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Creep tests on GFRP pultruded specimens subjected to traction or shear

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ABSTRACT

In this paper, experimental long-term tests on pultruded GFRP specimens are presented. Specimens have been subjected to constant traction and shear forces for about 760 days. The tests have been performed under controlled temperature (20 °C) and humidity (60% RH) inside a climatic room. The specimens under traction have been cut from plates and from the flanges of a wide flange GFRP pultruded beam; the specimens under shear loadings have been extracted from the web of the same beam. Moreover, some specimens have been stiffened by bonding CFRP sheets to both sides, in order to study how their introduction may reduce the specimen deformability under long term loading. Results from the unstiffened specimens have been interpreted by means of the Findley law, the reference model for creep in polymers and FRP, in terms of strains and creep coefficient. A simple model has been finally proposed to predict strains in stiffened specimens and by taking stress redistribution into account.

1. Introduction

Modern structural engineering has recently introduced among the possible solutions the adoption of composite structural shapes as components of framed systems or trusses. They are usually produced by using pultrusion process, which allow their manufacturing with different materials arranged with different proportions. Accordingly, their mechanical properties vary significantly with the choice and the relative quantities of the materials employed for the matrix and the fibre reinforcement, so that the composite material can be designed with properties to meet specific design needs.

In the production of pultruded shapes for civil engineering applications, E-glass fibres are mostly used for the reinforcement. They are characterized by lower cost but also by a reduced stiffness with respect to other fibres, e.g. carbon fibres. The pultrusion process allows creating prismatic profiles where the fibres orientation is optimized, being oriented along the longitudinal direction; nevertheless, others layers of fibres with different orientation must be merged in the composite during the process in order to assure to the pultruded shape a sufficient strength also for local or impact loadings. Usually, continuous strand mats are alternated to unidirectional layers with the purpose of improving the transversal strength and stiffness; as a drawback, the longitudinal stiffness is reduced with respect to a shape with only longitudinal fibres.

The relatively low stiffness of these profiles can be a significant drawback in real applications: the profiles must be often designed with reference to a service limit state, i.e., by prescribing a maximum value of deformability (e.g. maximum deflection) rather than of strength. Verifications against ultimate limit states must be also performed, in particular with respect to local and global instability failures [1–5].

Moreover, as far as the service limit state verifications are concerned, the pultruded shapes obtained with glass fibres may undergo considerable long-term deformations under a load sustained in time [6–9].

The mechanical behaviour in time is strictly related to the rheological properties of both matrix and fibres; for example, glass fibres are subjected to creep deformation much greater than carbon fibres when subjected to the same sustained stress, as studied for example by Barbero [10]. For pultruded shapes made with glass fibres, the creep deformation can be comparable with the instantaneous deformation of the beam. Moreover, in computing the deflection of pultruded beams, the shear deformability can be significant even for slender elements (see for example [11–13]). In fact, the ratio between the shear and the Young modulus is much smaller for orthotropic unidirectional composites than for isotropic materials. This circumstance may have significant consequences also in the case of a sustained loadings: for a load kept constant in time, the deflection contribution due to the creep shear strains is much greater than that of creep uniaxial strains (e.g., due to bending). The different values of creep coefficients for shear and bending may also lead, for some constraint and loading condition, to significant stress redistribution with time even under sustained service loading, as shown by Bottoni et al. [14].

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Some studies can be found concerning the rheological properties of pultruded composites. Mottram [15] tested under the three point bending scheme two assembled beams, composed of two I-beams bonded together by plates glued on their top and bottom faces. The tests have been performed under controlled environmental conditions, but their duration was very short (24 h). MacClure and Mohammadi [16] have performed accurate compression tests on coupons and angle stub for more than 2500 h, under constant environmental conditions. During the creep tests, both stubs and coupons have been subjected to a constant load 45% of the instantaneous buckling load, with strain gages placed in order to verify the onset of a possible buckling failure. Shao and Shanmugam [17] tested coupons cut from the flanges and the web of a wide flange beam under compression. Finally, Scott and Zureick [18] tested a composite sheet piling under three-point bending test during 9000 h, with loads equal to 50% and 25% of the failure load, respectively. Prediction of the mid-span deflection is obtained by means of the Timoshenko beam model and using averaged tensile and shear moduli. These are calculated from strain measurements on web and flange of the same beam. Results are interesting, however they are obtained without control of the ambient conditions and strain measurements are taken with only two gages (one gage in traction and a rosette for shear).

