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AXIAL COMPRESSIVE BEHAVIOR OF FRP-CONFINED CONCRETE: EXPERIMENTAL TEST DATABASE AND A NEW DESIGN-ORIENTED MODEL

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ABSTRACT

A large number of experimental studies have been conducted over the last two decades to understand the behavior of FRP-confined concrete columns. This paper presents a comprehensive test database constructed from the results of axial compression tests on 832 circular FRP-confined concrete specimens published in the literature. The database was assembled through an extensive review of the literature that covered 3042 test results from 253 experimental studies published between 1991 and the middle of 2013. The suitability of the results for the database was determined using carefully chosen selection criteria to ensure a reliable database. This database brings reliable test results of FRP-confined concrete together to form a unified framework for future reference. Close examination of the test results reported in the database led to a number of important observations on the influence of important parameters on the behavior of FRP-confined concrete. A new design-oriented model that was developed to quantify these observations is presented in the final part of the paper. It is shown that the predictions of the proposed model are in close agreement with the test results and the model provides improved predictions of the ultimate conditions of FRP-confined concrete compared to any of the existing models.

KEYWORDS: FRP-confined concrete; A. Fibers; B. Plastic deformation; B. Strength; D. Mechanical testing

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1. INTRODUCTION

Axial compressive behavior of FRP-confined concrete has received significant attention over the last two decades, and it is now well understood that the confinement of concrete with fiber reinforced polymer (FRP) composites can substantially enhance concrete strength and deformability. A large number of experimental studies have produced over 3000 test results on FRP-confined concrete and resulted in the development of over 90 axial stress-axial strain models, 88 of which were recently reviewed and assessed in Ozbakkaloglu et al. [1]. It became evident from the results of the assessment reported in Ozbakkaloglu et al. [1] the performances of a large proportion of the existing models were compromised when assessed against a large test database with a parametric range that is much wider than the databases used in the development of these models. These observations clearly revealed the need for an extensive and reliable experimental test database of FRP-confined concrete for the development of models of higher accuracy.

In this paper, a carefully prepared database of circular FRP-confined concrete specimens tested under monotonic uniaxial compression is presented. The database was assembled through an extensive review of the literature that catalogued 3042 test results from 253 experimental studies published between 1991 and the middle of 2013. These results were then assessed according to criteria that had been critically determined to establish a reliable database. Assessment using these criteria resulted in a final database of 832 test results from 99 different sources. This database serves as a valuable reference document for: i) future model development and verification; ii) assessment of existing models; and iii) future database establishment. The important factors that influence the overall behavior of FRP-confined concrete, as identified from the results reported in the comprehensive database, are then discussed. In the final part of the paper, a new design-oriented model developed using the database to predict the ultimate condition of FRP-confined concrete is presented.

2. CONSTRUCTION OF EXPERIMENTAL TEST DATABASE

2.1. Previous databases

Due to the inherent complexity of the behavior of FRP-confined concrete, test databases serve as a vital verification tool in assessing the performance of a model. Recognition of the importance of systematically collecting and categorizing the existing test results has led to a number of previous attempts to develop test databases for FRP-confined concrete. All relevant details of these previous databases are summarized in Table 1. The earlier databases reported by Lam and Teng [2, 3], De Lorenzis and Tepfers [4] and Bisby et al. [5] are extensive and include the majority of the experimental data with sufficient detail that were available at the time the databases were published. More recently, Turgay et al. [6] compiled a database of carbon FRP-confined concrete specimens and Realfonzo and Napoli [7] reported a fairly large database of carbon and glass FRP-wrapped specimens. However, a comprehensive review of the literature indicated that a large number of the currently available test results summarized in Table 2 were not included in any of the existing databases.

2.2. Selection criteria for the new database

The suitability of the results for the database was assessed using carefully established selection criteria to ensure both the reliability and consistency of the test data. This resulted in a final database of 832 datasets, which makes it by far the most comprehensive database reported in the literature. The test results included in this database, summarized in Table 2 and presented in Tables 3 to 7, met the following requirements:

1) Only the specimens with unidirectional fibers orientated in the hoop direction were included in the database.
2) Specimens with transverse and/or longitudinal steel or internal FRP reinforcement were excluded.

3) Only the specimens that were confined with continuous FRP jackets were included. Specimens with partial wrapping (i.e., FRP strips) were excluded.
4) Specimens with a height-to-diameter *(H / D)* ratio greater than three were excluded from the database to eliminate the influence of specimen slenderness.
5) Specimens with unconfined concrete compressive strengths greater than 55 MPa were excluded to limit the database to only normal-strength concrete.
6) Only the specimens that failed due to FRP rupture at the ultimate condition were included. Specimens that failed prematurely due to other types of failure, such as FRP shell debonding or premature failure due to excessive eccentricity were excluded.
7) Specimens for which the ultimate conditions were not recorded accurately due to inadequate testing equipment or instrumentation errors were excluded.
8) Specimens reported with insufficient details in regards to material and geometric properties were excluded.

The specimens that satisfied the above conditions, and hence were included in the test database, were then subjected to an additional set of conditions to establish their suitability for their inclusion in the assessment of the existing models and development of the new model. The specimens with compressive strengths (f'_{cc}) and ultimate axial strains (ε_{cu}) that deviated significantly from the global trends of relevant strength and strain enhancement ratios (i.e. more than ±40% of f'_{cc} / f'_{co} and ±70% of $\varepsilon_{cu} / \varepsilon_{co}$) were excluded in the model assessment and development. The specimens that were excluded from the calculations of the strength and strain enhancement ratios (f'_{cc} / f'_{co} and $\varepsilon_{cu} / \varepsilon_{co}$) are marked respectively with the superscripts '*s*' and '*a*' in Tables 3 to 7. Furthermore, the specimens with hoop rupture strain reduction factors (k_ε) that deviated significantly from the average values of the corresponding material (i.e. more than ±20% of average k_ε) are marked with the superscript '^' in Tables 3 to 7, and they were excluded in the development of the expression for the hoop rupture strain reduction factor (k_ε). In addition to these, datasets from specimens exhibiting a stress-strain curve with a descending second branch (marked with superscript '*d*' in database tables) and ones from specimens having tubes that were fabricated using an automated manufacturing method (marked with superscript '*fm*' in database tables) were also excluded in the model development and assessment to limit the investigation to specimens with ascending second branches and manually manufactured FRP jackets.

3. NEW TEST DATABASE

The complete test database assembled in the present study is displayed in Tables 3 to 7. The database consists of the following information for each specimen: confinement technique (wrapped or tube-encased concrete); specimen geometric properties (diameter D and height H); unconfined concrete strength (f'_{co}) and strain (ε_{co}); material properties of the FRP shell (elastic modulus E_{frp}, tensile strength f_{frp}, total thickness t_{frp}); material properties of the fibers used in the FRP shell (elastic modulus E_f, tensile strength f_f, total thickness t_f); compressive strength (f'_{cc}) and ultimate axial strain (ε_{cu}) of confined concrete, and average FRP hoop strain at rupture ($\varepsilon_{h,rup}$); and hoop rupture strain reduction factor based on fiber properties ($k_{\varepsilon,f}$) and FRP material properties ($k_{\varepsilon,frp}$).

The test data presented in the database were sorted into eight groups based on two main confinement parameters: confinement technique (wraps or tubes) and type of FRP material [carbon FRP (CFRP); S- or E-glass FRP (GFRP); aramid FRP (AFRP); high-modulus carbon FRP (HM CFRP); or ultra-high-modulus carbon FRP (UHM CFRP)]. 755 specimens in the database were FRP-wrapped, whereas 77 specimens were confined by FRP tubes. 495 of the specimens were confined by CFRP; 206 by GFRP; 79 by AFRP; 40 by HM CFRP; and 12 by UHM CFRP.

The results of FRP-wrapped specimens are presented in Tables 3 to 6, categorized according to fiber type, and the results of all FRP tube-encased specimens are given in Table 7. It is worthwhile noting that for some of the datasets, a single entry in Tables 3 to 7 may represent the average results of more than one nominally identical specimen, as reported in the original study. These datasets are clearly marked in Table 2. In addition, a group of unbonded-wrapped specimens tested by Harries and Carey [8], Mirmiran et al. [9], Mastrapa [10] and Matthys et al. [11] were grouped under the category of tube-encased specimens in the database. Furthermore, except for the datasets from Saafi et al. [12], Hong and Kim [13] and Ozbakkaloglu and Vincent [14], all the datasets included in the database tables were obtained from specimens that were confined by FRP shells (wraps or tubes) manufactured using a manual hand lay-up technique. The specimens of Ozbakkaloglu and Vincent [14] and Hong and Kim [13], on the other hand, were confined by FRP tubes that were manufactured using an automated filament winding technique; and the specimens of Saafi et al. [12] were confined with FRP tubes supplied by a manufacturer, with no specific manufacturing method reported in the source document. These datasets are marked with a superscript *'fm'* in Table 7 to highlight the fact that the FRP shells of these specimens were manufactured using an automated manufacturing method rather than a manual one.

The diameters of the specimens (D) included in the test database varied between 47 and 600 mm, with the majority of the specimens having a diameter of 150 mm. The unconfined concrete strength (f'_{co}) and strain (ε_{co}), as obtained from concrete cylinder tests, varied from 6.2 to 55.2 MPa and 0.14% to 0.70%, respectively. The actual confinement ratio, defined as the ratio of the actual ultimate confining pressure to the unconfined concrete strength ($f_{lu,a} / f'_{co}$), varied from 0.02 to 4.74. The FRP material properties reported in the database were obtained either from the material test results (i.e., coupon or ring splitting tests) reported in the original study or the specifications provided by the manufacturers. The specimens with FRP properties that differed significantly from the reference properties of the corresponding material were marked with the superscript '*m*' in Tables 3 to 7, to point to potential errors in these properties.

3.1. Material properties of fibers and FRP composites reported in the database

In FRP-confined circular concrete sections, the lateral confining pressure (f_l) provided by the FRP shell can be assumed to be uniformly distributed around the circumference (Figure 1). The confinement exerted by the FRP shell on the concrete core is passive; that is, this pressure arises as a result of the lateral expansion of the concrete under axial compression. As the FRP shell is subjected to tension along its hoop direction, the confining pressure (f_l) increases proportionally with the lateral expansion until the eventual failure of the system when the FRP shell ruptures. Based on the deformation compatibility between the confining shell and the concrete surface and assumption of a uniform confining pressure distribution, the lateral confining pressure applied to the concrete by the FRP shell at ultimate (f_{lu}) can be theoretically calculated from Eq. 1 as a function of the ultimate tensile strain of the fibers (ε_f).

$$f_{lu} = \frac{2E_f t_f \varepsilon_f}{D} \qquad \textit{Eq. 1}$$

However, it has been well documented that the ultimate strain measured on the FRP shell at the time of FRP hoop rupture ($\varepsilon_{h,rup}$) is often lower than the ultimate tensile strain of the fibers (ε_f) or FRP material (ε_{frp}) (e.g. [3, 4, 8, 9, 11, 15-25]). Several causes have been given for the observed differences between hoop rupture strains and material ultimate tensile strains, including: (i) the quality of workmanship; (ii) overlaps of fiber sheets in the FRP shell; (iii) manufacturing imperfections (e.g., misalignment of fibers); (iv) shrinkage of the concrete (for FRP tube-encased concrete); (v) localized or non-uniform effects caused by imperfections in FRP shells and/or heterogeneity of cracked concrete; (vi) load eccentricities caused by specimen imperfections and/or test setup imprecisions; (vii) multiaxial stress condition generated on the FRP shell; and (viii) effect of the curvature of the FRP shell.

To establish the relationship of the hoop rupture strain of the FRP shell ($\varepsilon_{h,rup}$) and the ultimate tensile strain of the material (ε_f or ε_{frp}) , a strain reduction factor (k_ε) was defined by Pessiki et al.

[17] (Eq. 2). Lam and Teng [3] then defined a term called the actual confining pressure ($f_{lu,a}$) (Eq. 3), by replacing the ultimate tensile strain (ε_f or ε_{frp}) of the material with the hoop rupture strain of the FRP shell ($\varepsilon_{h,rup}$) in Eq. 1.

$$\varepsilon_{h,rup} = k_{\varepsilon,f}\varepsilon_f \text{ or } \varepsilon_{h,rup} = k_{\varepsilon,frp}\varepsilon_{frp} \quad \textit{Eq. 2}$$

$$f_{lu,a} = \frac{2E_f t_f \varepsilon_{h,rup}}{D} \quad \textit{Eq. 3}$$

In Eq. 2, due attention should be given to ensure that the strain reduction factors ($k_{\varepsilon,f}$ or $k_{\varepsilon,frp}$) are used consistently with the corresponding ultimate material tensile strain (ε_f or ε_{frp}). In the studies examined, the properties of the FRP confinement systems were reported in several different ways. The reported details included: (i) the manufacturer specified properties of fibers; (ii) the manufacturer specified properties of FRP (iii) FRP properties as determined from flat coupon tests based on measured coupon thickness; (iv) FRP properties as determined from flat coupon tests based on nominal fiber sheet thickness; and (v) FRP properties as determined from ring-splitting tests. Only a small number of studies [10, 26, 27] reported the FRP properties obtained from ring-splitting tests, and the majority of the studies provided the properties obtained from flat coupon tests or supplied by manufacturers. As for the FRP properties obtained from flat coupon tests, in some of the studies [18, 28-36] the elastic moduli (E_{frp}) and tensile stresses (f_{frp}) were calculated based on nominal fiber thickness instead of the measured thickness of flat FRP coupons. The datasets from these studies are marked with the superscript '*t*' in Tables 3 to 7.

