



# Experiences on Anchorage Systems for FRP Rods

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**Abstract.** In recent years, investigation on FRP rods for prestressing tendons both for high strength and high resistance to corrosion, lightweight, nonconducting, and nonmagnetic properties is increasing. Anchorage systems are often not completely reliable because the characteristic of orthotropic material of FRP with high strength for loads parallel to the axis while a low capacity in normal direction to axis doesn't allow to use anchorage systems typically used for steel. This paper presents experimental experiences on anchorage systems for FRP rods. Firstly, the behaviour of anchorages with metallic tubular and filled resin around the FRP rod, adopted in tensile tests of Carbon and Glass FRP rods is investigated. Then, anchorage for prestressing FRP rods with experimental tests on clamp and split wedge anchorage types is analysed. Results of experimental campaign are shown and discussed with the aim to provide recommendations for the future research.

**Keywords:** Anchorage system · Carbon-Glass FRP Rods · Tensile test · Prestressing

## 1 Introduction

The use of Fibre Reinforced Polymers (FRPs) is increasing in civil engineering especially in the rehabilitation of damaged RC beams or to retrofit RC elements [1–3]. FRPs are available in lamina, strips, tendons, reinforcing bars and meshes. One between techniques usually adopted in the RC concrete elements like beams and columns consist in the use of near surface mounted (NSM) FRP rods/strips inserted into grooves in the cover of sections [4–6]. NSM technique is usually based on FRP rods with or without pretension as a strengthening of damaged reinforced concrete (RC) beams and slab of bridges often subjected to process of corrosion. Corrosion of steel reinforcing and prestressing steel tendons cause reduction of ductility of structural elements with dangerous effect on the safety. In recent years as an emerged alternative to steel is the use of FRP composites also for prestressing tendons [7] due to high strength and high resistance to corrosion, lightweight, nonconducting, and nonmagnetic properties. FRP anchoring systems is one of main topic that was studied and investigated [8] although some aspect should be deeply developed. First research on prestressing FRP rods started in Germany at the end of seventy years of last century; next in Japan and USA extensive studies and experimental research have been developed [9, 10] on Glass-FRP tendons and anchorages. The characteristic of orthotropic material for FRP with high strength for loads

parallel to the axis while a low capacity in normal direction to axis doesn't allow to use anchorage systems typically used for steel because they would crush transversally the FRP rods. Recently, innovative technique based on soft computing have been adopted to civil engineering problems [11, 12]. New frontiers of research about anchor systems for FRP are focused on the implementation of artificial neural network (ANN) models for the anchorage reliability assessment [12].

The anchorage system and orthotropic material are two aspects that must be taken in account also in the investigation of FRP rods under tensile tests to obtain correct results about ultimate strength,  $f_t$ , Young's modulus,  $E$ , and develop of strains,  $\varepsilon$ .

The first part of this paper deals about anchorages with metallic tubular and filled resin around the FRP rod, adopted in tensile tests of Carbon/Glass-FRP rods. The second part of this paper is focused on the anchorage for prestressing CFRP rods with experimental tests on split wedge and clamp anchorages [8].

## 2 Anchorage Systems for FRP Rod Under Tensile Load and Tests

IN This Paper, FRP Rods Made with an Epoxy Matrix Reinforced with Unidirectional Fibers Are Analyzed. With the Aim to Evaluate the Ultimate Tensile Strength and the Elastic Modulus of FRP Rods, the Test Methods Indicated by the American ACI [13] and Italian CNR [14] Codes of Practice Were Taken as Reference.

The anchorage system is of fundamental importance and can seriously affect the test's performance even if many factors can contribute to changing the results of the tests. For example, the gripping system of the test machine can influence the experimental campaign, since if the lateral pressure applied is not high enough, the specimen may slip during the tore phase, while an excessive pressure can cause premature rupture of the sample.

