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## Carbon and Glass Fibre Reinforced Polymer bar materials for concrete reinforcement — Specification



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## Foreword

Uganda National Bureau of Standards (UNBS) is a parastatal under the Ministry of Trade, Industry and Cooperatives established under Cap 327, of the Laws of Uganda, as amended. UNBS is mandated to co-ordinate the elaboration of standards and is

(a) a member of International Organisation for Standardisation (ISO) and

(b) a contact point for the WHO/FAO Codex Alimentarius Commission on Food Standards, and

(c) the National Enquiry Point on TBT Agreement of the World Trade Organisation (WTO).

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Draft Uganda Standards adopted by the Technical Committee are widely circulated to stakeholders and the general public for comments. The committee reviews the comments before recommending the draft standards for approval and declaration as Uganda Standards by the National Standards Council.

The committee responsible for this document is Technical Committee UNBS/TC 04, *Mechanical engineering and metallurgy.*



 

# Carbon and Glass Fibre Reinforced Polymer bar materials for concrete reinforcement — Specification

## 1 Scope

**1.1** This specification describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements for carbon and glass fibre reinforced polymer (FRP) bars to be used as reinforcement for non-pre-stressed concrete.

**Note Due consideration should be taken when using FRP bars covered by this standard for reinforcement in suspended structural elements such as a beams and slabs.**

**1.2** Only carbon and Glass FRP bars are covered by this specification.

**1.3** FRP bars made of more than one fibre type (hybrid FRP) are not covered by this specification.

**1.4** Pultruded FRP bars with no external surface enhancement (that is, plain or smooth bars) to facilitate bond with concrete are not covered by this specification. Similarly, hollow FRP bars are not considered due to lack of documented performance as reinforcement for concrete.

**1.5** Plain FRP bars used as dowels (that is, devices that transfer shear across concrete joints) where the intended function requires slip of the dowel are not covered by this specification.

**1.6** This specification does not cover pre-manufactured grids and gratings made with FRP materials. FRP mats resulting from assembly of deformed FRP bars, however, are covered by this document.

**1.7** This specification does not cover FRP bars when used for external and near-surface-mounted strengthening applications.

**1.8** The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

## 2 Normative references

The following referenced documents referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 62, Plastics — Determination of water absorption

ISO 7822, Textile glass reinforced plastics — Determination of void content — Loss on ignition, mechanical disintegration and statistical counting methods

ASTM D3171-06 Standard Test Methods for Constituent Content of Composite Materials

ISO 11667, Fibre-reinforced plastics — Moulding compounds and prepregs — Determination of resin, reinforced-fibre and mineral-filler content — Dissolution methods



 

ASTM D5117-17, Standard Test Method for Dye Penetration of Solid Fiberglass Reinforced Pultruded Stock

ISO 10406-1, Fibre-reinforced polymer (FRP) reinforcement of concrete — Test methods — Part 1: FRP bars and grids

ISO 11357-2, Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature and glass transition step height

ISO 6721-11, Plastics — Determination of dynamic mechanical properties — Part 11: Glass transition temperature

US 1834, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

US 1840, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory

US 1837, Standard Test Method for Slump of Hydraulic-Cement Concrete

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**commercial-grade material**
a material formulated for and used in industrial (not consumer) applications

**3.2**
**production lot**
any lot of FRP bar produced from start to finish with the same constituent materials used in the same proportions without changing any production parameter, such as cure temperature or line speed

**3.3**
**property, nominal**
a value provided by the manufacturer no greater than the mean of at least the required number of samples tested according to a specified method. This definition is applicable to tensile elastic modulus, moisture absorption, and resistance to alkaline environment

**3.4**
**Pultruded bar**
linear composite bar produced continuously by the pultrusion process and usually of constant cross-section and characteristics

**3.5**
**Glass transition**
reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one

**3.6**
**glass transition temperature**
approximate midpoint of the temperature range over which a glass transforms between elastic and viscoelastic behaviour characterized by the onset of a rapid change in its coefficient of thermal expansion



 

# 4 Classification

FRP bars shall be classified according to fibre composition with the first letter of the acronym designating fiber type as follows:

a) CFRP: carbon fibre-reinforced polymer bar

b) GFRP: glass fibre-reinforced polymer bar.

# 5 Materials and manufacture

## 5.1 Fibres

Fibres shall be in the form of unidirectional rovings (glass fibres) or unidirectional tows (carbon fibres) of given size and mass. Fibre sizings and coupling agents shall be compatible with the resin system used to impregnate them.

