# GFRP bar: Determining tensile strength with bending test.

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**Abstract:** In order to obtain GFRP reinforcement bars it is necessary to undertake tests regulated code which require important mechanical tools. This paper presents a method which allows for determining GFRP rebars tensile strength value from their flexural strength value which has been obtained with a simple, inexpensive and reliable test. This method results will be verified by applying it to values obtained in a series of bending tests and comparing these results with values obtained in tensile tests. Values concordance for small diameter GFRP rebars is very good.

## Introduction

Glass-fiber reinforced plastic rebars are increasingly used by engineers when designing structures because of their excellent strength properties. This material strength is characterized by its capacity to bear a load without excessive deformation or failure. When a sample of GFRP is tested under axial force, the applied force when divided by the area of the cross-section (stress) is proportional to the ratio between length increase and its initial length (strain). When the applied load is moved away, GFRP gets back to its initial shape and length. In other words, GFRP rebars have linear elastic behavior under axial forces.

Having typified and certified GFRP rebars strength properties [1], it is necessary to determine rebars tensile strength by means of a simple, inexpensive and reliable method which obviates undertaking the laborious tests established in the code.

Not only the lack of regulations and design guides but also the huge variability of applications and the lack of standardization of GFRP components frequently demands carrying out specific experimental programs aimed to confirm theoretical results within particular cases.

For other materials such as concrete, codes consider the possibility of determining tensile stress by means of an indirect tensile test until failure (UNE 83306:1985) [2] or by means of a bending essay (UNE-EN 14651:2007+A1:2008) [3]. Therefore, if guidelines of tests developed for other materials [2, 3] are followed, GFRP reinforcement bars tensile strength could be determined by means of similar tests.

The present paper is presented as an experimental procedure to determine GFRP rebars tensile strength by means of a bending test with three points which is much more simple and inexpensive. Procedure's reliability will be verified by means of applying it to the values obtained in a series of bending tests and its comparison with the values obtained in pure tensile tests. Values obtained will be valid as long as tested rebars accomplish certain specifications.

## Tensile strength determining by means of bending test

Rebars tensile behavior was assessed from flexural strength which was determined considering the load-displacement diagram. Bending test consisted of applying a point load perpendicularly to the specimen axis in its middle point. The bar was simply resting on both ends.

Considering European Codes UNE-EN ISO 178 [4] and UNE-EN 13706-2:2003 [5], in order to determine their flexural strength, specimens to be tested should accomplish the following geometrical ratio between its length between bearing points and the bar diameter.

$$L = 20 \cdot \phi \tag{1}$$

Being L the length between bearing points and ϕ the specimen diameter.

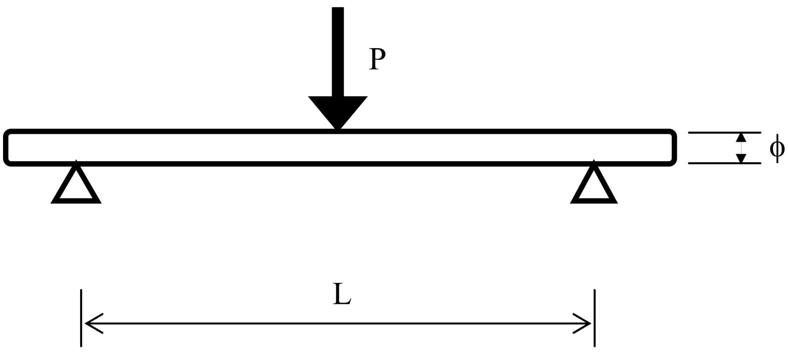


Figure 1. Dynamic test scheme

Bending moment in the bay center produced by a centered point load P has a maximum value:

$$M = \frac{P}{2} \cdot \frac{L}{2} \tag{2}$$

If we assume Navier's hypothesis and accepting that linear behavior is kept until failure then stresses distribution within the cross-section can be obtained by means of the following equation:

$$\sigma_{\max} = \frac{M}{I} \cdot y = \frac{P \cdot L/4}{\pi \cdot \phi^4/64} \cdot \frac{\phi}{2} = \frac{8 \cdot P \cdot L}{\pi \cdot \phi^3} \tag{3}$$

Anyhow in order to determine this strength, it will be mandatory to undertake the tensile test established by code whenever the ratio between the applied point load and the tested rebar diameter does not accomplish equation (4):

$$P \geq 12 \cdot \phi^2 \tag{4}$$

## Testing plan and results

Tests were carried out with the laboratory equipment of the Department of Continuum Mechanics and Theory of Structures of the Universitat Politècnica de València. For the three points bending test a universal testing press was employed. This device is certified according to the EN 7500-1 Code by SERVOSIS S.A. and its main characteristics are:

- Specimens are simply resting on both ends on cylindrical metallic pieces.
- Press can apply a maximum load of 98kN (10Tn).