The anchoring system adopted for this experimental campaign is shown in Fig. 1. The design of the anchorage was done with reference to the suggestions reported in [13, 14]. The rods have been inserted into steel tubes filled with epoxy resin. The minimum anchor length,  $l_a$ , is set as 15 times the diameter of the rod,  $d_b$ . The overall length of the steel tube, however, has been extended by 1 cm, to allow the insertion of rubber caps to prevent the resin from leaking. The total rod's length,  $l_p$ , was determined by referring to the greater of the two relations defined in the considered standards [13, 14]:

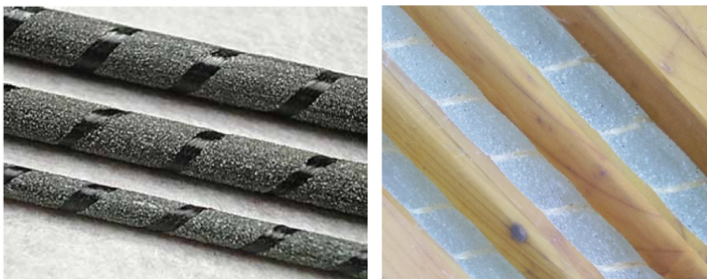
$$l_p \geq 100 + 2 \cdot l_a; \quad l_p \geq 40 \cdot d_b + 2 \cdot l_a. \quad (1)$$

### 2.1 Tensile Test for G/CFRP Rods

CFRP and GFRP rods, with a nominal diameter, respectively, of 8 mm and 9 mm, with high resistance and high glass transition temperature, were subjected to tensile tests. The rods had a special superficial treatment to improve adhesion, obtained by surface sandblasting of spheroidal quartz and helical winding in carbon/glass threads (Fig. 2). Tables 1 and 2 show the mechanical and geometric characteristics, provided by the manufacturer.



**Fig. 1.** Manufacturing of GFRP and CFRP rods samples.



**Fig. 2.** CFRP and GFRP rods adopted for experimental tensile tests.

The two-component epoxy resin with high adhesion was used for the application of the tubular metallic socket. Table 3 shows the dimensional characteristics of the samples, depending on the nominal diameter of the tested rod.

The specimens were subjected to an increased tensile load under displacement control. A strain gauge was placed on the middle section of rod to record the evolution of axial strain during tests. Glass fiber specimens showed an explosive failure, with the detachment of the fibers in the classic “brush” way but without the complete disintegration (Fig. 3). According to the ASTM notation, this failure can be classified in both cases as XGM (Explosive, Gage, Middle). For carbon fiber rods, failure was reached only for a single specimen and it was localized near the anchor (Fig. 3). In this case, failure can be classified as a LAB type (Linear A, at Grip, Bottom) e XMV (Explosive Multiple Various). Main results of uniaxial tensile tests are shown in Fig. 4. Results of the tensile tests confirm the reliability of the anchoring system adopted, with resistance values of tested specimens higher than those declared by the manufacturer (Table 4).

**Table 1.** Mechanical characteristics of tested CFRP rods by the manufacturer\*.

CFRP rods	
Nominal section [mm <sup>2</sup> ]	50
Nominal diameter [mm]	8
Characteristic tensile strength, $f_{tk}$ , ASTM D 3039 [MPa]	1800
Average tensile Young's modulus, ASTM D 3039 [GPa]	130
Average ultimate tensile strain, ASTM D 3039 [%]	1.8
Glass transition temperature, ASTM 1356 [°C]	> 250

\* BASF Construction Chemicals Italia S.p.A.

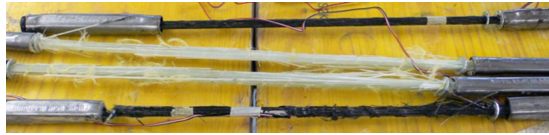
**Table 2.** Mechanical characteristics of tested CFRP rods by the manufacturer\*.