In the database provided in Tables 3 to 7, due attention was given to establish a clear distinction between the fiber and FRP properties in the reported values of the elastic modulus (E_f or E_{frp}), tensile strength (f_f or f_{frp}), and total thickness (t_f or t_{frp}) of the confining material. In the model assessment and development, if a dataset included both fiber and FRP properties, the model predictions were based on the fiber properties, unless the fiber properties were marked with the superscript '*f*' indicating they were either incomplete or established to be inaccurate based on the analysis of the database.

3.2. FRP confinement technique

A potentially important distinction, often recognized by the models assessed in the present study, is the one that is made between FRP-wrapped and FRP tube-encased specimens. Previously, both Mirmiran et al. [9] and Lam and Teng [2] reported that there was no significant difference between the behaviors of FRP-wrapped and FRP tube-encased concrete specimens. On the other hand, Saafi et al. [12] concluded that the ultimate condition of FRP-confined concrete was influenced by the adopted confinement technique.

In the present study, the test database was sorted into two categories and the results of the FRP-wrapped and FRP tube-encased specimens are presented in separate tables. Tables 3 to 6 show the results for FRP-wrapped concrete, whereas Table 7 reports the results for FRP tube-encased specimens. Comparison of the trends of the strength and strain enhancement ratios of FRP-wrapped specimens with those of FRP tube-encased specimens (Figures 2 and 3) indicate that there are noticeable differences between the ultimate conditions of these two groups of specimens. However, it is not possible to draw a definitive conclusion based on these observations, as in the database the FRP-wrapped specimens significantly outnumber the FRP tube-encased specimens. It is possible that observed differences might have been caused partly or entirely by the differences in the data ranges and specimen distributions between the two sets of test results.

3.3. Type of FRP material

Several previous studies have focused on the influence of the types of FRP materials on the behavior of FRP-confined concrete (e.g., [3, 18, 37, 38]). Most of these studies reported that, for a given confinement ratio ($f_{lu,a}$ / f'_{co}), the compressive strength (f'_{cc}) of FRP-confined concrete is influenced only marginally by the type of FRP material; whereas, it was found that the ultimate strain of FRP-confined concrete (ε_{cu}) is highly sensitive to the material properties of the confining FRP. It is now understood that, for a given confinement ratio ($f_{lu,a}$ / f'_{co}), the ultimate axial strain of the FRP-confined concrete increases with the increased ultimate tensile strain (ε_f or ε_{frp}) of the materials used in confining it. This understanding is supported by the trends of the test results reported in the database of the present study [Figures 4 (a) and (b)]. It is evident from these figures that the trend lines of the strain enhancement ratios are sensitive to the type of FRP, whereas the strength enhancement ratio is not highly influenced by changes in the type of FRP.

Given its direct influence on the actual confinement ratio ($f_{lu,a}$ / f'_{co}) and therefore the ultimate condition of FRP-confined concrete, it is obvious that the accurate determination of hoop rupture strains plays an instrumental role in the prediction of the ultimate condition of FRP-confined concrete. The average values of the strain reduction factors determined from the database reported in the present study (Table 8), point to the influence of the fiber type on the strain reduction factor ($k_{\varepsilon,f}$) and hence on the hoop rupture strains. This influence, which was also reported previously in Ozbakkaloglu and Akin [39] and Dai et al. [40], is discussed further later in the paper.

3.4. Instrumentation details of specimens reported in the database

The ultimate axial strains (ε_{cu}) and FRP hoop rupture strains ($\varepsilon_{h,rup}$) in the database are the average values obtained by strain gauges or deformation measuring devices. In the previous studies, a number of measurement methods were used to record the ultimate axial strains, including: (i) strain gauges attached to the surface of FRP shells (AS); (ii) deformation measuring devices, such as linear variable deformation transducers (LVDTs), extensometers or dial gauges mounted between each platen of the axial compression test machine (AFL); and (iii) measuring devices mounted within a certain gauge length along the height of the specimens (AML).

Similarly, different measuring methods have been used in measuring the hoop strains, including methods (i) and (iii) noted above, with strain gauges or measuring devices oriented in the hoop direction. Information regarding the specific methods in the measurement of both of these strains is reported in the final column of Table 2 for each study included in the database. For the specimens where multiple hoop strain gauges were used, such as the specimens tested by Lam and Teng [18], Smith et al. [36], and Wu and Jiang [24], the average values of the strain gauge measurements have been recorded in the database. In the calculations of the average values, due attention was given to the exclusion of inconsistent strain gauge readings, such as those coming from the overlap regions of FRP sheets.

3.5. Test database size and scatter

Test databases inherently produce a scatter of test results. Bisby et al. [5] reported that the scatter of test results caused an average absolute error (*AAE*) of no less than 13% for the strength enhancement ratio (f'_{cc} / f'_{co}) and 35% *AAE* for the strain enhancement ratio ($\varepsilon_{cu} / \varepsilon_{co}$) in their database of approximately 200 datasets. The natural scatter of the database reported in the present study was lower than these thresholds, with *AAE* values of 11% and 23% for strength and strain enhancement ratios respectively, even though the size of the database was significantly larger with 832 datasets. The relatively low scatter of this database was achieved through the use of carefully chosen selection criteria in the collection of the test data, as outlined previously, to ensure consistency and reliability.

As was reported previously in De Lorenzis and Tepfers [4], variability in material properties of the test specimens, such as the stiffness of the FRP confining shell, the type and size of aggregates used in the concrete mix, and the mix proportions and moisture content of the concrete, contribute to the scatter found in test databases. As discussed in Section 3.4, the differences in the instrumentation of the specimens and the setups used in testing them also contribute significantly to scatter. In particular, the two key ultimate condition properties, the ultimate axial strain (ε_{cu}) and hoop rupture strain ($\varepsilon_{h,rup}$), are highly sensitive to the instrumentation arrangement used in specimen testing. Figure 5 shows the variation of the strain enhancement ratios (ε_{cu} / ε_{co}) with the actual confinement ratios ($f_{lu,a}$ / f'_{co}), as obtained using different axial strain measurement methods. Only CFRP-wrapped specimens, which formed the largest sub-group in the database, were included in Figure 5 in order to eliminate the additional influences caused by differences in the type of FRP and the method of confinement. Differences in the trendlines shown in Figure 5 suggest that the recorded ultimate axial strains may be influenced by the measurement method used in their determination.

Similarly, it should be expected that the average recorded hoop rupture strains ($\varepsilon_{h,rup}$) will be influenced by the number and placement of strain gauges used in the measurement of these strains. As reported originally in Lam and Teng [3], hoop strains measured within the overlap regions of the FRP jackets are known to be lower than those measured elsewhere around the perimeter of the same FRP jacket. It follows, therefore, that the differences in the hoop strain gauge arrangements of the specimens included in the database are one of the main reasons for the inherent scatter in the hoop rupture strain data reported in the database.

4. A NEW DESIGN-ORIENTED MODEL

This section presents a new design-oriented model to predict the ultimate condition of FRP-confined concrete. The model contains closed-form expressions that were developed using the test database presented in Tables 3 to 7. Not all the datasets included in the database contained all the relevant details required for the development of all the components of the model. Furthermore, as discussed previously, the results that failed to satisfy the criteria outlined in Section 2.2 were excluded from model development. The total number of datasets that were used in the calibration of the hoop strain reduction factor (k_ε), strength enhancement coefficient (k_1), and strain enhancement coefficient (k_2) are given in Tables 8 to 10, respectively.

4.1. Hoop rupture strain of FRP-confined concrete

Table 8 provides the values of the strain reduction factors ($k_{\varepsilon,f}$ and $k_{\varepsilon,frp}$) determined from the database presented in this paper. Using these values together with the ones obtained from the tests of over 250 FRP-confined high-strength concrete specimens reported in Lim and Ozbakkaloglu [41], the key parameters that influence the strain reduction factor were indentified. It was found that the increase in either the compressive strength of concrete (f'_{co}) or elastic modulus of confining fibers (E_f) result in a decrease in the recorded hoop rupture strains ($\varepsilon_{h,rup}$) and hence in the strain reduction factors ($k_{\varepsilon,f}$ and $k_{\varepsilon,frp}$). The former influence was first reported in Ozbakkaloglu and Akin [39] and it can be attributed to the increased concrete brittleness with increasing concrete strength, which alters the concrete crack patterns from heterogenic microcracks to localized macrocracks. The observed dependence of the strain reduction factor to the type of confining fibers was previously noted in Ozbakkaloglu and Akin [39] and Dai et al. [40]. Further observations from the comprehensive database reported in this study on the relationship between the elastic modulus of confining fibers (E_f) and recorded hoop rupture strains ($\varepsilon_{h,rup}$) indicate that the influence of the fiber brittleness on the strain reduction factor resembles the aforementioned influence of the concrete brittleness on the same factor. The statistical quantification of the influences of these two parameters resulted in the expression given in Eq. 4 for the calculation of the hoop rupture strain reduction factor of fibers ($k_{\varepsilon,f}$) . The expression is capable of predicting the $k_{\varepsilon,f}$ for FRP-confined concrete with an unconfined concrete strength up to 120 MPa, and confined by any of GFRP, AFRP, CFRP, HM FRP or UHM CFRP.

$$k_{\varepsilon,f} = 0.9 - 2.3 f'_{co} \times 10^{-3} - 0.75 E_f \times 10^{-6} \qquad \textit{Eq. 4}$$

where f'_{co} and E_f are in MPa.

4.2. Compressive strength of FRP-confined concrete

The proposed compressive strength expression (Eq. 5) incorporates several important parameters which were previously identified in Ozbakkaloglu et al. [1]. The strength enhancement effect at the first peak stress (f'_{c1}) of the stress-strain response is captured using Eq. 6 as a function of the confinement stiffness of the FRP shell (K_l). In order for the FRP-confined concrete to achieve a strain-hardening response after the first peak stress (f'_{c1}), the stiffness of the FRP reinforcing shell (K_l) has to exceed a minimum threshold value. The confining pressure at the corresponding condition is defined as the threshold confining pressure (Eq. 7) and can be estimated based on the corresponding hoop strain (ε_{l1}) (Eq. 8) in the FRP shell. As the proposed strength expression (Eq. 5) is only applicable to specimens that achieves strength enhancement after the first peak stress (f'_{c1}), the expression satisfies the confinement stiffness threshold requirement as given in Eq. 9. The prediction of the strength enhancement effect after the first peak stress (f'_{c1}) is based on the net confining pressure, that is, the reduced actual confining pressure ($f_{lu,a}$) after subtraction of the threshold confining pressure (f_{lo}). The strength enhancement effect generated by the net confining pressure is quantified using the coefficient of strength enhancement (k_1) in Eq. 5. It was found that establishing the compressive strength expression based on the net confining pressure yields an improved model prediction especially for specimens with higher unconfined concrete strengths (f'_{co}).

$$f'_{cc} = c_1 f'_{co} + k_1\left(f_{lu,a} - f_{lo}\right) \qquad \textit{Eq. 5}$$

$$c_1 = \frac{f'_{c1}}{f'_{co}} = 1 + 0.0058\frac{K_l}{f'_{co}} \qquad \textit{Eq. 6}$$

$$f_{lo} = K_l \varepsilon_{l1} \qquad \textit{Eq. 7}$$

$$\varepsilon_{l1} = \left(0.43 + 0.009\frac{K_l}{f'_{co}}\right)\varepsilon_{co}$$ *Eq. 8*

$$K_l = \frac{2E_f t_f}{D} \text{ and } K_l \geq f'^{1.65}_{co}$$ *Eq. 9*

where K_l and f'_{co} are in unit MPa. It should be noted that the expression given in Eq. 5 is intended for FRP-confined concrete exhibiting a stress-strain curve with an ascending second branch. To this end, a statistically established condition equation, which is based on the observed influence of the confinement stiffness (K_l) and concrete strength (f'_{co}) on the trend of the second branch, is given in Eq. 9 as part of the proposed expression.

Table 9 summarizes the values of the strength enhancement coefficient (k_1) calibrated from the database for different types of FRP materials and confinement methods. It should be noted that the k_1 values of the UHM CFRP-wrapped and HM and UHM CFRP tube-encased specimens are not presented in the table due to unreliability of the results caused by very limited number of available datasets. Additional experimental results are required to be able to determine reliable k_1 values for these specific subgroups. In the absence of these results, the average value of k_1 established from the database (i.e. $k_1 = 3.2$) can be used for conservative estimates of these specimens.

4.3. Ultimate axial strain of FRP-confined concrete

As reported in Ozbakkaloglu et al. [1] almost all of the better performing ultimate strain enhancement expressions proposed in the literature have non-linear forms in their predictions of the strain enhancement ratio (ε_{cu} / ε_{co}) as a function of confinement ratios ($f_{lu,a}$ / f'_{co}) (e.g. [42, 43]). This is due to the dependency of the strain enhancement ratio (ε_{cu} / ε_{co}) to the ultimate tensile strain of the material (ε_f or ε_{frp}), in addition to the confinement ratio ($f_{lu,a}$ / f'_{co}), as was pointed out in a number of previous studies [3, 18, 37, 39]. To develop unified strain enhancement expressions for different types of FRP materials in model presented in this paper, the axial strain (ε_{cu}) was quantified as a non-linear function of the confinement stiffness (K_l), hoop rupture strain ($\varepsilon_{h,rup}$), and unconfined concrete strength (f'_{co}), as given in Eq. 10. In the equation, k_2 is the coefficient of strain enhancement and c_2 (Eq. 11) is the concrete strength factor, which is incorporated into the proposed expression to allow for the change in the shape of the stress-strain curve of unconfined concrete with the variation of concrete strength (f'_{co}). In Eq. 10, the axial strain corresponding to the unconfined concrete peak strength (ε_{co}) is determined by the expression given by Tasdemir et al. [44] (Eq. 12).

$$\varepsilon_{cu} = c_2 \varepsilon_{co} + k_2 \left(\frac{K_l}{f'_{co}} \right)^{0.9} \varepsilon_{h,rup}^{\;\;1.35} \qquad \textit{Eq. 10}$$

$$c_2 = 2 - \frac{\left(f'_{co} - 20\right)}{100} \text{ and } c_2 \geq 1 \qquad \textit{Eq. 11}$$

$$\varepsilon_{co} = \left(-0.067 f'^{\,2}_{co} + 29.9 f'_{co} + 1053\right) \times 10^{-6} \qquad \textit{Eq. 12}$$

In Eqs. 11 and 12, f'_{co} is in MPa.