- Point load is applied in the specimen center point by means of an element with a cylindrical head.
- Applied loads and displacements produced are registered by software installed in the press by SERVOSIS S.A.

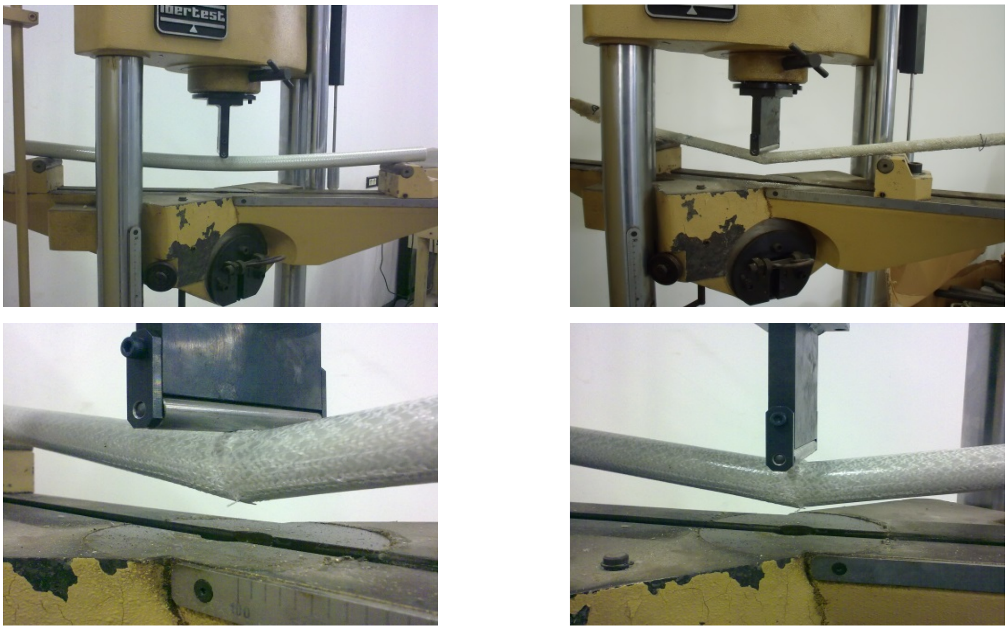

Figure 2. Bending test in order to determine tensile strength

Figure 3 shows a specimen cross-section which has reached failure during the bending essay. It clearly displays compressive fibers and tensile fibers.

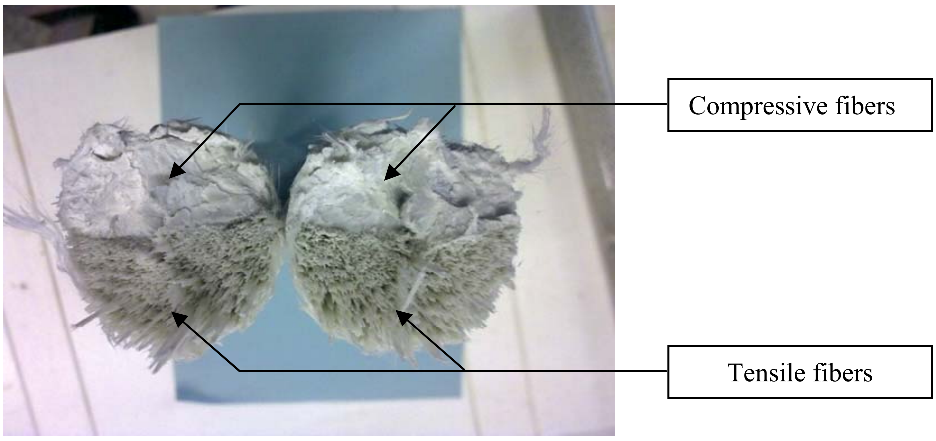


Figure 3. Bending test: compressive and tensile fibers

Bending test has been carried out on a series of specimens and bending failure load has been obtained. Tensile strength will be determined from this value. Results obtained are presented in the following tables for each diameter tested. Nevertheless, an estimator has been used in order to assure a minimum value of the assessed characteristic. It has a confidence level of 95% as stipulated in UNE 66040:2003 [6].