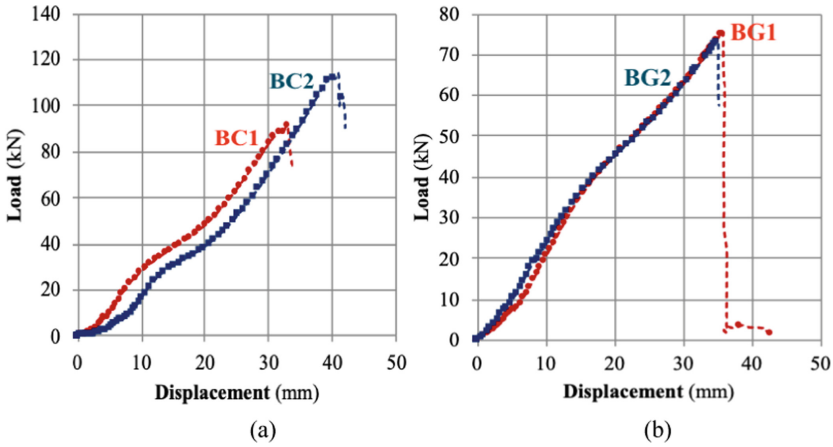
GFRP rods	
Nominal section [mm <sup>2</sup> ]	71.26
Nominal diameter [mm]	9.53
Characteristic tensile strength, $f_{tk}$ , ASTM D 3039 [MPa]	760
Average tensile Young's modulus, ASTM D 3039 [GPa]	40.80

\* Mapei S.p.A.

**Table 3.** Geometrical characteristics of tested specimens.

Material	Specimen	Nominal diameter	Nominal area	Outside diameter of steel tube, $d$	Bond length $l_a$	Length of steel tube $l_{tube}$	Free length $l$	Length of specimen $l_p$
		[mm]	[mm <sup>2</sup> ]	[mm]	[mm]	[mm]	[mm]	[mm]
CFRP	CB1, CB2	8.0	50.27	25	150	160	380	690
GFRP	GB1, GB2	9.53	71.26	25	120	130	320	570

**Fig. 3.** Failure of tested specimens.



**Fig. 4.** Exp. Diagram load, kN, vs displacement for tested (a) CFRP and (b) GFRP rods.

**Table 4.** Experimental mechanical parameters of CFRP and GFRP rod.

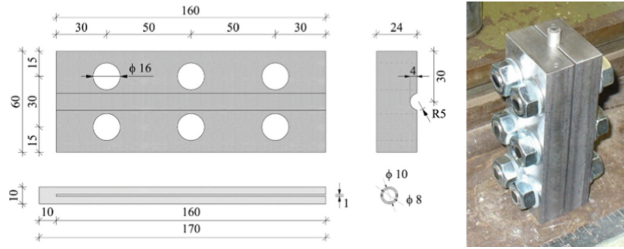
Material	Specimen	$F_{max}$	$A_b$	$f$	$E$	Type of failure
		[N]	[mm <sup>2</sup> ]	[N/mm <sup>2</sup> ]	[GPa]	
CFRP	BC1	91904	50.27	1828.37	–	LAB
CFRP	BC2	114316	50.27	2274.24	157.21	XMV
GFRP	BG1	75470	71.26	1059.08	–	XGM
GFRP	BG2	73630	71.26	1033.26	33.59	XGM

### 3 Anchor Systems for Prestressed CFRP Rod

An experimental campaign on anchor systems for prestressing FRP rods was carried out. The anchoring technique analyzed was the split wedge developed by Täljsten (2009) [15], for the anchor of CFRP rod. This anchor was subjected to short-term tensile strength tests using, for the other end of the cable, a clamp anchorage. This anchorage has the function of creating a firm locking of the cable, to contrast the prestressing force applied to the split wedge anchorage and transmitted along the entire cable (Fig. 6).