Table 10 summarizes the values of the strain enhancement coefficient (k_2) values calibrated from the database for different types of FRP materials, confinement methods and axial strain measurement methods. As discussed previously in Section 3.5, the magnitude of the recorded ultimate axial strains may be influenced by the methods used in the measurement of the strains. In Table 10, in addition to the average values of the strain enhancement coefficients (k_2), its specific values obtained from each of the three aforementioned axial strain measurement methods are also given. As can be seen in Table 10, k_2 is not sensitive to FRP type and hence it is recommended that an average value of k_2 = 0.27 can be used in Eq.10 independent of FRP material type.

4.4. Comparison with test data

Figure 6 shows comparisons of the strength and strain enhancement (f'_{cc}/f'_{co} and $\varepsilon_{cu}/\varepsilon_{co}$) predictions of the proposed model with results from the database presented in this paper. These comparisons indicate that the model predictions are in close agreement with the test results, which are quantified through the use of statistical indicators: average absolute error (*AAE*) to establish overall model accuracy; mean (*M*) to establish average overestimation or underestimation of the model; and standard deviation (*SD*) to establish the magnitude of the associated scatter. The details of the assessment procedure can be found in Ozbakkaloglu et al. [1].

To establish the relative performance of the proposed model, its prediction statistics were compared with those of a group of selected models, which were identified as the best performing models [3-5, 7, 32, 42, 43, 45-53] among over 80 existing models reviewed in Ozbakkaloglu et al. [1] and a few additional models proposed in 2012 and 2013. The lists of the 10 most accurate strength and strain models are given in Tables 11 and 12, respectively, together with their prediction statistics for strength and strain enhancement ratios (f'_{cc}/f'_{co} and $\varepsilon_{cu}/\varepsilon_{co}$). Figures 7(a) and 7(b), respectively, show the average absolute errors (*AAE*) of the strength and strain enhancement ratio predictions of these models. The comparisons of the model prediction statistics shown in Figure 7 and Tables 11 and 12 demonstrate the improved accuracy of the proposed model over the best performing existing models. The improvement on the prediction of the ultimate strain enhancement ratio ($\varepsilon_{cu}/\varepsilon_{co}$) is particularly significant, which is achieved through the use of an expression (Eq.10) that accurately captures the relative influences of the key parameters. It might be worth noting that in the evaluation of the models, the experimentally recorded hoop rupture strains ($\varepsilon_{h,rup}$) were used rather than the values or expressions recommended by the original models for the calculation of $\varepsilon_{h,rup}$. In the absence of the experimental values, $\varepsilon_{h,rup}$ was established using the average value of $k_{\varepsilon,f}$ or $k_{\varepsilon,frp}$ reported in Table 8 in the assessment of the existing models, and it was calculated from Eq.4 in the assessment of the proposed model. It might be worth noting that the proposed model would have outperformed the existing models even more significantly if the hoop rupture strains were established using the original model expressions.

5. CONCLUSIONS AND RECOMMENDATIONS

This paper has presented a comprehensive test database of 832 datasets that was assembled by the authors through an extensive review of the literature that covered 253 experimental studies published on the compressive behavior of FRP-confined concrete. Initially, 3042 test results were collected from the published literature. The suitability of these results for the database was then assessed using carefully composed selection criteria to ensure the reliability and consistency of the database. Using the criteria to refine the contents of the database resulted in a final database size of 832 datasets collected from 99 experimental studies published between 1992 and the middle of 2013. Key features of each study included in the database, including the range of the key test parameters and the specimen instrumentation information, have been summarized and important observations regarding these studies have been marked on the database tables. The database that has been presented in this paper will serve as a valuable reference document for future model development efforts. In the final part of the paper, a design-oriented model for predicting the ultimate conditions of FRP-confined concrete is presented. The proposed model provides improved predictions of the compressive strength and ultimate axial strain of FRP-confined concrete compared to the existing models.

Based on the observations made during the compilation of the experimental database, the following conclusions can be drawn:

1. Analysis of the results reported in the database indicates that the average values of the hoop strain reduction factors based on fiber and FRP properties ($k_{\varepsilon,f}$ and $k_{\varepsilon,frp}$) are equal to 0.675 and 0.709, respectively. The observed variation of the average k_{ε} values according to fiber type points to the possible influence of the type of fibers on the strain reduction factor.

2. Two key ultimate condition properties, namely ultimate axial strain (ε_{cu}) and hoop rupture strain ($\varepsilon_{h,rup}$), are both highly sensitive to the instrumentation arrangement used in specimen testing. Therefore, the variability in the instrumentation arrangements used in different studies contributes to scatter in the database.
3. There are differences between the strength and strain enhancement ratios of FRP-wrapped and FRP-tube encased specimens included in the database of the present study. However, due to the differences between the number and parametric ranges of FRP-wrapped and FRP tube-encased specimens, it is not possible to draw a definitive conclusion based on these observations.

As noted previously, it was not possible to include all the test results published in the literature in the database presented in this paper, due to a lack of information in regards to the material properties, geometric properties or ultimate conditions of these specimens. Therefore, in future studies, effort should be made to ensure that the results of the experiments are presented with a complete set of information, providing as much relevant information as possible about the material and geometric properties of the specimens, test setup and instrumentation, recorded capacities of the specimens and their failure modes. Furthermore, in future experimental studies due consideration should be given to the instrumentation of the specimens for the accurate measurement of ultimate axial strains and hoop rupture strains.

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7. NOTATION

AAE	Average absolute error
c_1	Parameter in ultimate strength expression
c_2	Parameter in ultimate strain expression
D	Diameter of concrete core (*mm*)
E_f	Elastic modulus of fibers (*MPa*)
E_{frp}	Elastic modulus of FRP material (*MPa*)
f'_{cc}	Ultimate axial compressive stress of FRP-confined concrete (*MPa*)
f'_{co}	Peak axial compressive stress of unconfined concrete (*MPa*)
f'_{c1}	Axial compressive stress of FRP-confined concrete at first peak (*MPa*)
f_f	Ultimate tensile strength of fibers; $f_f = E_f\,\varepsilon_f$ (*MPa*)
f_{frp}	Ultimate tensile strength of FRP material; $f_{frp} = E_{frp}\,\varepsilon_{frp}$ (*MPa*)
f_l	Confining pressure (*MPa*)
f_{lo}	Threshold confining pressure (*MPa*)
f_{lu}	Nominal lateral confining pressure at ultimate; $f_{lu} = K_l\,\varepsilon_f$ or $f_{lu} = K_l\,\varepsilon_{frp}$ (*MPa*)
$f_{lu,a}$	Actual lateral confining pressure at ultimate; $f_{lu,a} = K_l\,\varepsilon_{h,rup}$ (*MPa*)
H	FRP confined concrete specimen height (mm)
K_l	Lateral confinement stiffness (*MPa*); $K_l = 2\,E_f\,t_f\,/\,D$ or $2\,E_{frp}\,t_{frp}\,/\,D$
k_1	Axial strength enhancement coefficient
k_2	Axial strain enhancement coefficient
k_ε	Hoop strain reduction factor
$k_{\varepsilon,f}$	Hoop strain reduction factor of fibers
$k_{\varepsilon,frp}$	Hoop strain reduction factor of FRP material
M	Mean
SD	Standard deviation
t_f	Total nominal thickness of fibers (*mm*)
t_{frp}	Total thickness of FRP material (*mm*)
ε_{co}	Axial strain of unconfined concrete at f'_{co}
ε_{c1}	Axial strain of FRP-confined concrete at f'_{c1}
ε_{cu}	Ultimate axial strain of FRP-confined concrete
ε_f	Ultimate tensile strain of fibers
ε_{frp}	Ultimate tensile strain of FRP material
$\varepsilon_{h,rup}$	Hoop rupture strain of FRP shell
ε_{l1}	Hoop strain of FRP-confined concrete at f'_{c1}

8. REFERENCES

1. Ozbakkaloglu, T., Lim, J. C, and Vincent, T., (2013). "FRP-confined concrete in circular sections: Review and assessment of stress–strain models." *Eng. Struct.,* 49, p. 1068–1088.
2. Lam, L., and Teng, J. G. , (2002). "Strength models for fiber-reinforced plastic-confined concrete." *ASCE J. Struct. Eng.,* 128(5), p. 612-623.
3. Lam, L., and Teng, J. G. , (2003). "Design-oriented stress-strain model for FRP-confined concrete." *Constr. Build. Mater.,* 17(6-7), p. 471-489.
4. De Lorenzis, L., and Tepfers, R. , (2003). "Comparative study of models on confinement of concrete cylinders with fiber reinforced polymer Composites." *ASCE J. Compos. Constr.,* 7(3), p. 219-237.
5. Bisby, L.A., Dent, A. J. S., Green, M. F. , (2005). "Comparison of confinement models for fiber-reinforced polymer-wrapped concrete." *ACI Struct. J.,* 102(1), p. 62-72.
6. Turgay, T., Köksal, H. O., Polat, Z., and Karakoc, C. , (2009). "Stress-strain model for concrete confined with CFRP jackets." *Materials and Design,* 30(8), p. 3243-3251.
7. Realfonzo, R. and Napoli, A., (2011). "Concrete confined by FRP systems: Confinement efficiency and design strength models." *Composites Part B: Engineering,* 42, p. 736-755.
8. Harries, K.A., and Carey, A. , (2002). "Shape and 'gap' effects on the behavior of variably confined concrete." *Cem. Concr. Res.,* 33(6), p. 873-880.
9. Mirmiran, A., Shahawy, M., Samaan, M., El Echary, H., Mastrapa, J. C., and Pico, O. , (1998). "Effect of Column Parameters on FRP-confined Concrete." *ASCE J. Compos. Constr.,* 2(4), p. 175-185.
10. Mastrapa, J.C., (1997). "Effect of construction bond on confinement with fiber composites." Masters, University of Central Florida, Orlando, Fla.
11. Matthys, S., Taerwe, L., and Audenaert, K. , (1999). "Tests on axially loaded concrete columns confined by fiber reinforced polymer sheet wrapping." *Proc. 4th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Reinforced Concrete Structures*, Detroit.
12. Saafi, M., Toutanji, H. A., and Li, Z. , (1999). "Behavior of concrete columns confined with fiber reinforced Polymer tubes." *ACI Struct. J.,* 96(5), p. 500-509.
13. Hong, W.K., and Kim, H. C. , (2004). "Behavior of concrete columns confined by carbon composite tubes." *Can. J. Ci. Eng.,* 31(2), p. 178-188.
14. Ozbakkaloglu, T. and Vincent, T., (2013). "Axial compressive behavior of high- and ultra high-strength concrete-filled FRP tubes." *J. Compos. Constr.,* (Submitted).
15. Xiao, Y., and Wu, H. , (2000). "Compressive behavior of concrete confined by carbon fiber composite jackets." *J. Mater. Civ. Eng.,* 12(2), p. 139-146.
16. Shahawy, M., Mirmiran, A., and Beitelman, T. , (2000). "Tests and modeling of carbon-wrapped concrete columns." *Composites Part B: Engineering.,* 31(471 - 480).
17. Pessiki, S., Harries, K. A., Kestner, J., Sause, R., and Ricles, J. M. , (2001). "The axial behavior of concrete confined with fiber reinforced composite jackets." *ASCE J. Compos. Constr.,* 5(4), p. 237-245.
18. Lam, L., and Teng, J. G. , (2004). "Ultimate condition of FRP-confined concrete." *ASCE J. Compos. Constr.,* 8(6), p. 539-548.
19. Ozbakkaloglu, T., and Oehlers, D. J., (2008). "Concrete-filled Square and Rectangular FRP Tubes under Axial Compression." *ASCE J. Compos. Constr.,* 12(4), p. 469-477.
20. Ozbakkaloglu, T., and Oehlers, D. J. , (2008). "Manufacture and testing of a novel FRP tube confinement system." *Eng. Struct.,* 30, p. 2448-2459.
21. Cui, C., and Sheikh, A. , (2009). "Behaviour of normal and high strength concrete confined with fibre reinforced polymers (FRP)." Masters, Univ. of Toronto.
22. Ozbakkaloglu, T., (2012). "Concrete-filled FRP Tubes: Manufacture and Testing of New Forms Designed for Improved Performance." *ASCE J. Compos. Constr.,* 17(2), p. 280 -291.
23. Ozbakkaloglu, T., (2012). "Axial Compressive Behavior of Square and Rectangular High-Strength Concrete-Filled FRP Tubes." *ASCE J. Compos. Constr.,* 17(1), p. 151-161.