$$\sigma_{caract} = \sigma - (1 - \delta \cdot t_{1-\alpha}) \quad (5)$$

Being σ the arithmetical mean of all values obtained, δ the quotient between the arithmetic mean and the mean deviation and t1-α the coefficient for a confidence level: α = 95%

Table 1. Bending test results for diameter 8mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 8 | 8.00 | 50.27 | 160 | 0.910 | 10.71 | 724.2 |
| 8 | 8.00 | 50.27 | 160 | 0.838 | 12.45 | 666.9 |
| 8 | 8.00 | 50.27 | 160 | 0.871 | 12.12 | 693.1 |
| 8 | 8.00 | 50.27 | 160 | 0.856 | 11.94 | 681.2 |
| 8 | 8.00 | 50.27 | 160 | 0.934 | 11,24 | 743.3 |
| 8 | 8.00 | 50.27 | 160 | 0.904 | 10.85 | 719.4 |
| Average | 8.00 | | | 0.9 | | 704.7 |
| Deviation | 0.00 | | | 0.03 | | 24.27 |
| δ | 0.0% | | | 3.4% | | 3.4% |
| Characteristic | 8.00 | | | 0.82 | | 655.75 |

Table 2. Bending test results for diameter 10mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 10 | 10.00 | 78.54 | 200 | 1.216 | 10.19 | 619.3 |
| 10 | 10.00 | 78.54 | 200 | 1.674 | 15.19 | 852.6 |
| 10 | 10.00 | 78.54 | 200 | 1.560 | 13.16 | 794.5 |
| 10 | 10.00 | 78.54 | 200 | 1.464 | 12.76 | 745.6 |
| 10 | 10.00 | 78.54 | 200 | 1.650 | 15.99 | 840.3 |
| 10 | 10.00 | 78,54 | 200 | 1,482 | 12.79 | 754.8 |
| Average | 10.00 | | | 0.9 | | 767.8 |
| Deviation | 0.00 | | | 0.03 | | 61.29 |
| δ | 0.0% | | | 3.4% | | 8.0% |
| Characteristic | 10.00 | | | 0.82 | | 644.36 |

Table 3. Bending test results for diameter 12mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 12 | 12.00 | 113.10 | 240 | 2.135 | 16.03 | 755.1 |
| 12 | 12.00 | 113.10 | 240 | 2.177 | 16.47 | 770.0 |
| 12 | 12.00 | 113.10 | 240 | 2.209 | 17.64 | 781.3 |
| 12 | 12.00 | 113.10 | 240 | 2.126 | 15.99 | 751.9 |
| 12 | 12.00 | 113.10 | 240 | 2.547 | 18.26 | 900,8 |
| 12 | 12.00 | 113.10 | 240 | 2.165 | 17.74 | 765.7 |
| 12 | 12.00 | 113.10 | 240 | 2.132 | 17.25 | 754.0 |
| 12 | 12.00 | 113,10 | 240 | 2.090 | 16.91 | 739.2 |
| Average | 12.00 | | | 2.2 | | 775.0 |
| Deviation | 0.00 | | | 0.08 | | 29.34 |
| δ | 0.0% | | | 3.8% | | 3.8% |
| Characteristic | 12.00 | | | 2.04 | | 720.45 |