With the aim to focus attention on the behavior of the split wedge anchorage, the anchorage at the opposite end must ensure the absence of sliding and negligible deformations. A mechanical clamped anchorage was chosen for this function, consisting of 2 steel plates with longitudinal semicircular cavity on both. These plates are locked around the cable by means of 6 bolts with a diameter of 16 mm, through a thin aluminum interface sleeve (Figure 5). Figure 6 shows the executive drawings of the cylinder and the wedge and the completed pieces. The mechanical properties of each anchorage component are summarized in Table 5.

First, the aluminum wedge was inserted inside the external steel cylinder. The specimen was then placed in a vertical position on the universal tensile testing machine. The



**Fig. 5.** Geometrical dimension of clamp anchorage.

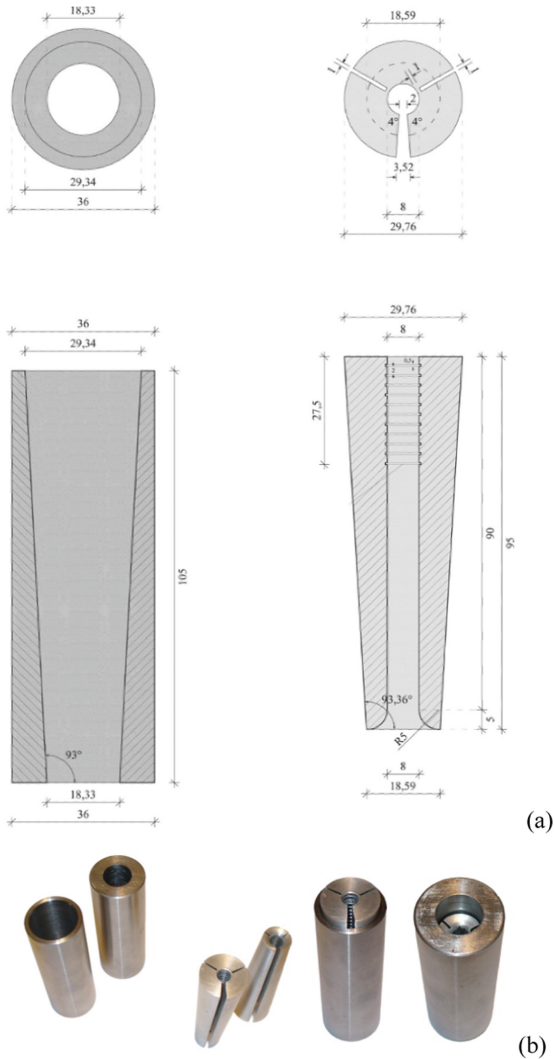
mechanical clamp anchor was then positioned in the free end, paying attention to the bolts' clamping [16]. During this first phase, the aluminum wedge was pushed inside the steel cylinder, in order to block the CFRP cable and inhibit much of the sliding during the subsequent pretension of rod. The wedge insertion procedure was carried out thanks to a hydraulic jack, contrasted by a frame specially made in laboratory. The force was applied on the wedge, by means of an interface cylinder 60 mm long, made by high resistance steel, with an internal diameter of 12 mm, greater than that of the cable, and an external diameter of 22 mm, smaller than the internal diameter of the cylinder. In Fig. 7(a) the phases of the procedure are schematized, while in Fig. 7(b) the positioning of the interface cylinder on the anchor is shown. The result that occurs after this preliminary operation is the complete locking of the only open slot of the wedge, which results in a shrinkage of the internal diameter of the wedge itself with consequent clamping of the CFRP cable. Regarding the pre-tensioning operation of the cable and therefore the execution of the experimental test, a small frame was created specifically for the purpose of this test, which consists of two steel plates of  $225 \cdot 204 \cdot 20$  dimensions, connected with 4 threaded bolted bars having a diameter of 24 mm (Fig. 8).

The insertion of this small frame on the test machine is of fundamental importance in order to create a contrast to the anchorage, and, above all, to recreate the conditions of contrast and constraint that are likely to be realistic.