24. Wu, Y.-F. and Jiang, J.-F., (2013). "Effective strain of FRP for confined circular concrete columns." *Composite Structures,* 95, p. 479–491.
25. Ozbakkaloglu, T., (2013). "Compressive behavior of concrete-filled FRP tube columns: Assessment of critical column parameters." *Engineering Structures,* 51, p. 188-199.
26. Rousakis, T., You, C., De Lorenzis, L., and Tamuzs, V. , (2003). "Concrete Cylinders Confined by Carbon FRP Sheets Subjected to Monotonic and Cyclic Axial Compressive Loads." *Proc. 6th Int. Symp. On FRP Reinforcement for Concrete Structures.*
27. Valdmanis, V., De Lorenzis, L., Rousakis, T., and Tepfers, R. , (2007). "Behaviour and capacity of CFRP-confined concrete cylinders subjected to monotonic and cyclic axial compressive load." *Structural Concrete,* 8(4), p. 187-190.
28. Watanabe, K., Nakamura, R., Honda, Y., Toyoshima, M., Iso, M., Fujimaki, T., Kaneto, M., and Shirai, N. , (1997). "Confinement effect of FRP sheet on strength and ductility of concrete cylinders under uniaxial compression." *Proc. Non-metallic Reinforcement for Concrete Structures*.
29. Lam, L., Teng, J. G., Cheung, C. H., and Xiao, Y. , (2006). "FRP-confined concrete under cyclic axial compression." *Cem. Concr. Compos.,* 28(10), p. 948-958.
30. Stanton, J.F., and Owen, L. M. , (2006). "The Influence of Concrete Strength and Confinement Type on the Response of FRP-Confined Concrete Cylinders." *ACI Special Publication October 2006,* 238, p. 347-362.
31. Wu, G., Lu, Z. T., and Wu, Z. S. , (2006). "Strength and ductility of concrete cylinders confined with FRP composites." *Constr. Build. Mater.,* 20(3), p. 134-148.
32. Jiang, T., and Teng, J. G. , (2007). "Analysis-oriented stress-strain models for FRP-confined concrete." *ASCE J. Eng. Struct.,* 29(11), p. 2968-2986.
33. Wang, L.M., and Wu, Y. F. , (2008). "Effect of Corner Radius on the Performance of CFRP-Confined Square Concrete Columns: Test." *Eng. Struct.,* 30(2), p. 493-505.
34. Wong, Y.L., Yu, T., Teng, J. G., and Dong, S. L. , (2008). "Behavior of FRP-confined concrete in annual section columns." *Composites Part B: Engineering.,* 39, p. 451-466.
35. Wu, G., Wu, Z. S., Lu, Z. T., and Ando Y. B. , (2008). "Structural Performance of Concrete Confined with Hybrid FRP Composites." *J. Reinf. Plas. Compos.,* 27(12), p. 1323-1348.
36. Smith, S.T., Kim, S. J. and Zhang, H. , (2010). "Behavior and Effectiveness of FRP Wrap in the Confinement of Large Concrete Cylinders." *ASCE J. Compos. Constr.,* 14, p. 573-582.
37. Karbhari, V.M., and Gao, Y. , (1997). "Composite jacketed concrete under uniaxial compression-verification of simple design equations." *J. Mater. Civ. Eng.,* 9(4), p. 185-193.
38. Lin, H.J., and Chen, C. T. , (2001). "Strength of concrete cylinder confined by composite materials." *J. Reinf. Plas. Compos.,* 20(18), p. 1577-1600.
39. Ozbakkaloglu, T., and Akin, E. , (2011). "Behavior of FRP-confined normal- and high-strength concrete under cyclic axial compression." *ASCE J. Compos. Constr.,* 16(4), p. 451–463.
40. Dai, J.G., Bai, Y. L., and Teng, J. G. , (2011). "Behavior and modeling of concrete confined with FRP composites of large deformability." *ASCE J. Compos. Constr.,* 15(6), p. 963–973.
41. Lim, J.C. and Ozbakkaloglu, T., (2013). "Confinement model for FRP-confined high-strength concrete." *J. Compos. Constr.,* doi: ASCE. 10.1061/(ASCE)CC.1943-5614.0000376.
42. Jiang, T., and Teng, J. G. , (2006). "Strengthening of short circular RC columns with FRP jackets: a design proposal." *Proc. 3rd Int. Conf. on FRP Composites in Civil Engineering*, Miami, Florida, USA.
43. Tamuzs, V., Tepfers., R, Zile, E., and Ladnova, O. , (2006). "Behavior of concrete cylinders confined by a carbon composite III: deformability and the ultimate axial strain." *Mech. Compos. Mater.,* 42(4), p. 303-314.
44. Tasdemir, M.A., Tasdemir, C., Jefferson, A.D., Lydon, F.D., and Barr, B.I.G., (1998). "Evaluation of strains at peak stresses in concrete: A three-phase composite model approach." *Cement and Concrete Research,* 20(4), p. 301-318.

45. Al-Salloum, Y., and Siddiqui, N. , (2009). "Compressive Strength Prediction Model for FRP-Confined Concrete." *Proc. 9th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Sydney, Australia. .
46. Binici, B., (2005). "An analytical model for stress-strain behavior of confined concrete." *Eng. Struct.,* 27(7), p. 1040-1051.
47. Fahmy, M., and Wu, Z. , (2010). "Evaluating and proposing models of circular concrete columns confined with different FRP composites." *Composites Part B: Engineering. ,* 41(3), p. 199-213.
48. Teng, J.G., Huang, Y. L., Lam, L., and Ye, L. , (2007). "Theoretical model for fiber reinforced polymer-confined concrete." *ASCE J. Compos. Constr.,* 11(2), p. 201-210.
49. Teng, J.G., Jiang, T., Lam, L. and Luo, Y. , (2009). "Refinement of a Design-Oriented Stress-Strain Model for FRP-Confined Concrete." *ASCE J. Compos. Constr.,* 13(4), p. 269-278.
50. Wei, Y.Y. and Wu, Y.F., (2012). "Unified stress-strain model of concrete for FRP-confined columns." *Construction and Building Materials,* 26(1), p. 381-392.
51. Wu, Y.F. and Wang, L.M., (2009). "Unified strength model for square and circular concrete columns confined by external jacket." *Journal of Structural Engineering,* 135(3), p. 253-261.
52. Wu, Y.F., and Zhou, Y. , (2010). "Unified Strength Model Based on Hoek-Brown Failure Criterion for Circular and Square Concrete Columns Confined by FRP." *ASCE J. Compos. Constr.,* 14(2), p. 175-184.
53. Youssef, M.N., Feng, M. Q., and Mosallam, A. S. , (2007). "Stress-strain model for concrete confined by FRP composites." *Composites Part B: Engineering.,* 38(5-6), p. 614-628.
54. Abdollahi, B., Bakhshi, M., Motavalli, M., and Shekarchi, M. , (2007). "Experimental modeling of GFRP confined concrete cylinders subjected to axial loads." *Proc. The 8th Int. Symp. on Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Patras, Greece.
55. Ahmad, S.M., Khaloo, A. R., and Irshaid, A. , (1991). "Behaviour of concrete spirally confined by fiberglass filaments." *Mag. Concr. Res.,* 43(56), p. 143-148.
56. Aire, C., Gettu, Casas, J., Marques, S. and Marques, D. , (2010). "Concrete laterally confined with fibre-reinforced polymers (FRP): experimental study and theoretical model." *Materiales de Construcción,* 60, p. 297.
57. Akogbe, R.K., M. Liang, and Wu, Z. M, (2011). "Size effect of axial compressive strength of CFRP confined concrete cylinders." *Int. J. Conc. Struct. Mater.,* 5(1), p. 49-55.
58. Almusallam, T.H., (2007). "Behaviour of normal and high-strength concrete cylinders confined with E-glass/epoxy composite laminates." *Composites Part B: Engineering.,* 38, p. 629-639.
59. Au, C., and Buyukozturk, O. , (2005). "Effect of fiber orientation and ply mix on fiber reinforced polymer-confined concrete." *ASCE J. Compos. Constr.,* 9(5), p. 397-407.
60. Benzaid, R., Mesbah, H., and Chikh, N. , (2010). "FRP-confined Concrete Cylinders: Axial Compression Experiments and Strength Model." *J. Reinf. Plas. Compos.,* 29(16), p. 2469-2488.
61. Berthet, J.F., Ferrier. E., and Hamelin. P. , (2005). "Compressive behavior of concrete externally confined by composite jackets. Part A: experimental study." *Constr. Build. Mater., ,* 19(3), p. 223-232.
62. Bisby, L., Take, W. A., and Caspary, A. , (2007). "Quantifying strain variation FRP confined using digital image correlation: proof-of-concept and initial results." *Asia-Pacific Conference on FRP in Structures*.
63. Bisby, L.A., Chen, J. F., Li, S. Q., Stratford, T. J., Cueva, N., and Crossling, K. , (2011). "Strengthening fire-damaged concrete by confinement with fibre-reinforced polymer wraps." *Eng. Struct,* 33, p. 3381-3391.
64. Bullo, S., (2003). "Experimental study of the effects of the ultimate strain of fiber reinforced plastic jackets on the behavior of confined concrete." *Proc. of the Int. Conf. Compos. in Constr.*, Cosenza, Italy.

65. Campione, G., Miraglia, N., and Scibilia, N. , (2001). "Compressive behaviour of RC members strengthened with carbon fibre reinforced plastic layers." *Advances in Earthquake Engineering,* 9, p. 397-406.
66. Carey, S.A., and Harries, K. A. , (2005). "Axial behavior and modeling of confined small, medium, and large scale circular sections with carbon fiber-reinforced polymer jackets." *ACI Struct. J.,* 102(4), p. 596-604.
67. Comert, M., Goksu, C., and Ilki, A. , (2009). "Towards a tailored stress-strain behavior for FRP confined low strength concrete." *Proc. 9th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Sydney, Australia.
68. Cui, C., and Sheikh, A. , (2010). "Experimental Study of Normal- and High-Strength Concrete Confined with Fiber-Reinforced Polymers." *ASCE J. Compos. Constr.,* 14(5), p. 553-561.
69. Demers, M., and Neale, K. W. , (1994). "Strengthening of concrete columns with unidirectional composite sheets." *Proc. Developments in Short and Medium Span Bridge Engineering*, Montreal, Que.
70. Elsanadedy, H.M., Al-Salloum, Y.A., Alsayed, S.H., and Iqbal, R.A., (2012). "Experimental and numerical investigation of size effects in FRP-wrapped concrete columns." *Construction and Building Materials,* 29, p. 56–72.
71. Erdil, B., Akyuz, U., and Yaman, I. O. , (2011). "Mechanical behavior of CFRP confined low strength concretes subjected to simultaneous heating-cooling cycles and sustained loading." *Mater. Struct.,* (223-233).
72. Evans, J., Kocman, M. and Kretschmer, T. , (2008). "Hybrid FRP Confined Concrete Columns." Honours, *The School of Civil, Environmental and Mining Engineering*, Univ. of Adelaide., Adelaide, Australia.
73. Green, M.F., Bisby, L. A., Fam, A. Z., and Kodur, V. K. R. , (2006). "FRP confined concrete columns: behaviour under extreme conditions." *Cem. Concr. Res.,* 28(10), p. 928-993.
74. Harmon, T.G., and Slattery, K. T. , (1992). "Advanced composite confinement of concrete." *Proc. Advanced Composite Materials for Bridges and Structures I*, Montreal, Canada.
75. Harries, K.A., and Kharel, G. , (2002). "Behavior and modeling of concrete subject to variable confining pressure." *ACI Mater. J.,* 99(2), p. 180-189.
76. Hosotani, K., Kawashima, K., and Hoshikuma, J. , (1997). "A model for confinement effect for concrete cylinders confined by carbon fiber sheets." *NCEER-INCEDE Workshop on Earthquake Engineering Frontiers of Transportation Facilities*, State Univ. of New York, Buffalo, NY.
77. Howie, I., and Karbhari, V. M. , (1994). "Effect of materials architecture on strengthening: efficiency of composite wraps for deteriorating columns in the North-East." *Proc. 3rd Materials Engineering Conference*, San Diego.
78. Ilki, A., Kumbasar, N., and Koc, V. , (2002). "Strength and deformability of low strength concrete confined by carbon fibre composite sheets." *Proc. 15th Engineering Mechanics Conference*, New York, NY.
79. Ilki, A., Kumbasar, N., and Koc, V. , (2004). "Low strength concrete members externally confined with FRP sheets." *Struct. Eng. Mech,* 18(2), p. 167-194.
80. Issa, C.A., (2007). "The effect of elevated temperatures on CFRP wrapped concrete cylinders." *Proc. 8th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Patras, Greece.
81. Issa, C.A., and Karam, G. N. , (2004). "Compressive strength of concrete cylinders with variable widths CFRP wraps." *Proc. 4th Int. Conf. on Advanced Composite Materials in Bridges and Structures*, Calgary, Alberta, Canada.
82. Karabinis, A.I., and Rousakis, T. C. , (2002). "Concrete confined by FRP material: a plasticity approach." *ASCE J. Eng. Struct.,* 24(7), p. 923-932.
83. Karam, G.N., and Tabbara, M. , (2004). "Corner effects in CFRP wrapped square columns." *Mag. Concr. Res.,* 56(8), p. 461-464.