Table 4. Bending test results for diameter 16mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 16 | 16.00 | 201.06 | 320 | 3.985 | 19.97 | 792.8 |
| 16 | 16.00 | 201.06 | 320 | 3.853 | 20.40 | 766.5 |
| 16 | 16.00 | 201.06 | 320 | 4.099 | 21.94 | 815.5 |
| 16 | 16.00 | 201.06 | 320 | 3.835 | 21.64 | 762.9 |
| 16 | 16.00 | 201.06 | 320 | 3.688 | 20.87 | 733.7 |
| 16 | 16.00 | 201.06 | 320 | 3.629 | 19.76 | 722.0 |
| 16 | 16.00 | 201.06 | 320 | 3.452 | 18.45 | 686.8 |
| 16 | 16.00 | 201.06 | 320 | 3.509 | 18.07 | 698.1 |
| Average | 16.00 | | | 3.8 | | 757.6 |
| Deviation | 0.00 | | | 0.21 | | 42.22 |
| δ | 0.0% | | | 5.6% | | 5.6% |
| Characteristic | 16.00 | | | 3.41 | | 679.10 |

Table 5. Bending test results for diameter 20mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 20 | 20.00 | 314.16 | 400 | 5.895 | 26.32 | 750.6 |
| 20 | 20.00 | 314.16 | 400 | 5.694 | 25.87 | 725.0 |
| 20 | 20.00 | 314.16 | 400 | 5.300 | 21.52 | 674.8 |
| 20 | 20.00 | 314.16 | 400 | 5.694 | 23.67 | 725.0 |
| 20 | 20.00 | 314.16 | 400 | 4.997 | 22.83 | 636.2 |
| 20 | 20.00 | 314.16 | 400 | 5.772 | 24.17 | 734.9 |
| Average | 20.00 | | | 5.6 | | 707.8 |
| Deviation | 0.00 | | | 0,27 | | 34.82 |
| δ | 0.0% | | | 4.9% | | 4.9% |
| Characteristic | 20.00 | | | 5.01 | | 637.60 |

Table 6. Bending test results for diameter 25mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 25 | 25.00 | 490.87 | 500 | 8.036 | 30.04 | 654.8 |
| 25 | 25.00 | 490.87 | 500 | 7.751 | 30.66 | 631.6 |
| 25 | 25.00 | 490.87 | 500 | 7.712 | 28.05 | 628.4 |
| 25 | 25.00 | 490.87 | 500 | 7.745 | 29.38 | 631.1 |
| 25 | 25.00 | 490.87 | 500 | 7.805 | 29.15 | 636.0 |
| 25 | 25.00 | 490.87 | 500 | 7.563 | 27.32 | 616.3 |
| Average | 25.00 | | | 7.8 | | 633.0 |
| Deviation | 0.00 | | | 0.10 | | 8.25 |
| δ | 0.0% | | | 1.3% | | 1.3% |
| Characteristic | 25.00 | | | 7.56 | | 616.43 |

Table 7. Bending test results for diameter 32mm

| ϕ(mm) | ϕ real (mm) | Cross Area ($mm^2$) | Span (mm) | Pmax (kN) | Deflection (mm) | σ max (MPa) |
|---|---|---|---|---|---|---|
| 32 | 32.00 | 804.25 | 640 | 13.439 | 38.22 | 668.4 |
| 32 | 32.00 | 804.25 | 640 | 13.589 | 39.53 | 675.9 |
| 32 | 32.00 | 804.25 | 640 | 13.820 | 38.78 | 687.4 |
| 32 | 32.00 | 804.25 | 640 | 13.472 | 36.51 | 670,0 |
| 32 | 32.00 | 804.25 | 640 | 14.329 | 39.70 | 712.7 |
| 32 | 32.00 | 804.25 | 640 | 14.275 | 39.65 | 710.0 |
| Average | 32.00 | | | 13.8 | | 687.4 |
| Deviation | 0.00 | | | 0.32 | | 15.96 |
| δ | 0.0% | | | 2.3% | | 2.3% |
| Characteristic: | 32.00 | | | 13.17 | | 655.22 |

## Comparison with pure tensile test

In order to verify the validity of the proposed method, results obtained by means of bending test have been compared (Table 8) with those obtained in a pure tensile test [7] carried out on specimens from the same production batch.