Once the additional frame was positioned, it was possible to arrange the CFRP rod cable equipped with the previously locked wedge anchorage. Once the specimen was positioned, the mechanical clamp anchorage was placed in the free upper end, paying attention to the tightening of the bolts (Fig. 8(a)).

The tensile force was applied by vertical upward displacement of the machine's upper structure, with which the mechanical clamp anchorage also moved, while the wedge anchorage remained fixed in its original position. At both ends of the cable, the portions of the protruding cable were preliminary measured, in order to evaluate, at the end of the test, the actual sliding of the cable itself, with respect to the anchor.

Three short-term tensile tests were carried out with increasing monotonic load. The load speed was  $1 \text{ N/mm}^2$  per second. A strain gauges was positioned at the middle of the CFRP cable to record the evolution of strain with a frequency of 2 Hz.



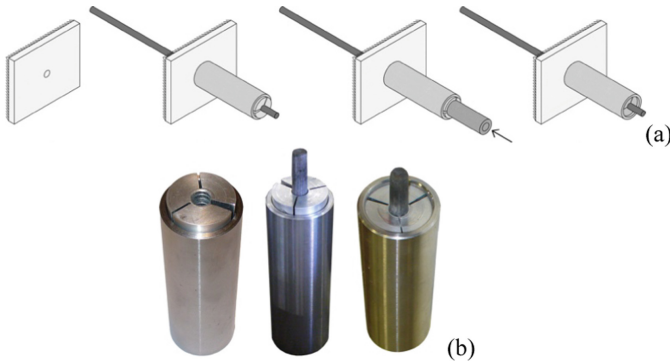
**Fig. 6.** (a) Technical drawings of split wedge anchorage; (b) components of anchorage.

### 3.1 Results of Experimental Tests

The first experimental test was interrupted at a load value of 21.9 kN due to sliding along the cable-wedge interface for about 15 mm. In Fig. 9, it can be seen the residues of fibers accumulated near the end of the anchorage, as evidence of a flaking of the hollow lateral surface. On the contrary, no sliding occurred in the mechanical clamp anchor. The split wedge anchorage was then modified by adding a two-component resin in the cable-wedge interface. However, the test was very similar to the previous one. In this case the sliding occurred at a load of 21 kN, in the mechanical clamp anchorage, for an amount equal to 10 mm. The split wedge anchorage equipped with resin, on the

**Table 5.** Mechanical properties of each anchorage components.

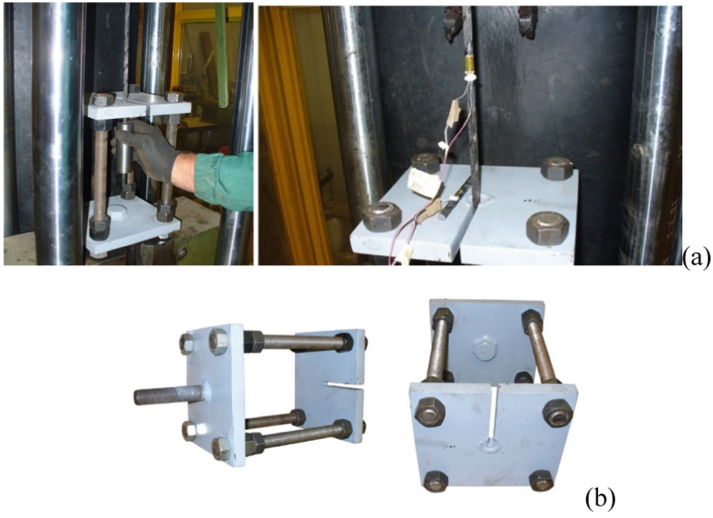
Components	Material	Yielding strength $f_y$ (MPa)	Ultimate strength $f_u$ (MPa)	Young's modulus E (GPa)
Cable	CFRP	–	1800	130
Wedge	Alluminium 6262-T9	400	430	70
Conical socket	Steel C40	450	700	210
Sleeve	Alluminium 6060-T6	200	230	70
Slabs	Steel S355	355	510	210
Bolts	Steel	640	800	210