84. Karantzikis, M., Papanicolaou, C. G. Antonopoulos, C. P., and Triantafillou, T. C. , (2005). "Experimental investigation of nonconventional confinement for concrete using FRP." *ASCE J. Compos. Constr.,* 9(6), p. 480-487.
85. Kono, S., Inazuni, M., and Kaku, T. , (1998). "Evaluation of confining effects of CFRP sheets on reinforced concrete members." *Proc. 2nd Int. Conf. on Composites in Infrastructures*.
86. Lee, J., Yi C., Jeong, H., Kim, S., and Kim, J. , (2009). "Compressive Response of Concrete Confined with Steel Spirals and FRP Composites." *J. Compos. Materials.,* 44(4), p. 481-504.
87. Li, G., Maricherla, D., Singh, K., Pang, S. S., and John, M. , (2006). "Effect of fiber orientation on the structural behavior of FRP wrapped concrete cylinders." *J. Compos. Struct.,* 74(4), p. 475-483.
88. Li, Y., and Ou, (2007). "Compressive behavior and nonlinear analysis of selfsensing concrete-filled frp tubes and frp-steel composite tubes." *Proc. 8th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Patras, Greece.
89. Liang, M., Wu, Z.-M., Ueda, T., Zheng, J.-J., and Akogbe1, R., (2012). "Experiment and modeling on axial behavior of carbon fiber reinforced polymer confined concrete cylinders with different sizes." *Journal of Reinforced Plastics and Composites,* 31(6), p. 389–403.
90. Lin, C., and Li, Y. , (2003). "An Effective Peak Stress Formula for Concrete Confined with Carbon Fibre Reinforced Plastics." *J. Civ. Eng.,,* 30, p. 882-889.
91. Lin, H.J., and Liao, C. I. , (2004). "Compressive strength of reinforced concrete column confined by composite material." *J. Compos. Struct.,* 65(239 - 250).
92. Mandal, S., Hoskin, A., and Fam, A. , (2005). "Influence of concrete strength on confinement effectiveness of fiber-reinforced polymer circular jackets." *ACI Struct. J.,* 102(3), p. 383-392.
93. Micelli, F., Myers, J. J., and Murthy, S. , (2001). "Effect of environmental cycles on concrete cylinders confined with FRP." *Proc. Int. Conf. on Composites in Construction*, Porto, Portugal.
94. Miyauchi, K., Nishibayashi, S., and Inoue, S. , (1997). "Estimation of strengthening effects with carbon fiber sheet for concrete column." *3rd Int. Symp. Of Non-Metallic Reinforcement for Concrete Structures*.
95. Miyauchi, K., Inoue, S., Kuroda, T., and Kobayashi, A. , (1999). "Strengthening effects with carbon fiber sheet for concrete column." *Japan Concr. Inst.*
96. Modarelli, R., Micelli, F., and Manni, O., (2005). "FRP-confinement of hollow concrete cylinders and prisms." *Proc. 7th Int. Symp. On Fiber Reinforced Polymer Reinforcement of Reinforced Concrete Structures*.
97. Nanni, A., and Bradford, N. M. , (1995). "FRP jacketed concrete under uniaxial compression." *Constr. Build. Mater.,* 9(2), p. 115-124.
98. Ongpeng, J.M.C., (2006). "Retrofitting RC circular columns using CFRP sheets as confinement." *Symp. On Infrastructure Development and the Environment*, Diliman, Quezon City.
99. Owen, L.M., (1998). "Stress-strain behavior of concrete confined by carbon fiber jacketing." Masters, Univ. of Washington, Seattle.
100. Park, J.H., Jo, B. W., Yoon, S. J., and Park, S. K. , (2011). "Experimental investigation on the structural behavior of concrete filled FRP tubes with/without steel re-bar." *KSCE J. Civ. Eng.,* 15(2), p. 337-345.
101. Picher, F., Rochette, P., and Labossiére, P. , (1996). "Confinement of concrete cylinders with CFRP." *Proc. 1st Int. Conf. on Composites in Infrastructure*, Tucson, Arizona.
102. Piekarczyk, J., Piekarczyk, W., and Blazewicz, S. , (2011). "Compression strength of concrete cylinders reinforced with carbon fiber laminate." *Constr. Build. Mater.,* 25(2365-2369).
103. Pon, T.H., Li, Y. F., Shih, B. J., Han, M. S., Chu, G. D., Chiu, Y. J., Lin, J. C., and Cheng, Y. S. , (1998). "Experiments of scale effects on the strength of FRP reinforced concrete." *Proc. 4th National Conference on Structural Engineering*, Taipei, Taiwan.
104. Rochette, P., and Labossiére, P. , (2000). "Axial testing of rectangular column models confined with composites." *ASCE J. Compos. Constr.,* 4(3), p. 129-136.

105. Rousakis, T., (2001). "Experimental investigation of concrete cylinders confined by carbon FRP sheets under monotonic and cyclic axial compressive load." *Research Report*, Chalmers Univ. of Technology, Göteborg, Sweden.
106. Saenz, N., and Pantelides, C. P. , (2006). "Short and medium term durability evaluation of FRP-confined circular concrete." *ASCE J. Compos. Constr.,* 10(3), p. 244-253.
107. Santarosa, D., Filho, A. C., Beber, A. J., and Campagnolo, J. L. , (2001). "Concrete columns confined with CFRP sheets." *Proc. Int. Conf. of FRP Composites in Civil Engineering*, Hong Kong.
108. Shao, Y., Zhu, Z., and Mirmiran, A. , (2006). "Cyclic modeling of FRP-confined concrete with improved ductility." *Cem. Concr. Res.,* 28(10), p. 959-968.
109. Shehata, I.A.E.M., Carneiro, L. A. V., and Shehata, L. C. D. , (2002). "Strength of short concrete columns confined with CFRP sheets." *Mater. and Struct.,* 35, p. 50-58.
110. Shehata, I.A.E.M., Carneiro, L. A. V., and Shehata, L. C. D. , (2007). "Strength of confined short concrete columns." *Proc. 8th Int. Symp. On Fiber Reinforced Polymer Reinforcement for Concrete Structures*, Patras, Greece.
111. Silva, M.A.G., and Rodrigues, C. C. , (2006). "Size and relative stiffness effects on compressive failure of concrete columns wrapped with glass FRP." *ASCE J. Mater. Civ. Eng.,* 18(3), p. 334-342.
112. Song, X., Gu, X., Li, Y., Chen, T., and Zhang, W., (2013). "Mechanical Behavior of FRP-Strengthened Concrete Columns Subjected to Concentric and Eccentric Compression Loading." *Journal of Composites for Construction,* 17(3), p. 336-346.
113. Suter, R., and Pinzelli, R. , (2001). "Confinement of concrete columns with FRP sheets." *Proc. 5th Symp. On Fibre Reinforced Plastic Reinforcement for Concrete Structures*, London.
114. Tamuzs, V., Valdmanis, V., Tepfers, R. & Gylltoft, K. , (2008). "Stability analysis of CFRP-wrapped concrete columns strengthened with external longitudinal CFRP sheets." *Mech. Compos. Mater.,* 44, p. 199-208.
115. Teng, J.G., Yu, T., Wong, Y. L., and Dong, S. L. , (2007). "Hybrid FRP-concrete-steel tubular columns: concept and behaviour." *Constr. Build. Mater.,* 21(4), p. 846-854.
116. Thériault, M., Neale, K. W., M. ASCE, and Claude, S. , (2004). "Fiber reinforced polymer-confined circular concrete columns: investigation of size and slenderness effects." *ASCE J. Compos. Constr.,* 8(4), p. 323-331.
117. Vincent, T. and Ozbakkaloglu, T., (2013). "Influence of concrete strength and confinement method on axial compressive behavior of FRP confined high- and ultra high-strength concrete." *Composites Part B-Engineering,* 50, p. 413–428.
118. Vincent, T. and Ozbakkaloglu, T., (2013). "Influence of fiber orientation and specimen end condition on axial compressive behavior of FRP-confined concrete." *Constr. Build. Mater.,* doi: 10.1016/j.conbuildmat.2013.05.085.
119. Wang, Y.F., and Wu, H. L, (2011). "Size effect of concrete short columns confined with aramid FRP jackets." *ASCE J. Compos. Constr.,* 15(4), p. 535-544.
120. Wang, Y., and Zhang, D. , (2009). "Creep-Effect on Mechanical Behaviour of Concrete Confined by FRP under Axial Compression." *ASCE J. Eng. Mech. Div.,* 135(11), p. 1315-1322.
121. Wu, Y.-F. and Jiang, C., (2013). "Effect of load eccentricity on the stress–strain relationship of FRP-confined concrete columns." *Composite Structures,* 98, p. 228–241.
122. Wu, H., Wang, Y., Yu, L. and Li, X. , (2009). "Experimental and Computational Studies on High-Strength Concrete Circular Columns Confined by Aramid Fiber-Reinforced Polymer Sheets." *ASCE J. Compos. Constr.,* 13(2), p. 125-134.
123. Yan, Z., Pantelides, C. P., Reaveley, D. , (2006). "Fiber-reinforced polymer jacketed and shape-modified compression members: I-Experimental Behavior." *ACI Struct. J.,* 6, p. 885-893.
124. Zhang, S., Ye, L., and Mai, Y. W. , (2000). "Study on polymer composite strengthening systems for concrete columns." *Applied Compos. Mater.,* 7(2), p. 125-138.

List of Table Captions

Table 1. Summary of existing databases of axial compression tests on circular FRP-confined concrete specimens

Paper	Number of studies covered	Number of test data	Confinement technique	Fiber type	Unconfined concrete strength range, f'_{co} (MPa)	Nominal confinement ratio range, f_{lu}/f_{co}	Specimen Diameter range, D (mm)	Specimen Height range, H (mm)
Lam and Teng [2, 3]	30	275	Tube and wrap	CFRP, GFRP, AFRP, and HM CFRP	18.0 - 62.4	0.03 - 2.30	51 - 200	102 - 788
De Lorenzis and Tepfers [4]	17	180	Tube and wrap	CFRP, GFRP, and AFRP	19.4 - 82.1	0.06 - 2.31	51 - 219	102 - 438
Bisby et al. [5]	23	197	Wrap	CFRP, GFRP, and AFRP	15 - 103	-	50 - 300	-
Turgay et al. [6]	20	127	Tube and wrap	CFRP	17.4 - 171.0	0.032 - 0.95	51 - 200	102 - 610
Realfonzo and Napoli [7]	63	465	Wrap	CFRP, GFRP	15.2 - 169.7	0.002 - 2.22	51 - 406	102 - 1824

Table 2. Summary of test results included in the database

Paper	Total number of datasets	Confinement technique	Fiber type	Diameter, D (mm)	Height, H (mm)	Unconfined concrete strength range, f'_{co} (MPa)	Strength enhancement ratio range, f'_{cc}/f'_{co}	Strain enhancement ratio range, $\varepsilon_{cu}/\varepsilon_{co}$	Actual confinement ratio range, $f_{lu,a}/f_{co}$	Number of identical specimens per entry in the database	Lateral strain measurement method (see notes)	Axial strain measurement method (see notes)
Abdollahi et al. [54]	5	Wrap	GFRP	150	300	14.8 - 41.7	1.24 - 3.32	1.54 - 12.04	0.06 - 0.43	2	N/A	AFL
Ahmad et al. [55]	2	Wrap	GFRP	102	203	39.0 - 50.5	2.68 - 2.96	-	0.55 - 0.73	Single	N/A	N/A
Aire et al. [56]	6	Wrap	CFRP, GFRP	150	300	42.0	0.97 - 2.57	3.33 - 13.17	0.09 - 0.71	3	HS	AFL
Akogbe et al. [57]	12	Wrap	CFRP	100 - 300	200 - 600	21.7 - 26.5	2.38 - 3.19	7.03 - 12.68	0.26 - 0.32	Single	HS	AML
Almusallam [58]	4	Wrap	GFRP	150	300	47.7 - 50.8	1.09 - 2.10	-	0.14 - 0.46	3	HL	N/A
Al-Salloum [45]	2	Wrap	CFRP	150	300	32.4 - 36.2	2.35 - 2.57	15.77	0.30 - 0.33	Single	HS	AML
Au and Buyukozturk [59]	1	Wrap	GFRP	150	375	24.2	1.81	6.19	0.26	3	HL	AML
Benzaid et al. [60]	4	Wrap	CFRP	160	320	25.9 - 49.5	1.07 - 2.55	1.48 - 5.57	0.09 - 0.59	Single	HL	AML
Berthet et al. [61]	42	Wrap	CFRP, GFRP	160	320	25.0 - 52.0	1.12 - 4.15	2.18 - 13.50	0.07 - 0.95	Single	HL	AML
Bisby et al. [62]	3	Wrap	CFRP	150	300	34.4	1.25 - 1.28	2.42 - 2.73	0.10 - 0.13	Single	N/A	N/A
Bisby et al. [63]	3	Wrap	CFRP	100	200	28.0	1.89 - 2.25	4.24 - 5.28	0.20 - 0.22	Single	N/A	N/A
Bullo [64]	12	Wrap	GFRP, HM CFRP	150	300	32.5	1.62 - 4.17	3.36 - 19.53	0.11 - 0.60	Single	HL	AFL
Campione et al. [65]	1	Wrap	CFRP	100	200	20.1	2.47	12.32	0.36	N/A	N/A	N/A
Carey and Harries [66]	2	Wrap	CFRP	152 - 254	305 - 762	33.5 - 38.9	1.40 - 1.41	3.47 - 4.04	0.15 - 0.17	≥ 2	HL	AML
Comert et al. [67]	2	Wrap	GFRP	150	300	39.0	1.56 - 1.64	9.92 - 10.86	0.23	Single	HS	AFL
Cui and Sheikh [68]	24	Wrap	CFRP, GFRP, HM CFRP	152	305	45.6 - 48.1	1.21 - 3.38	4.24 - 13.92	0.07 - 0.48	Single	HS	AML
Dai et al. [40]	9	Wrap	AFRP	152	305	39.2	1.42 - 3.01	9.75 - 22.52	0.09 - 0.39			
Demers and Neale [69]	8	Wrap	CFRP, GFRP	152	305	32.2 - 43.7	0.96 - 1.72	4.35 - 10.48	0.07 - 0.24	Single	HS	AFL