**Note** The fibre type and fibre amount determine the physical and mechanical properties of the FRP bar.

## 5.2 Matrix resins

**5.2.1** Vinylester and epoxy resin systems are permitted provided the finished product meets the physical and durability requirements of this specification. Blending of Vinylester and epoxy resins is permitted.

**5.2.2** The base polymer in the resin system shall not contain any polyester.

**5.2.3** Styrene is permitted to be added to the polymer resin during processing. Added styrene shall be less than 10% by mass of the polymer resin. The amount of styrene, as a mass percentage of the polymer resin, added during processing shall be reported.

**5.2.4** Constituent content of resin shall be determined by ASTM D3171.

## 5.3 Fillers and additives

**5.3.1** Only commercial-grade inorganic fillers such as kaolin clay, calcium carbonate, and alumina trihydrate are permitted, and shall not exceed 20% by mass of the polymer resin constituent.

**5.3.2** Only commercial-grade additives and process aids, such as release agents, low-profile shrink additives, initiators, promoters, hardeners, catalysts, pigments, fire retardants, and ultraviolet inhibitors are permitted and depend on the processing method. Shrink additives, if used, shall be less than 10% by mass of the polymer resin.

**5.3.3** Only commercial-grade inorganic or organic nonwoven surfacing mats or veils are permitted.

## 5.4 Manufacturing process

**5.4.1** The manufacturer shall produce FRP bars using variations of the pultrusion process.

**5.4.2** Process or material modifications are not permitted during the production of a single lot.

**5.4.3** The manufacturer shall document the process used and report the date of production and production lot size.

# 6 Physical properties

## 6.1 Fiber content

The fiber content shall be measured by ASTM D3171 or D2584. When ASTM D3171 is used, fiber content shall not be less than 55% by volume. When ISO 7822 is used, fiber content shall not be less than the fraction by mass corresponding to 55% by volume. The manufacturer shall report the fiber content of the end product by volume or by mass in accordance with the method used.

## 6.2 Glass transition temperature

The glass transition temperature Tg of the resin shall not be less than 110 °C (see Note 3). The glass transition temperature shall be measured on a coupon cut from the as-produced bar using either the Differential Scanning Calorimetry (DSC) method in ISO 11357-2 or the Dynamic Mechanical Analysis (DMA) method in ISO 6721-11. When using the DSC method, test results for both the first scan (according to ISO 11357-2) and the second scan shall be reported.

**Note** This temperature does not represent the maximum permitted service temperature, and is intended for purchaser's quality assurance only.

## 6.3 Bar sizes

**6.3.1** Only FRP bars of solid round or elliptical cross-section shape are allowed.

**6.3.2** The size of FRP bars shall be as listed in Table 1.

**Table 1—Bar size of FRP round bars**

| Nominal diameter mm | Tolerances, % |
|---|---|
| 6 | +5 |
| 7 | |
| 8 | |
| 10 | |
| 12 | |
| 16 | +4 |
| 20 | |
| 22 | |
| 25 | |
| 32 | |

**6.3.3** The calculated diameter of an FRP bar is equivalent to that of a smooth round bar having the same area as the FRP bar measured in accordance with US ISO 10406-1.

**6.3.4** When the FRP bar is of elliptical shape, the minimum and maximum outside dimensions of the bar cross section shall be provided in addition to the calculated diameter. The calculated diameter of elliptical FRP bars is equivalent to that of a solid round bar having the same cross-sectional area as determined according to ISO 10406-1.



 

**6.3.5** The nominal diameter of an FRP bar to be used for designation and design shall be equal to the calculated diameter. When the calculated diameter does not correspond to one of the nominal values given in Table 1, the next immediately smaller nominal diameter given in such table shall be used.

# 7 Mechanical properties

## 7.1 Tensile strength

**7.1.1** The tensile strength for product certification shall be measured according to US ISO 10406-1 based on nominal dimensions and at a frequency and number of specimens, as indicated in Section 11. The minimum tensile strength shall be 800 N/mm$^2$ for GFRP and 1400 N/mm$^2$ for CFRP**.** The manufacturer shall report the individual test results.

**7.1.2** The tensile strength of a production lot shall be measured according to ISO 10406-1 at a frequency and number of specimens as indicated in Section 11. The strength of each specimen shall be reported and be not less than the strength reported by the manufacturer. Otherwise, the production lot shall be rejected.

