD-ROM Proceeding, (2003).

[9] Ascione L., Berardi V.P., Feo L., Giordano A., “Il fenomeno del creep nel placcaggio strutturale con FRP: progettazione di un dispositivo sperimentale”, *XXXIII Convegno AIAS*, Salerno, CD-ROM Proceeding, (2004).

[10] ACI Committee 440, Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures, (2000).
[11] CEB-FIP, “Externally bonded FRP reinforcement for RC structures”, (2001).
[12] CNR-DT 200/2004, “Istruzioni per la Progettazione, l’Esecuzione ed il Controllo di Interventi di Consolidamento Statico mediante l’utilizzo di Compositi Fibrorinforzati-Materiali, strutture di c.a. e di c.a.p., strutture murarie”, (2004).
[13] Ascione, L., Berardi, V.P., D’Aponte, A., “Un modello meccanico per lo studio del comportamento differito dei laminati compositi fibrorinforzati”, *Colloquium Lagrangianum*, Scilla, (2006).
[14] Ascione, L., Berardi, V.P., D’Aponte, A., “Viscous constitutive law of FRP Materials”, *IPMM*, Salerno, (2007).
[15] Ascione, L., Berardi, V.P., D’Aponte, A., “The durability of fiber reinforced polymer materials in structural retrofitting and upgrading”, *Thermo-mechanial modeling of solids*, Ecole Polytecnique, Parigi, (2007).
[16] Ascione, L., Berardi, V.P., D’Aponte, A., “Viscous behavior of FRP materials: a mechanical model”, *AIMETA Congress*, Brescia, (2007).
[17] Ascione, L., Berardi, V.P., D’Aponte, A., “Il comportamento a lungo termine dei materiali compositi fibrorinforzati: un modello micromeccanico”, *AICAP Conference*, Salerno (2007).
[18] Ascione, L., Berardi, V.P., D’Aponte, A., “Problemi di durabilità dei materiali compositi fibrorinforzati nel consolidamento strutturale”, *Colloquium Lagrangianum*, Ecole Polytechnique, Parigi, (2007).
[19] Ascione, L., Berardi, V.P., D’Aponte, A., “Viscous constitutive laws for FRP materials”, *I.C.M.M.S. Congress*, Bangalore, (2008).