Elsanadedy et al. [70]	6	Wrap	CFRP	50 - 150	100 - 300	41.1 - 53.8	1.86 - 3.51	2.61 - 4.54	0.20 - 0.59	2 to 5	N/A	AML
Erdil et al. [71]	2	Wrap	CFRP	150	300	11.1 - 20.8	2.28 - 2.96	11.67 - 14.00	0.23 - 0.44	3	HS	AML
Evans et al. [72]	1	Wrap	CFRP	150	300	37.3	1.73	6.31	0.28	Single	HS	AFL
Green et al. [73]	3	Wrap	CFRP, GFRP	152	305	46.0 - 54.0	1.15 - 1.28	-	0.05 - 0.10	Single	HS	N/A
Harmon and Slattery [74]	4	Wrap	CFRP	51	102	41.0	2.10 - 5.88	5.08 - 15.70	0.19 - 1.42	Single	HS	AFL
Harries and Carey [8]	4	Wrap, unbonded wrap	GFRP	152	305	31.8	1.06 - 1.52	2.32	0.08 - 0.21	≥ 5	HL	AML
Harries and Kharel [75]	10	Wrap	CFRP, GFRP	152	305	32.1	1.02 - 1.87	1.43 - 4.93	0.02 - 0.33	≥ 5	HL	AML
Hong and Kim [13]	2	Tube	CFRP	300	600	17.5	4.32 - 4.58	14.33 - 18.51	1.11	Single	HS	AML
Hosotani et al. [76]	2	Wrap	CFRP, HM CFRP	200	600	41.7	2.16 - 2.23	4.41 - 6.18	0.23 - 0.25	Single	N/A	N/A
Howie and Karbhari [77]	12	Wrap	CFRP	152	305	38.6	1.09 - 2.33	-	0.06 - 0.40	Single	HL	N/A
Ilki et al. [78]	5	Wrap	CFRP	150	300	32.0	1.48 - 3.37	7.20 - 24.80	0.12 - 0.79	Single	HS	AFL
Ilki et al. [79]	12	Wrap	CFRP	150	300	6.2	3.13 - 17.47	13.00 - 52.00	0.55 - 4.74	Single	HS	AFL
Issa [80]	3	Wrap	CFRP	150	300	23.6 - 23.9	1.66 - 1.77	-	0.17 - 0.18	Single	HL	N/A
Issa and Karam [81]	9	Wrap	CFRP	150	300	30.5	1.17 - 2.48	-	0.14 - 0.41	Single	HL	N/A
Jiang and Teng [32]	23	Wrap	CFRP, GFRP	152	305	33.1 - 47.6	0.88 - 4.24	2.66 - 17.05	0.06 - 0.99	Single	HS	AML
Karabinis and Rousakis [82]	16	Wrap	CFRP	200	320	35.7 - 38.5	1.08 - 1.89	1.26 - 8.99	0.07 - 0.23	Single	N/A	AML
Karam and Tabbara [83]	2	Wrap	CFRP	150	300	12.8	1.39 - 2.48	2.91 - 5.91	0.29 - 0.59	2	HL	AML
Karantzikis et al. [84]	2	Wrap, unbonded wrap	CFRP	200	350	12.1	1.78 - 2.42	5.27 - 8.73	0.22	3	N/A	AML
Karbhari and Gao [37]	3	Wrap	CFRP	152	305	38.4	1.56 - 2.33	6.18 - 11.42	0.25 - 0.41	≥ 3	HL	AFL
Kono et al. [85]	15	Wrap	CFRP	100	200	32.3 - 34.8	1.46 - 3.16	3.93 - 12.37	0.14 - 0.62	Single	N/A	N/A
Lam and Teng [18]	18	Wrap	CFRP, GFRP	152	305	34.3 - 38.5	1.31 - 2.84	5.44 - 13.38	0.13 - 0.42	Single	HS	AML
Lam et al. [29]	6	Wrap	CFRP	152 - 152.5	304 - 305	38.9 - 41.1	1.28 - 2.03	3.52 - 8.32	0.11 - 0.31	Single	HS	AML
Lee et al. [86]	5	Wrap	CFRP	150	300	36.2	1.15 - 2.88	4.17 - 12.92	0.11 - 0.56	Single	HL	AML
Li et al. [87]	1	Wrap	GFRP	152.4	305	45.6	1.08	-	0.24	3	N/A	N/A
Li et al. [88]	2	Tube	GFRP	150	300	47.5	1.07 - 1.80	2.25 - 5.25	0.09 - 0.15	N/A	N/A	N/A
Liang et al. [89]	12	Wrap	CFRP	100	200	22.7 - 25.9	2.4 - 3.04	7.78 - 12.27	0.29 - 0.44	Single	HL	AFL
Lin and Chen [38]	10	Wrap	GFRP, HM CFRP	120	240	32.7	1.52 - 3.20	-	0.10 - 0.55	Single	N/A	N/A
Lin and Li [90]	27	Wrap	CFRP	100 - 150	200 - 300	17.7 - 25.9	1.92 - 5.23	-	0.19 - 1.23	3	HS	N/A
Lin and Liao [91]	6	Wrap	CFRP	100	200	23.9	2.57 - 3.91	-	0.51 - 0.96	Single	N/A	N/A
Mandal et al. [92]	9	Wrap	CFRP, GFRP	102 - 105	200	30.7 - 54.5	1.17 - 2.58	1.33 - 11.41	0.16 - 0.74	3	N/A	AML
Mastrapa [10]	13	Wrap, unbonded wrap	GFRP	152.5	305	29.8 - 37.2	0.90 - 3.10	7.96 - 32.54	0.19 - 1.03	Single	HS	AFL
Matthys et al. [11]	4	Wrap, unbonded wrap	CFRP, UHM CFRP	150	300	34.9	1.17 - 1.27	1.71 - 4.22	0.10 - 0.12	Single	HS	AS
Micelli et al. [93]	2	Wrap	CFRP, GFRP	102	204	32.0 - 37.0	1.61 - 1.62	4.93 - 8.93	0.19 - 0.23	N/A	N/A	N/A
Mirmiran et al. [9]	26	Wrap, unbonded wrap	GFRP	152.5	305	29.8 - 31.2	1.04 - 3.24	5.31 - 32.80	0.15 - 0.78	Single	HS	AFL
Miyauchi et al. [94]	10	Wrap	CFRP	100 - 150	200 - 300	31.2 - 51.9	1.31 - 3.26	4.32 - 10.32	0.07 - 0.42	2	N/A	AS
Miyauchi et al. [95]	6	Wrap	CFRP	100 - 150	200 - 300	23.6 - 26.3	1.55 - 3.23	8.83 - 13.24	0.14 - 0.55	N/A	N/A	N/A
Modarelli et al. [96]	3	Wrap	CFRP, GFRP	150	300	28.4 - 38.2	1.64 - 1.95	2.37 - 4.49	0.13 - 0.26	3	HS	AFL
Nanni and Bradford [97]	17	Wrap	GFRP, AFRP	150	300	35.6 - 36.3	1.13 - 5.40	9.21 - 47.37	0.18 - 1.66	Single	N/A	AFL
Ongpeng [98]	2	Wrap	CFRP	180	500	27.0	1.38 - 1.90	-	0.12 - 0.25	Single	N/A	N/A
Owen [99]	8	Wrap	CFRP	102 - 152	203 - 305	47.9 - 53.0	1.33 - 4.89	3.86 - 17.02	0.15 - 1.66	1 to 4	N/A	N/A
Ozbakkaloglu and Akin [39]	4	Wrap	AFRP	152	305	39.0	1.72 - 2.25	10.95 - 14.80	0.25 - 0.45	Single	HS	AFL
Ozbakkaloglu and Vincent [14]	24	Tube	CFRP, AFRP, UHM CFRP	74 - 302	152 - 600	34.0 – 55.0	1.06 - 2.47	3.29 - 15.97	0.05 - 0.38	Single	HS	AFL
Park et al. [100]	12	Tube	GFRP	150	300 - 450	32.0 - 54.0	1.69 - 3.82	7.73 - 15.69	0.11 - 0.58	Single	N/A	AFL
Picher et al. [101]	1	Wrap	CFRP	152	304	39.7	1.41	5.01	0.21	3	HL	AFL
Piekarczyk et al. [102]	2	Wrap	CFRP	47	112	55.0	2.18 - 3.44	2.86 - 4.00	0.52 - 0.86	Single	N/A	N/A
Pon et al. [103]	8	Wrap	CFRP	150 - 600	300 - 1200	7.1 - 9.6	1.73 - 4.68	-	0.28 - 1.30	N/A	N/A	N/A
Rochette and Labossiére [104]	7	Wrap	CFRP, AFRP	100 - 150	200 - 300	42.0 - 43.0	1.10 - 1.75	5.01 - 7.86	0.08 - 0.26		HL	AFL
Rousakis [105]	20	Wrap	HM CFRP	150	300	25.2 - 51.8	1.36 - 2.67	2.22 - 7.88	0.07 - 0.46	Single	HS	AFL
Rousakis et al. [26]	6	Wrap	CFRP	150	300	20.4 - 49.2	1.61 - 3.09	2.06 - 5.46	0.13 - 0.95	Single	HS	AML

Saafi et al. [12]	6	Tube	GFRP, HM CFRP	152	435	35.0	1.51 - 2.77	4.00 - 12.00	0.07 - 0.40	3	HS	AFL
Saenz and Pantelides [106]	4	Wrap	CFRP	152	304	40.3 - 47.5	1.72 - 2.68	3.79 - 9.49	0.22 - 0.59	3	HS	AML
Santarosa et al. [107]	3	Wrap	CFRP	150	300	15.3 - 28.1	1.37 - 3.05	3.01 - 8.70	0.11 - 0.42	2	HS	AS
Shahawy et al. [16]	9	Wrap	CFRP	152.5	305	19.4 - 49.0	1.21 - 4.13	2.14 - 10.79	0.30 – 4.00	5	HS	AML
Shao et al. [108]	2	Wrap	GFRP	152	305	40.2	1.23 - 1.78	-	0.18 - 0.37	Single	HS	N/A
Shehata et al. [109]	4	Wrap	CFRP	150	300	25.6 - 29.8	1.71 - 2.42	5.86 - 8.29	0.19 - 0.41	9	N/A	N/A
Shehata et al. [110]	4	Wrap	CFRP	150 - 225	300 - 450	34.0	1.29 - 2.41	3.10 - 5.50	0.10 - 0.29	9	N/A	N/A
Silva and Rodrigues [111]	7	Wrap	GFRP	150 - 250	300 - 750	29.6 - 31.2	1.79 - 3.03	4.54 - 11.33	0.20 - 0.58	Single	HS	N/A
Smith et al. [36]	4	Wrap	CFRP	250	500	35.0	1.43 - 1.69	-	0.11 - 0.17	Single	HS	N/A
Song et al. [112]	12	Wrap	CFRP	100 - 150	300 - 450	22.4	1.40 - 5.30	4.01 - 19.61	0.12 - 0.88	2	HS	AFL
Stanton and Owen [30]	5	Wrap	CFRP	152.5	305	49.0	1.41 - 5.63	4.24 - 19.51	0.11 - 0.90	N/A	N/A	N/A
Suter and Pinzelli [113]	16	Wrap	CFRP, GFRP, AFRP, UHM CFRP	150	300	33.3 - 54.0	1.14 - 3.12	1.16 - 8.92	0.09 - 0.46	≥ 1	N/A	N/A
Tamuzs et al. [114]	4	Wrap	CFRP	150	300	20.8 - 48.8	1.48 - 2.03	3.21 - 5.48	0.25 - 0.62	Single	HS	AS
Teng et al. [115]	6	Wrap	GFRP	152.5	305	39.6	0.94 - 1.66	3.14 - 9.73	0.07 - 0.26	Single	HS	AML
Thériault et al. [116]	5	Wrap	CFRP, GFRP	51 - 304	102 - 608	18.0 - 37.0	1.73 - 3.89	-	0.25 - 1.15	3	N/A	N/A
Valdmanis et al. [27]	6	Wrap	CFRP	150	300	40.0 - 44.3	1.65 - 2.60	3.18 - 8.00	0.09 - 0.28	Single	HS	AML
Vincent and Ozbakkaloglu [117]	6	Wrap	CFRP	152	305	35.5 – 38.0	1.21 - 1.74	3.79 – 7.88	0.11 - 0.23	Single	HS	AFL
Vincent and Ozbakkaloglu [118]	12	Wrap, tube	AFRP	152	305	49.4	2.09 - 2.24	12.59 - 15.76	0.30 - 0.42	Single	HS	AFL
Wang and Wu [33]	12	Wrap	CFRP	150	300	30.9 - 52.1	1.28 - 2.85	-	0.09 - 0.43	Single	HS	N/A
Wang and Wu [119]	18	Wrap	AFRP	70 - 194	210 - 582	24.0 - 51.6	0.98 - 3.37	1.36 - 5.68	0.04 - 0.35	N/A	N/A	N/A
Wang and Zhang [120]	2	Wrap	AFRP	150	450	47.3 - 51.1	1.73 - 1.78	6.01 - 6.99	0.20 - 0.22	Single	N/A	AS
Watanabe et al. [28]	9	Wrap	CFRP, AFRP, UHM CFRP	100	200	30.2	1.29 - 3.46	2.48 - 24.13	0.14 - 0.79	N/A	N/A	N/A
Wong et al. [34]	4	Wrap	GFRP	152.5	305	36.5 - 46.7	1.24 - 1.73	5.58 - 8.40	0.14 - 0.27	Single	HS	AML
Wu and Jiang [121]	4	Wrap	CFRP	150	300	28.7 - 30.1	1.91 - 3.00	-	0.17 – 0.32	Single	N/A	AML
Wu and Jiang [24]	34	Wrap	CFRP	150	300	20.6 - 36.7	1.69 - 6.83	-	0.15 – 1.31	Single	HS	AML
Wu et al. [31]	4	Wrap	CFRP, AFRP, HM CFRP, GFRP	150	300	23.0	1.96 - 2.30	-	0.15 - 0.23	Single	HS	N/A
Wu et al. [35]	10	Wrap	CFRP, GFRP, AFRP, UHM CFRP	150	300	23.1	1.94 - 3.55	4.49 - 14.04	0.15 - 0.42	Single	HS	AFL
Wu et al. [122]	2	Wrap	AFRP	100	300	46.4	1.69 - 2.77	3.54 - 7.37	0.17 - 0.34	Single	N/A	AML
Xiao and Wu [15]	27	Wrap	CFRP	152	305	33.7 - 55.2	1.05 - 2.83	1.66 - 15.27	0.06 - 0.51	Single	HS	AS
Yan et al. [123]	1	Wrap	CFRP	305	610	15.2	2.49	5.50	0.39	Single	HS	AML
Youssef et al. [53]	40	Wrap	CFRP, GFRP	152.4 - 406.4	304.8 - 812.8	29.4 - 44.6	1.44 - 4.31	2.56 - 14.24	0.10 - 0.88	Single	HS	AML
Zhang et al. [124]	1	Wrap	CFRP	150	300	34.3	1.73	10.50	0.30	5	N/A	AFL