## 7.2 Tensile modulus of elasticity

The nominal tensile modulus of elasticity of GFRP bars shall be at least 50 N/mm$^2$ regardless of bar size or geometry. The tensile modulus of elasticity of CFRP bars shall be at least 130 N/mm$^2$ regardless of bar size or geometry. The tensile modulus of elasticity is derived from specimens tested in accordance with US ISO 10406-1 at a frequency and number of specimens as indicated in Section 11. The manufacturer shall report the individual test results.

## 7.3 Shear strength (perpendicular to bar)

The transverse shear strength of FRP bars shall be at least 150 N/mm$^2$ as determined by a test method in US ISO 10406-1 at a frequency and number of specimens as indicated in Section 11. The manufacturer shall report the individual test results.

## 7.4 Ultimate tensile strain

The ultimate tensile strain shall be calculated for the purpose of product certification (that is, nominal value). The nominal ultimate tensile strain shall be calculated by dividing the tensile strength by the nominal elastic modulus. The nominal ultimate tensile strain of CFRP and GFRP bars obtained by this procedure shall be at least 0.5% and 1.2%, respectively.

**Note** The calculation method is based on the assumption that the stress-strain behavior is linear elastic

## 7.5 Bond strength

The bond strength of FRP bars shall be at least 10 MPa as determined in accordance with a test method in US ISO 10406-1, at a frequency and number of specimens as indicated in Section 11. The manufacturer shall report the individual test results and the method used for casting the test specimens.

# 8 Durability properties

## 8.1 Moisture absorption

Moisture absorption tests shall be determined (that is, nominal value) in accordance with ISO 62, Section 7.4, using a water temperature of 50 °C at a frequency and number of specimens as indicated in Section 11. The individual moisture absorption test results shall be reported, and their average shall be less than 1.0%.

### 8.2 Resistance to alkaline environment

Resistance to alkaline environment tests shall be determined (that is, nominal value) in accordance with a test method in US ISO 10406-1 at a frequency and number of specimens as indicated in Section 11. The manufacturer shall report the individual test results and the test method. Tensile strength reduction shall be less than 25 %

### 8.3 Longitudinal wicking

Five consecutive 25 mm long segments cut from an FRP bar shall be tested in accordance with ASTM D5117 at a frequency as indicated in Section 11. No continuous voids shall be permitted in the resin. A continuous void is one that appears in all five consecutive test specimens. The presence of hollow fibers is not considered a void.

**Note** This requirement is intended to check for continuous voids that could occur due to shrinkage of the resin during processing or as the result of poor consolidation of the fiber and resin matrix during production.

## 9 Other requirements

### 9.1 Bend radius

Bends shall be formed in FRP bars that are made with thermosetting resin and only while the resin is in a physical liquid state. The minimum inside bend radii for factory-formed FRP bar bends are specified in Table 2.

**Note** After the resin has passed the liquid state, bending or alteration of the FRP bar is not possible due to the inability of the fibers to move [or reorient] within the resin matrix. Because thermosetting polymers are highly cross linked, heating the bar on site will not be allowed as it leads to a decomposition of the resin, thus creating a loss of strength in the FRP bar.

**Table 2 — Minimum inside bend radius of bent bars**

| Nominal bar diameter<br>mm | Bend radius<br>mm |
|---|---|
| 6 | 19 |
| 7 | |
| 8 | |
| 10 | 28 |
| 12 | |
| 16 | 48 |
| 20 | |
| 22 | 67 |
| 25 | 76 |
| 32 | 127 |

### 9.2 Strength of bends

**9.2.1** The strength of bends shall be at least 70% and 60% of the tensile strength of corresponding straight bars of CFRP and GFRP respectively as determined in accordance with a method contained in Annex A. Testing frequency and number of specimens shall be as indicated in clause 11. The manufacturer shall report the individual test results.



 

**9.2.2** For a measure of the manufacturer's quality control and purchaser's quality assurance on FRP bends, one of the two test methods listed as follows shall be used at a frequency and number of specimens as indicated in clause 11. The manufacturer shall report the individual test results.

**9.2.2.1** When it is possible to extract a straight portion of the tail of the bent bar of sufficient length, such an element shall be tested according to US ISO 10406-1. The strength of each specimen shall be not less than the strength reported by the manufacturer for the bar of that diameter.