In the literature there are still a limited number of long-term experimental tests of pultruded composites, not sufficient to assess the creep behaviour of pultruded materials. The tests are often of short duration and performed only on structural elements and almost never on composite coupons. In tests on structural elements, the stress state may vary during time due to stress redistributions within the cross-section; moreover, it is not possible to distinguish the two deflection contributions due to flexural and shear deformation, respectively. This lack of experimental data is complicated by the fact that very often the manufacturers do not provide the composition of their pultruded materials, in particular the amount and direction of fibres. As a consequence, there is a need of knowledge for the rheological properties of commercial pultruded elements.

The experimental tests described in the present paper, performed at the Laboratory of Structural Testing of the University of Bologna, enlarge the knowledge on this topic. Creep tests have been performed on composite pultruded specimens subjected to two kind of long term forces, i.e., uniaxial traction and shear force. During tests, temperature and humidity have been kept constant and equal to 20 °C and 60% RH, respectively. The specimens have been kept under constant loading for more than 2 years, so providing information on the material long-term behaviour out of the usual time range. Some tests have been performed on specimens strengthened with additional layers of carbon fibres, glued on external faces of pultruded coupons. The idea is to propose this kind of strengthening as a mean to reduce the short- and long-term deformability of the glass fibre pultruded specimens.

The long-term behaviour of plain specimens has been interpreted by the Findley creep model, usually employed for plastics and often also applied to FRP. A simple model is then proposed for prediction of long-term deformation of CFRP stiffened specimens, whose behaviour is more complex due to stress redistribution, related to the presence of different materials on the cross-section (pultruded coupon and CFRP layer).

2. Testing method and materials

2.1. The pultruded specimens

The specimens for the long-term tests have been extracted from commercial pultruded shapes made of *E*-glass fibres embedded in a polyester matrix. Specimens have been extracted from both pultruded wide-flange beams and plates (Fig. 5). Even if the thickness of both beam flange and plate is the same (9.53 mm), they have different mechanical properties, because the percentage of strand mats is greater for the plates in order to assure a sufficient strength even when subjected to biaxial stress state. The average mechanical properties of the pultruded elements declared by the producer are listed in Table 1.

The specimens extracted from the plates and from the beam flanges have been subjected to long-term traction tests, whereas those obtained from the beam webs have been used for tests under long-term shear loadings. A number of specimens have been externally strengthened by bonding carbon fibres sheets, in order to increase their stiffness. Unidirectional plies have been added to specimens for traction tests (a), while sheets with ±45° have been bonded to specimens for shear tests (b).

A detailed scheme of tested specimens, with their size and carbon fibres direction, is given in Fig. 1. Four plain (unstiffened) specimens extracted from the plates have been subjected to long-term traction tests. Two different widths have been adopted, in order to study the effect of the stress level on the creep strain evolution with time: two specimens are 46 mm wide, while the remaining two are 65 mm wide; the specimens have similar width/length ratios, so that their lengths are 245 mm and 335 mm, respectively. A large width/length ratio is required for orthotropic materials in order to have the central portion of the specimens free of disturbances due to the end restraints, as explained by Tullini and Savoia [19,20]. Four additional specimens have been strengthened by externally bonding three unidirectional FRP carbon plies each; two of them have been obtained from plates and are 31 mm wide and 245 mm long, while the remaining two have been cut from beam flanges and are 44 mm wide and 335 mm long.

As far as the long-term shear tests are concerned, four specimens with dimensions 120 mm × 220 mm have been extracted from the beam web; two of them have been strengthened with two carbon fibre sheets with ±45° fibres orientation. As explained in Section 2.2, each specimen for shear test contains two loaded portions, which are given two different names (SP5 and SP6 for example).

The strengthening of the pultruded specimens subjected to traction has been done with two unidirectional carbon fibre plies on one surface and one ply on the opposite free surface. Hence, the cross-section is not perfectly symmetric, so that a small flexural moment arises. However, the average of the two strains measured on opposite surfaces will be equal to the strain measured on

Table 1
Average properties of pultruded shapes used to obtain specimens. For plates: LW = lengthwise, CW = crosswise.

Property	Value	Unit
Wide flange beam, 152.4 × 152.4		
Young modulus in tension	28.6	GPa
Young modulus in compression	26.5	GPa
Shear modulus	3.4	GPa
Tensile strength	275	MPa
Compressive strength	315.7	MPa
Poisson ratio	0.35	–
Plate		
Young modulus in tension (LW)	12.4	GPa
Young modulus in tension (CW)	6.9	GPa
Young modulus in compression (LW)	12.4	GPa
Young modulus in compression (CW)	6.9	GPa
Tensile strength (LW)	137	MPa
Tensile strength (CW)	69	MPa
Compressive strength (LW)	165	MPa
Compressive strength (CW)	110	MPa
Poisson ratio (LW)	0.32	–
Poisson ratio (CW)	0.25	–