Specimen instrumentation notes:

HS denotes hoop strains were measured by strain gauges attached on the surface of specimens

HL denotes hoop strains were measured by lateral LVDTs, extensometers, or dial gauges mounted on specimens

AS denotes axial strains were measured by strain gauges attached on the surface of specimens

AFL denotes axial strains were determined from LVDTs or dial gauges mounted on loading platens to measure deformations along the full height of specimens

AML denotes axial strains were determined from LVDTs, extensometers, or dial gauges mounted on specimens to measure deformations within a gauge length along the height of specimens

N/A denotes information that was either not applicable to the dataset or not available in the source document

Table 3. Test database of CFRP-wrapped concrete specimens

Paper	Specimen Dimensions		Concrete Properties		FRP Properties			Fiber Properties			Measured Ultimate Conditions			Hoop Rupture Strain Reduction Factors	
	D (mm)	H (mm)	f'_{co} (MPa)	ε_{co} (%)	E_{frp} (GPa)	f_{frp} (MPa)	t_{frp} (mm)	E_f (GPa)	f_f (MPa)	t_f (mm)	f'_{cc} (MPa)	ε_{cu} (%)	$\varepsilon_{h,rup}$ (%)	$k_{\varepsilon,frp}$	$k_{\varepsilon,f}$
Aire et al. [56]	150	300	42	0.24				240	3900	0.117	46	0.92	0.38		0.234^
Aire et al. [56]	150	300	42	0.24				240	3900	0.351	77	2.12	0.88		0.542
Aire et al. [56]	150	300	42	0.24				240	3900	0.702	108	3.16	1.32		0.812
Akogbe et al. [57]	100	200	26.5	0.31				242	3248	0.167	64.3	2.55			
Akogbe et al. [57]	100	200	26.5	0.31				242	3248	0.167	63.0	2.18			
Akogbe et al. [57]	100	200	26.5	0.31				242	3248	0.167	66.4	2.29			
Akogbe et al. [57]	100	200	26.5	0.31				242	3248	0.167	64.8	2.48			
Akogbe et al. [57]	200	400	21.7	0.22				242	3248	0.334	64.3[s]	2.79			
Akogbe et al. [57]	200	400	21.7	0.22				242	3248	0.334	69.1[s]	2.69			
Akogbe et al. [57]	200	400	21.7	0.22				242	3248	0.334	60.1	2.10			
Akogbe et al. [57]	200	400	21.7	0.22				242	3248	0.334	66.3[s]	2.54			
Akogbe et al. [57]	300	600	24.5	0.22				242	3248	0.501	58.8	1.80			
Akogbe et al. [57]	300	600	24.5	0.22				242	3248	0.501	59.4	2.00			
Akogbe et al. [57]	300	600	24.5	0.22				242	3248	0.501	63.0	1.90			
Akogbe et al. [57]	300	600	24.5	0.22				242	3248	0.501	60.6	2.00			
Al-Salloum [45]	150	300	32.4	0.205	75.1	935	1.2				83.16	3.233[a]			
Al-Salloum [45]	150	300	36.2	0.205	75.1	935	1.2				85.04	3.233[a]			
Benzaid et al. [60]	160	320	25.9	0.273				238	4300	0.13	39.63	1.28	1.31		0.725
Benzaid et al. [60]	160	320	25.9	0.273				238	4300	0.39	66.14	1.52[a]	1.32		0.731
Benzaid et al. [60]	160	320	49.5	0.169				238	4300	0.13	52.75	0.25[a]	0.29		0.161^
Benzaid et al. [60]	160	320	49.5	0.169				238	4300	0.39	82.91	0.73[a]	1.32		0.731
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.165	42.8	1.633	0.957		0.688
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.165	37.8	0.932	0.964		0.693
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.165	45.8	1.674	0.960		0.690
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.330	56.7	1.725	0.899		0.646
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.330	55.2	1.577	0.911		0.655
Berthet et al. [61]	160	320	25.0	0.233				230	3200	0.330	56.1	1.680	0.908		0.653
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.110	49.8	0.554	1.015		0.730
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.110	50.8	0.663	0.952		0.684
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.110	48.8	0.608	1.203		0.865^
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.165	53.7	0.660	0.880		0.633
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.165	54.7	0.619	0.853		0.613
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.165	51.8	0.639	1.042		0.749
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.220	59.7	0.599	0.788		0.566
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.220	60.7	0.693	0.830		0.597
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.220	60.2	0.730	0.809		0.581
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.440	91.6	1.443	0.924		0.664
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.440	89.6	1.364	0.967		0.695
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.440	86.6	1.166	0.885		0.636
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.990	142.4	2.461	0.989		0.711
Berthet et al. [61]	160	320	40.1	0.200				230	3200	0.990	140.4	2.389	1.002		0.720
Berthet et al. [61]	160	320	40.1	0.200				230	3200	1.320	166.3	2.700	0.999		0.718
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.330	82.6	0.832	0.934		0.671
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.330	82.8	0.699	0.865		0.622
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.330	82.3	0.765	0.891		0.640
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.660	108.1	1.141	0.667		0.479^
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.660	112.0	1.124	0.871		0.626
Berthet et al. [61]	160	320	52.0	0.227				230	3200	0.660	107.9	1.121	0.882		0.634
Bisby et al. [62]	150	300	34.4	0.33				231	4100	0.12	44.1	0.80	0.93		
Bisby et al. [62]	150	300	34.4	0.33				231	4100	0.12	44.1	0.87	1.10		
Bisby et al. [62]	150	300	34.4	0.33				231	4100	0.12	43.0	0.90	1.21		
Bisby et al. [63]	100	200	28.0	0.25				231	4100	0.12	63.0				
Bisby et al. [63]	100	200	28.0	0.25				231	4100	0.12	61.0	1.32	1.02		
Bisby et al. [63]	100	200	28.0	0.25				231	4100	0.12	53.0	1.06	1.00		
Campione et al. [65]	100	200	20.1	0.207				230	3430	0.165	49.6	2.55			
Carey and Harries [66]	254	762	38.9	0.30				72.5[p]	875[p]	1.0	54.8	1.04	1.00		0.829
Carey and Harries [66]	152	305	33.5	0.23				25[p]	350[p]	1.7	46.8	0.93	1.48		1.057^
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	1				86.6	1.53	1.124	1.171^	
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	2				109.4	2.01	0.968	1.008^	
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	2				126.7	2.66	1.212	1.263^	
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	3				162.7	3.09	1.158	1.206^	
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	3				153.6	2.89	1.035	1.078^	
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.11	57.7	1.21	1.678		1.111^
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.11	55.4	1.31[a]	1.599		1.059^
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.22	78.0	1.97[a]	1.616		1.070^
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.22	86.8	2.14[a]	1.801		1.193^
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.33	106.5	2.90[a]	1.786		1.183^
Cui and Sheikh [68]	152	305	45.6	0.247				241	3639	0.33	106.0	2.83[a]	1.798		1.191^
Cui and Sheikh [68]	152	305	48.1	0.222	85	816	1				80.9	1.51	1.052	1.096^	
Demers and Neale [69]	152	305	32.2		25[p]	380[p]	1				41.1	1.41			
Demers and Neale [69]	152	305	43.7		25[p]	380[p]	1				48.4	0.97			
Demers and Neale [69]	152	305	43.7		25[p]	380[p]	3				75.2	1.83			
Demers and Neale [69]	152	305	43.7		25[p]	380[p]	3				73.4	1.83			
Elsanadedy et al. [70]	50	100	53.8	0.344	77.3	846	1				146.2	1.563[a]			
Elsanadedy et al. [70]	100	200	49.1	0.361	77.3	846	1				94.5	1.091			
Elsanadedy et al. [70]	100	200	49.1	0.361	77.3	846	2				146.0	1.541[a]			
Elsanadedy et al. [70]	150	300	41.1	0.362	77.3	846	1				76.4	0.945			
Elsanadedy et al. [70]	150	300	41.1	0.362	77.3	846	2				111.5	1.335[a]			
Elsanadedy et al. [70]	150	300	41.1	0.362	77.3	846	3				144.2	1.485[a]			
Erdil et al. [71]	150	300	11.1	0.3				230	3430	0.165	32.9	4.2			
Erdil et al. [71]	150	300	20.8	0.3				230	3430	0.165	47.5	3.5[a]			
Evans et al. [72]	152	305	37.3					240	3800	0.234	64.4	1.31	1.39		0.878^
Green et al. [73]	152	305	46.0		22.4[p]	237[p]	1				53				
Green et al. [73]	152	305	46.0		22.4[p]	237[p]	2				59				
Harmon and Slattery [74]	51	102	41					235	3500	0.09	86				
Harmon and Slattery [74]	51	102	41					235	3500	0.179	117	1.1			

Harmon and Slattery [74]	51	102	41					235	3500	0.344	158	2.0			
Harmon and Slattery [74]	51	102	41					235	3500	0.690	241[s]	3.4[a]			
Harries and Kharel [75]	152	305	32.1	0.28	15.7	174	1	25[p]	350[p]	1	32.9	0.60	1.03	0.929^	0.736
Harries and Kharel [75]	152	305	32.1	0.28	15.7	174	2	25[p]	350[p]	2	41.0	0.86	1.19	1.074^	0.850
Harries and Kharel [75]	152	305	32.1	0.28	15.7	174	3	25[p]	350[p]	3	52.2	1.38	1.55	1.399^	1.107^
Hosotani et al. [76]	200	600	41.7	0.34	243	4227	0.44	230	3481	0.444	93.0	2.1			
Howie and Karbhari [77]	152	305	38.6		73.3	755	0.305				45.5				
Howie and Karbhari [77]	152	305	38.6		73.3	755	0.305				41.9				
Howie and Karbhari [77]	152	305	38.6		73.3	755	0.305				47.2				
Howie and Karbhari [77]	152	305	38.6		70.6	1047	0.61				56.5				
Howie and Karbhari [77]	152	305	38.6		70.6	1047	0.61				60.6				
Howie and Karbhari [77]	152	305	38.6		70.6	1047	0.61				61.9				
Howie and Karbhari [77]	152	305	38.6		77.5	1105	0.92				80.9				
Howie and Karbhari [77]	152	305	38.6		77.5	1105	0.92				76.4				
Howie and Karbhari [77]	152	305	38.6		77.5	1105	0.92				75.8				
Howie and Karbhari [77]	152	305	38.6		95.7	1352	1.22				89.5				
Howie and Karbhari [77]	152	305	38.6		95.7	1352	1.22				89.9				
Howie and Karbhari [77]	152	305	38.6		95.7	1352	1.22				89.0				
Ilki et al. [78]	150	300	32	0.2				230	3430	0.165	47.2	1.44	0.79		0.530
Ilki et al. [78]	150	300	32	0.2				230	3430	0.495	83.8	3.43	1.03		0.691
Ilki et al. [78]	150	300	32	0.2				230	3430	0.495	91.0	3.92[a]	1.08		0.724
Ilki et al. [78]	150	300	32	0.2				230	3430	0.825	107.1	4.96[a]	0.64		0.429^
Ilki et al. [78]	150	300	32	0.2				230	3430	0.825	107.7	4.32	1.00		0.671
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.165	25.3[s]	3.9[a]	0.67		0.449^
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.165	19.4	2.6			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.330	41.9	5.9	1.30		0.872
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.330	40.0	5.9			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.495	52.2	6.9			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.495	56.9	7.5	1.10		0.738
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.660	76.6	8.8			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.660	69.7	7.6			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.825	87.7	9.1			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.825	82.7	9.4			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.990	108.3	10.4			
Ilki et al. [79]	150	300	6.2	0.2				230	3430	0.990	103.3	9.6			
Issa [80]	150	300	23.7					231	4100	0.12	39.34				
Issa [80]	150	300	23.9					231	4100	0.12	39.83				
Issa [80]	150	300	23.6					231	4100	0.12	41.79				
Issa and Karam [81]	150	300	30.5					230	4100	0.122	35.8				
Issa and Karam [81]	150	300	30.5					230	4100	0.122	37.6				
Issa and Karam [81]	150	300	30.5					230	4100	0.122	42.0				
Issa and Karam [81]	150	300	30.5					230	4100	0.244	48.7				
Issa and Karam [81]	150	300	30.5					230	4100	0.244	50.0				
Issa and Karam [81]	150	300	30.5					230	4100	0.244	64.5				
Issa and Karam [81]	150	300	30.5					230	4100	0.366	68.7				
Issa and Karam [81]	150	300	30.5					230	4100	0.366	64.6				
Issa and Karam [81]	150	300	30.5					230	4100	0.366	75.6				
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					0.68	110.1	2.551	0.977		
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					0.68	107.4	2.613	0.965		
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					1.02	129.0	2.794	0.892		
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					1.02	135.7	3.082	0.927		
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					1.36	161.3	3.700	0.872		
Jiang and Teng [32]	152	305	38.0	0.217	240.7[t]					1.36	158.5	3.544	0.877		
Jiang and Teng [32]	152	305	37.7	0.275	260[t]					0.11	48.5	0.895	0.935		
Jiang and Teng [32]	152	305	37.7	0.275	260[t]					0.11	50.3	0.914	1.092		
Jiang and Teng [32]	152	305	42.2	0.260	260[t]					0.11	48.1	0.691	0.734		
Jiang and Teng [32]	152	305	42.2	0.260	260[t]					0.11	51.1	0.888	0.969		
Jiang and Teng [32]	152	305	42.2	0.260	260[t]					0.22	65.7	1.304	1.184		
Jiang and Teng [32]	152	305	42.2	0.260	260[t]					0.22	62.9	1.025	0.938		
Jiang and Teng [32]	152	305	47.6	0.279	250.5[t]					0.33	82.7	1.304	0.902		
Jiang and Teng [32]	152	305	47.6	0.279	250.5[t]					0.33	85.5	1.936	1.130		
Jiang and Teng [32]	152	305	47.6	0.279	250.5[t]					0.33	85.5	1.821	1.064		
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.117	43.0	0.796			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.117	41.6	0.714			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.117	46.0	0.349[a]			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.234	51.5	0.877			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.234	50.0	0.577			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.234	55.0	0.860			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.351	67.0	1.760			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.117	42.5	0.859			
Karabinis and Rousakis [82]	200	320	38.5	0.276				240	3720	0.117	42.0	1.238			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.117	41.0	0.296[a]			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.234	50.0	0.604			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.234	48.5	1.040			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.234	50.0	1.072			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.351	63.0	1.718			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.351	67.5	1.705			
Karabinis and Rousakis [82]	200	320	35.7	0.191				240	3720	0.351	65.5	1.686			
Karam and Tabbara [83]	150	300	12.8	0.47				231	3650	0.12	17.8[s]	1.37[a]			
Karam and Tabbara [83]	150	300	12.8	0.47				231	3650	0.24	31.8	2.78[a]			
Karantzikis et al. [84]	200	350	12.1	0.22				230	3500	0.12	29.25	1.92			
Karbhari and Gao [37]	152	305	38.4		138.1	1047	0.66	227	3500		59.7	1.3			
Karbhari and Gao [37]	152	305	38.4		77.39	1105	0.99	227	3500		77.7	2.2			
Karbhari and Gao [37]	152	305	38.4		95.7	1352	1.32	227	3500		89.5	2.4			
Kono et al. [85]	100	200	34.3					235	3820	0.167	57.4	0.785	0.84		0.517
Kono et al. [85]	100	200	34.3					235	3820	0.167	64.9	1.11	0.92		0.566
Kono et al. [85]	100	200	32.3					235	3820	0.167	58.2				
Kono et al. [85]	100	200	32.3					235	3820	0.167	61.8	1.07	0.96		0.591
Kono et al. [85]	100	200	32.3					235	3820	0.167	57.7	1.07	0.63		0.388^
Kono et al. [85]	100	200	32.3					235	3820	0.334	80.2	1.75	0.89		0.548
Kono et al. [85]	100	200	32.3					235	3820	0.501	86.9	1.65	0.77		0.474^
Kono et al. [85]	100	200	32.3					235	3820	0.501	90.1	1.59	0.67		0.412^