**9.2.2.2** When the bend size does not allow for the tensile testing of one of its straight portions, a specimen shall be obtained from the bend and tested for inter-laminar (horizontal) shear strength according to US ISO 10406-1 and for fiber content according to ISO 7510. The manufacturer shall report the individual test results. Minimum inter-laminar shear strength values have not yet been established. The fiber content of each specimen shall be not less than the minimum percent by volume reported in Section 6.1.

## 10 Marking

**10.1** Each bundle of bars shall be identified with a corresponding production lot number. Production lot numbers shall be printed on each bar or affixed to each bundle by means of a durable tag.

**10.2** Each bundle of bars shall be labeled with the following information:

a) manufacturer's name and address;

b) classification of fiber (that is, G for glass and C for carbon);

c) nominal bar diameter and length (in metric);

d) nominal tensile strength;

e) nominal modulus of elasticity; and

f) for bent bars, the shape of the bend, the radius of the bend, and the length of the legs

**10.3** The only marking required for each individual bar shall be the nominal bar diameter designation, and it shall be made by a durable means. Bar markings shall take the form of permanent physical marking of the bar size in metric on the product or permanent color coding applied to the bar as shown in Table 3

**Note** Markings will be used at the construction site to verify that the specified bars are being used.



**Table 3 — Colour codes for marking bar sizes**

| Nominal bar diameter mm | Colour* |
|---|---|
| 6 | Black |
| 7 | Royal blue |
| 8 | Gray |
| 10 | Orange |
| 12 | Green |
| 16 | Red |
| 20 | Blue |
| 22 | Yellow |
| 25 | Purple |

 

| | |
|---|---|
| 32 | Brown |
| ∗Color coding should be at least 150 mm of FRP at each end of bars. | |

## 11 Sampling

### 11.1 Sampling frequency and number of specimens

**11.1.1** For the determination of each of the mechanical and durability properties for the manufacturer's quality control tests and for the purchaser's quality assurance tests, at least five samples of sufficient length to perform the required tests shall be obtained from each production lot.

**11.1.2** For the determination of each of the mechanical and durability properties, at least 25 samples of sufficient length to perform the required tests shall be obtained in groups of five from five different production lots.

**11.1.3** For orders of bends in varying quantities that together will comprise a production lot of bends, at the discretion of the purchaser, testing of bends for the manufacturer's quality control and for the purchaser's quality assurance may be limited to a minimum of five samples of a 90-degree bend with the smallest bend radius to bar diameter ratio.

### 11.2 Methods of sample selection

Samples from each production lot to be used for preparing test specimens shall be selected by the manufacturer on a random basis.

# Annex A

# (normative)

# Test method for strength of FRP bent bars and stirrups at bend locations



## A.1 Scope

This test method specifies the test requirements for strength capacity of FRP bent bars used as an anchorage for stirrups in concrete structures

## A.2 Significance and use

**A.2.1** This test method is intended for use in laboratory tests to determine the strength capacity of the bent portion provided as an anchorage in which the principal variable is the size, bend radius, or type of FRP stirrup.

**A.2.2** Bending of FRP stirrups to develop anchorage leads to a significant reduction in the strength capacity of the stirrups. The bend radius and tail length beyond the bend are important factors affecting the bend capacity.

**A.2.3** This test method measures the ultimate load capacity of a single FRP stirrup subjected to tensile forces in the direction of the straight portion.

**A.2.4** This test method is intended to determine the bend capacity and strength reduction for material specifications, research and development, quality assurance, and structural design and analysis. The behavior of bent bars and stirrups should be measured according to the method given herein, in keeping with the intended purposes.

## A.3 Test equipment and requirements

The hydraulic cylinder and load cell should be calibrated, have a loading capacity in excess of the capacity of the specimen, and be capable of applying load at the required loading rate. The load cell should also be capable of giving readings of loading accurate to within 1% throughout the test.

## A.4 Specimen preparation

**A.4.1** The configuration of a typical specimen is shown in Figure 1. The dimensions of each concrete block used to anchor the FRP stirrup may be varied according to the dimensions of the stirrup used. The free length of the stirrup between the two blocks, however, should not be less than 200 mm (400 mm is suggested). The concrete block should be reinforced using steel stirrups, as shown in Figure 1, to prevent splitting of the concrete block before rupture of the stirrup at the bend. The dimensions of the stirrups might be variable, therefore, the tail length lt of the FRP stirrup tested to evaluate the bend capacity should not exceed 150 mm. The debonding tube is used to eliminate the straight-bar development of the hooked bar. The debonding tube should slip fit over the reinforcing bar. Fill the ends of the debonding tube with caulk to prevent the tubes from filling with concrete during casting.