Table 8. Tensile and bending test results classified according to diameter

| ϕ (mm) | $\sigma_{tensile}$ (MPa) | $\sigma_{bending}$ (MPa) | Difference (%) |
|---|---|---|---|
| 8 | 676.0 | 655.8 | 3.00% |
| 10 | 684.1 | 644.4 | 5.81% |
| 12 | 738.8 | 709.0 | 4.04% |
| 16 | 816.4 | 658.7 | 19.32% |
| 20 | 784.1 | 637.6 | 18.69% |
| 25 | 752.8 | 616.4 | 18.11% |
| 32 | 736.0 | 655.2 | 10.98% |
| Average | 741.2 | 653.9 | |

- Bending tests provides tensile strengths much more conservative than tensile test
- Within small diameters (8, 10 and 12) the difference between tensile strength obtained by means of a bending test and tensile strength obtained by means of a pure tensile test is smaller than 6%.
- Divergence of results increases as specimens diameter increases (16, 20, 25 and 32) reaching a maximum of 19.32% for specimens with a diameter of 16%.

Results graphical representation (Figure 4) clearly shows that divergence with respect to strength arithmetic mean is smaller in the bending test.

## Conclusions

This paper has shown the application of bending test in order to determine GFRP reinforcement bars tensile strength.

When compared with results obtained by means of a pure tensile test it is obvious that this method provides conservative values. There is a good concordance of values for small diameters.

Bending tests is a simple and inexpensive test which allows determining GFRP rebars tensile strength with a sufficient accuracy and avoids complex tests specified in the code regulations.

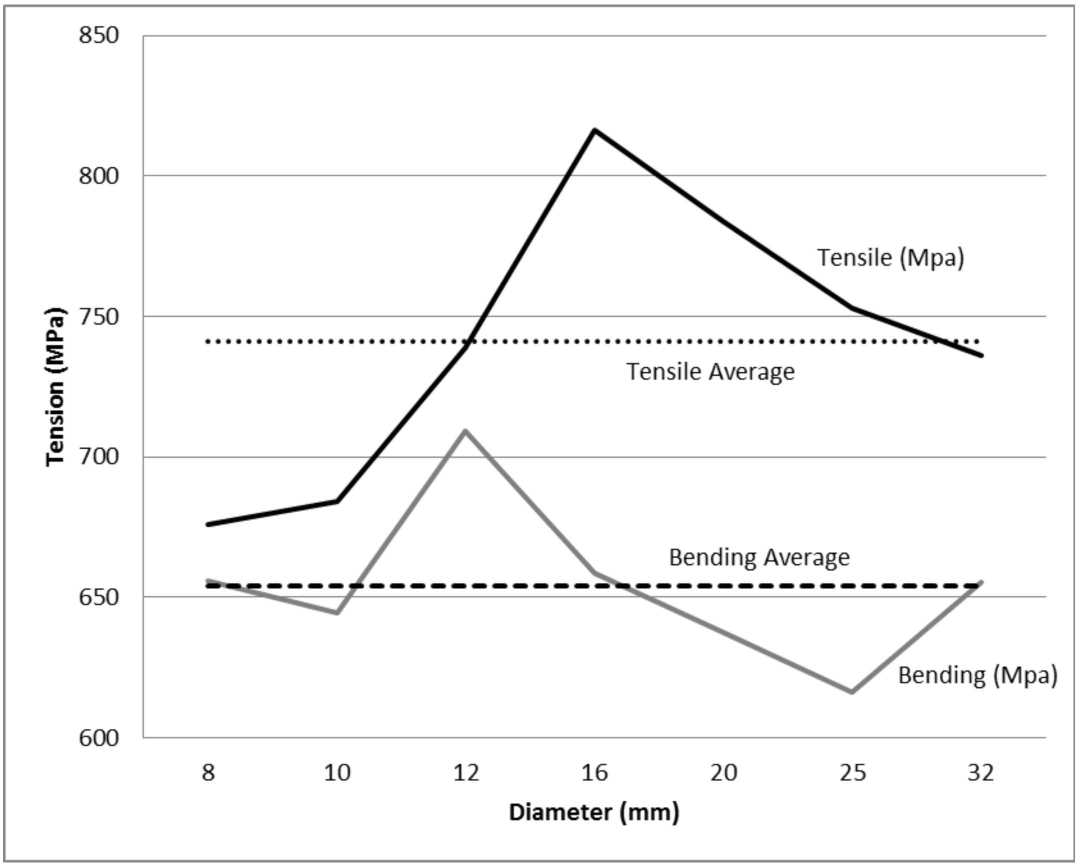


Figure 4. Results comparative

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