**Fig. 7.** (a) Wedge insertion's procedure; (b) positioning of the interface cylinder on the anchor.

other hand, has not undergone any sliding. In the third experimental test, however, the mechanical clamp anchorage was modified, by inserting a double interface aluminum sleeve, formed by two completely separate half-cylinders, in order to increase the radial compression tensions and therefore the friction load in the wedge-cable interface.

This modification was made on the same CFRP cable as the second specimen, using the same wedge anchor with additional resin. Result of tensile test did not allow to reach the maximum value of the resistant capacity of the CFRP rod but allowed to reach a value of 40% of the maximum expected failure load without any sliding of the anchorages. The split wedge anchorages did not undergo any sliding and an elastic modulus of 130 GPa was evaluated with reference to the tension of about 430 N/mm<sup>2</sup>. The experimental values of the modulus of elasticity, in agreement with that declared by the supplier, confirmed the validity of the project path carried out up to this point (Fig. 10).

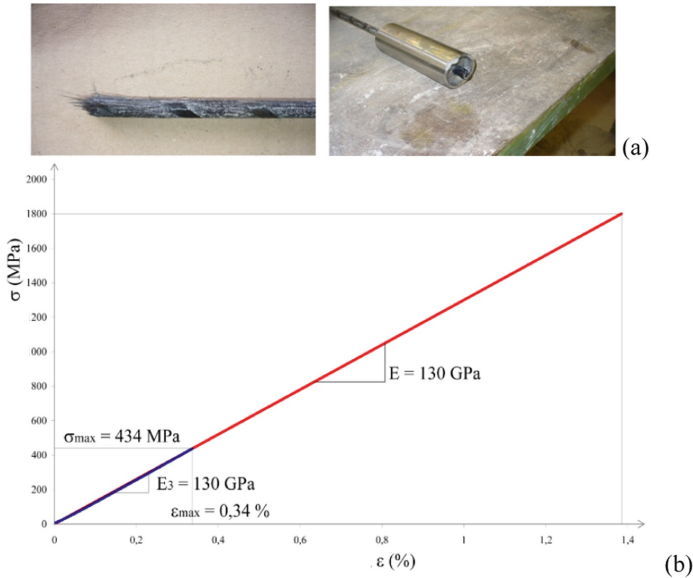




**Fig. 8.** (a) Set-up of tensile tests with (b) steel frame built for test.



**Fig. 9.** Residues of fibers accumulated near the end of the anchorage, after cable's slip.



**Fig. 10.** (a) Failure mode after third test; (b) strain-stress diagram for the third specimen (in blue), in comparison with the one declared by the manufacturer (in red).

## 4 Conclusion

This paper presents experimental experiences on anchorage systems for FRP rods. Firstly, the behaviour of anchorages adopted in tensile tests of Carbon and Glass FRP rods is investigated. Then, anchorage for prestressing FRP rods is analysed. Main results of experimental campaign, that can be considered as the first phase of a wider future work, are synthesized as follows:

- Results of tensile tests on CFRP and GFRP rods, confirm the reliability of the anchoring system adopted, with resistance values of tested specimens higher than those declared by the manufacturer.
- Results tensile test on pre-tensioned CFRP rod underline that the split wedge anchor without resin, was not able to cope with the slow sliding of the cable, which certainly represents the biggest obstacle for these systems.
- Regarding the split wedge anchor's design, it is necessary to concentrate in the development of further experimental tests, regarding the dynamic and long-term behavior, with tests of resistance to cyclic load and fatigue.
- The effect of thermal expansion on the anchoring elements and the scalability of the anchoring for cables of different diameters are some of the aspects that further require an in-depth research and experimentation program.

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