 

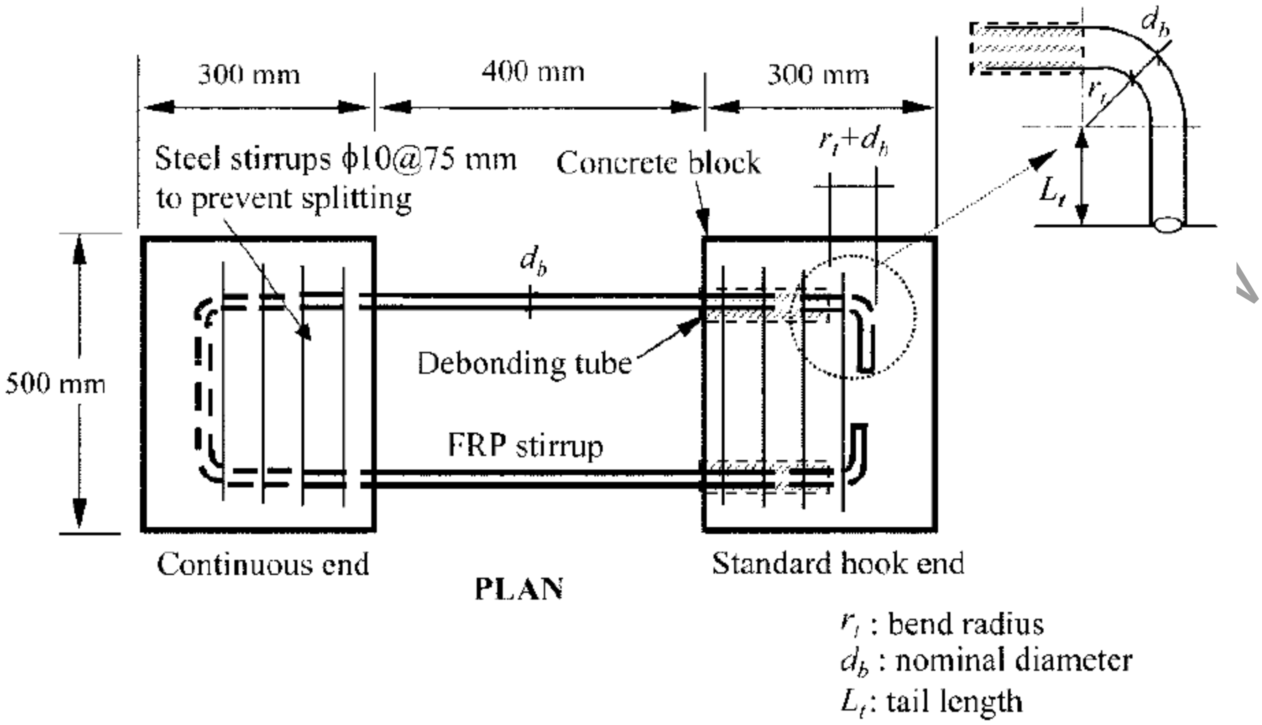


**Figure 1 — Configuration of specimen.**

**A.4.2** The concrete should be a standard mixture, with coarse aggregates having a maximum dimension of 20 to 25 mm. It should be batched and mixed in accordance with the applicable clauses of US 1840. The concrete should have slump of 100 ± 20 mm in accordance with US 1837, and the compressive strength at 28 days should be 30 ± 3 MPa in accordance with US 1834. A minimum of five standard 150 x 300 mm or 100 x 200 mm control cylinders should be made for determining compressive strength from each batch of concrete

**A.4.3** The number of test specimens for each test condition should not be less than five. If a specimen fails by splitting of the concrete block, an additional test should be performed on a separate specimen taken from the same lot as the failed specimen.

**A.4.4** If test specimens fail due to pullout of the bent bar from the concrete, this is an indication that the bend radius and tail length are inadequate for the bar being tested. It will be necessary to adjust these parameters, and perhaps the size of the test blocks as well, and retest.

## A.5 Conditioning

**A.5.1** Unless a different testing environment is specified as part of the experiment, the tests should be conducted at the standard laboratory atmosphere (23 ± 3 °C and 50 ± 10% relative humidity).

**A.5.2** Preconditioning of FRP bars before casting in concrete is permissible but must be reported.

## A.6 Test method

**A.6.1** The test setup, shown in Figure 2, consists of a hydraulic jack to apply the relative displacement between the two concrete blocks and a load cell to measure the applied load. Steel plates and plaster bags should be placed in front of the load cell and the hydraulic jack to distribute the applied load to the surface of the concrete. A spherical washer may also be used at the end of the ram. The two blocks should be placed on top of steel rollers to minimize the friction forces between the blocks and testing bed.



 

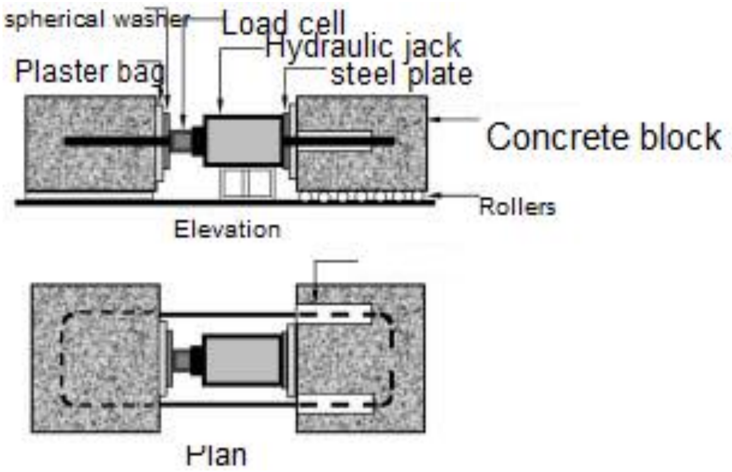


**Figure 2 — Test setup.**

**A.6.2** Tensile strength of straight FRP bars with the same diameter as the FRP stirrups should be determined in accordance with US ISO 10406-1

**A.6.3** The test specimens should not be subjected to any shock, vibration, or torsion during the test. Increase the force in the jack in a smooth, continuous manner until the specimen fails. Do not pause the application of load during the test.

The loading rate should be selected so that the specimen fails at a time of between 1 and 10 min from the start of the test.

**A.6.4** Record the failure load and failure mode for the specimen.

## A.7 Calculations

**A.7.1** The bend capacity of the FRP stirrup should only be assessed on the basis of the specimen undergoing failure at the bend. In cases where block splitting has clearly taken place, the data should be disregarded, and additional tests should be performed until the number of the test specimens failing at the bend is not less than five.

**A.7.2** The bend capacity of the FRP stirrup should be calculated according to Eq. (1), and rounded to three significant digits

$$f_{ub} = \frac{F_{ub}}{2A}$$

where

$f_{ub}$ bend capacity of the FRP stirrup, MPa

$F_{ub}$ ultimate load capacity according to bend tests, N; and

A cross-sectional area of single leg of the FRP stirrup, mm$^2$.

**A.7.3** The strength-reduction factor is calculated according to Eq. (2)

$$X = \frac{f_{ub}}{f_u}$$



 

where

χ strength-reduction factor due to bend effect; and

fu ultimate tensile strength parallel to the fibers, (MPa).

## A.8 Report

The test report should include the following items:

**A.8.1** Properties of concrete;

**A.8.1.1** The mixture proportions of cement, fine aggregate, coarse aggregate, admixture (if any used), and the w/c ratio.

**A.8.1.2** Slump of freshly mixed concrete as determined in accordance with US 1837.

**A.8.1.3** Twenty-eight-day strength of control cylinders as determined in accordance with US 1834.

**A.8.1.4** Any deviation from the stipulated standards in such aspects as mixing, curing, dates of demolding, and testing of control cylinders.

**A.8.2** Trade name, shape, and date of manufacture, if available, and lot number of FRP bar tested for stirrups.

**A.8.3** Type of fiber and matrix used in the FRP stirrup, and fiber volume fraction.

**A.8.4** Process used to fabricate the stirrups, as reported by the manufacturer.

**A.8.5** Numbers or identification marks of test stirrups.

**A.8.6** Designation, diameter, and cross-sectional area.

**A.8.7** Dimensions of concrete block, configuration (diameter and space) of steel stirrup confinement, debonded length, bend radius, and tail length of the bent bar.

**A.8.8** Preconditioning of FRP bars before casting.

**A.8.9** Date of test and test temperature.

**A.8.10** Type and capacity of load cell.

**A.8.11** Bend capacity and strength-reduction factor for each test stirrup.

**A.8.12** Average bend capacity and strength-reduction factor for all specimens that failed at the bend as intended



 

## Certification marking

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**ICS 91.100.30, 83.120**

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