Kono et al. [85]	100	200	34.8					235	3820	0.167	57.8	0.935	0.91		0.560
Kono et al. [85]	100	200	34.8					235	3820	0.167	55.6	1.05	0.89		0.548
Kono et al. [85]	100	200	34.8					235	3820	0.167	50.7	0.982	0.61		0.375^
Kono et al. [85]	100	200	34.8					235	3820	0.334	82.7	2.06	0.66		0.406^
Kono et al. [85]	100	200	34.8					235	3820	0.334	81.4		0.88		0.541
Kono et al. [85]	100	200	34.8					235	3820	0.501	103.3	2.36	0.91		0.560
Kono et al. [85]	100	200	34.8					235	3820	0.501	110.1	2.49	0.8		0.492
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.165	50.4	1.273	1.147	0.757	0.771
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.165	47.2	1.106	0.969	0.640	0.652
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.165	53.2	1.292	0.981	0.648	0.660
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.330	68.7	1.683	0.988	0.652	0.664
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.330	69.9	1.962	1.001	0.661	0.673
Lam and Teng [18]	152	305	35.9	0.203	250.5[t]	3795[t]		230	3420	0.330	71.6	1.850	0.949	0.626	0.638
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.495	82.6	2.046	0.799	0.527	0.537
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.495	90.4	2.413	0.884	0.584	0.595
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.495	97.3	2.516	0.968	0.639	0.651
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.165	50.3	1.022	0.908	0.599	0.611
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.165	50.0	1.082	0.890	0.587	0.599
Lam and Teng [18]	152	305	34.3	0.188	250.5[t]	3795[t]		230	3420	0.165	56.7	1.168	0.927	0.612	0.623
Lam et al. [29]	152.5	305	41.1	0.256	250.5[t]	3795[t]				0.165	52.6	0.90	0.81	0.533	
Lam et al. [29]	152.5	305	41.1	0.256	250.5[t]	3795[t]				0.165	57.0	1.21	1.08	0.711	
Lam et al. [29]	152.5	305	41.1	0.256	250.5[t]	3795[t]				0.165	55.4	1.11	1.07	0.704	
Lam et al. [29]	152.5	305	38.9	0.250	250.5[t]	3795[t]				0.330	76.8	1.91	1.06	0.697	
Lam et al. [29]	152.5	305	38.9	0.250	250.5[t]	3795[t]				0.330	79.1	2.08	1.13	0.744	
Lam et al. [29]	152.5	305	38.9	0.250	250.5[t]	3795[t]				0.330	65.80[s]	1.25[a]	0.79		
Lee et al. [86]	150	300	36.2	0.24				250	4510	0.11	41.7	1.0			
Lee et al. [86]	150	300	36.2	0.24				250	4510	0.22	57.8	1.5			
Lee et al. [86]	150	300	36.2	0.24				250	4510	0.33	69.1	2.0			
Lee et al. [86]	150	300	36.2	0.24				250	4510	0.44	85.4	2.7			
Lee et al. [86]	150	300	36.2	0.24				250	4510	0.55	104.3	3.1			
Lin and Li [90]	150	300	18.3					232	4170	0.138	38.62				
Lin and Li [90]	120	240	17.7					232	4170	0.138	43.62				
Lin and Li [90]	100	200	17.9					232	4170	0.138	46.08				
Lin and Li [90]	150	300	18.3					232	4170	0.275	55.74				
Lin and Li [90]	120	240	17.7					232	4170	0.275	63.47				
Lin and Li [90]	100	200	17.9					232	4170	0.275	71.46				
Lin and Li [90]	150	300	18.3					232	4170	0.413	73.57				
Lin and Li [90]	120	240	17.7					232	4170	0.413	85.61				
Lin and Li [90]	100	200	17.9					232	4170	0.413	93.33				
Lin and Li [90]	150	300	23.2					232	4170	0.138	45.41				
Lin and Li [90]	120	240	23.2					232	4170	0.138	49.11				
Lin and Li [90]	100	200	23.5					232	4170	0.138	57.37				
Lin and Li [90]	150	300	23.2					232	4170	0.275	61.98				
Lin and Li [90]	120	240	23.2					232	4170	0.275	76.90				
Lin and Li [90]	100	200	23.5					232	4170	0.275	81.91				
Lin and Li [90]	150	300	23.2					232	4170	0.413	84.46				
Lin and Li [90]	120	240	23.2					232	4170	0.413	91.17				
Lin and Li [90]	100	200	23.5					232	4170	0.413	103.77				
Lin and Li [90]	150	300	25.5					232	4170	0.138	49.02				
Lin and Li [90]	120	240	25.9					232	4170	0.138	56.40				
Lin and Li [90]	100	200	25.5					232	4170	0.138	62.26				
Lin and Li [90]	150	300	25.5					232	4170	0.275	69.82				
Lin and Li [90]	120	240	25.9					232	4170	0.275	81.29				
Lin and Li [90]	100	200	25.5					232	4170	0.275	90.54				
Lin and Li [90]	150	300	25.5					232	4170	0.413	88.73				
Lin and Li [90]	120	240	25.9					232	4170	0.413	98.73				
Lin and Li [90]	100	200	25.5					232	4170	0.413	109.48				
Liang et al. [89]	100	200	25.9	0.24	245	3248	0.167	242	3591	0.167	64.3	2.31	1.48	1.116^	0.997^
Liang et al. [89]	100	200	25.9	0.24	245	3248	0.167	242	3591	0.167	63.0	1.93	1.07	0.807	0.721
Liang et al. [89]	100	200	25.9	0.24	245	3248	0.167	242	3591	0.167	66.4	2.16	1.39	1.048^	0.937^
Liang et al. [89]	100	200	25.9	0.24	245	3248	0.167	242	3591	0.167	64.8	2.16	1.22	0.920	0.822
Liang et al. [89]	200	400	22.7	0.22	245	3248	0.334	242	3591	0.334	64.3	2.29	1.09	0.822	0.735
Liang et al. [89]	200	400	22.7	0.22	245	3248	0.334	242	3591	0.334	69.1	2.37	1.12	0.845	0.755
Liang et al. [89]	200	400	22.7	0.22	245	3248	0.334	242	3591	0.334	60.1	2.00	0.89	0.671	0.600
Liang et al. [89]	200	400	22.7	0.22	245	3248	0.334	242	3591	0.334	66.3	2.48	1.16	0.875	0.782
Liang et al. [89]	300	600	24.5	0.22	245	3248	0.501	242	3591	0.501	58.8	1.84	0.98	0.739	0.660
Liang et al. [89]	300	600	24.5	0.22	245	3248	0.501	242	3591	0.501	59.4	1.71	1.33	1.003^	0.896^
Liang et al. [89]	300	600	24.5	0.22	245	3248	0.501	242	3591	0.501	63.0	2.27	1.70	1.282^	1.146^
Liang et al. [89]	300	600	24.5	0.22	245	3248	0.501	242	3591	0.501	60.6	2.09	1.22	0.920	0.822
Lin and Liao [91]	100	200	23.9		23.83	455.4	1.84				62.42				
Lin and Liao [91]	100	200	23.9		23.83	455.4	1.84				62.06				
Lin and Liao [91]	100	200	23.9		23.83	455.4	1.84				61.45				
Lin and Liao [91]	100	200	23.9		22.46	403.1	3.89				93.56				
Lin and Liao [91]	100	200	23.9		22.46	403.1	3.89				90.69				
Lin and Liao [91]	100	200	23.9		22.46	403.1	3.89				88.98				
Mandal et al. [92]	102	200	30.7	0.27	47	784	0.8				73.8	3.08			
Mandal et al. [92]	102	200	46.3	0.23	47	784	0.8				77.1	1.84			
Mandal et al. [92]	102	200	54.5	0.24	47	784	0.8				72.1	0.80			
Matthys et al. [11]	150	300	34.9		198	2600		240	3900	0.117	44.3	0.85	1.15	0.876^	0.708
Micelli et al. [93]	102	204	37.0					227	3790	0.16	60	1.02	1.2		0.719
Miyauchi et al. [94]	150	300	31.2	0.195				230.5	3481	0.11	52.4	1.213			
Miyauchi et al. [94]	150	300	31.2	0.195				230.5	3481	0.22	67.4	1.554			
Miyauchi et al. [94]	150	300	31.2	0.195				230.5	3481	0.33	81.7	2.013			
Miyauchi et al. [94]	100	200	33.7	0.190				230.5	3481	0.11	69.6	1.406			
Miyauchi et al. [94]	100	200	33.7	0.190				230.5	3481	0.22	88.0	1.488			
Miyauchi et al. [94]	100	200	33.7	0.190				230.5	3481	0.33	109.9	1.900			
Miyauchi et al. [94]	150	300	45.2	0.219				230.5	3481	0.11	59.4	0.945			
Miyauchi et al. [94]	150	300	45.2	0.219				230.5	3481	0.22	79.4	1.245			
Miyauchi et al. [94]	100	200	51.9	0.192				230.5	3481	0.11	75.2	0.956			
Miyauchi et al. [94]	100	200	51.9	0.192				230.5	3481	0.22	104.6	1.275			
Miyauchi et al. [95]	150	300	23.6	0.18				230.5	3481	0.11	36.5	1.589[a]			
Miyauchi et al. [95]	150	300	23.6	0.18				230.5	3481	0.22	50.8	2.384[a]			

Miyauchi et al. [95]	150	300	23.6	0.18				230.5	3481	0.33	64.3				
Miyauchi et al. [95]	100	200	26.3	0.193				230.5	3481	0.11	50.7	1.991[a]			
Miyauchi et al. [95]	100	200	26.3	0.193				230.5	3481	0.22	70.9	2.356[a]			
Miyauchi et al. [95]	100	200	26.3	0.193				230.5	3481	0.33	84.9				
Modarelli et al. [96]	150	300	28.4	0.490	221	3070	0.165	230	3430	0.165	55.25	2.20	1.53		0.890^
Modarelli et al. [96]	150	300	38.2	0.630	221	3070	0.165	230	3430	0.165	62.73	1.49	1.32		0.768
Ongpeng [98]	180	500	27.0					231	3650	0.13	37.23				
Ongpeng [98]	180	500	27.0					231	3650	0.26	51.18				
Owen [99]	102	203	53		238	4200	0.165	262	4200	0.165	70.5	1	1.23	0.697	0.767
Owen [99]	102	203	53		238	4200	0.33	262	4200	0.33	108.8	1.82	1.53	0.867^	0.954^
Owen [99]	102	203	53		238	4200	0.66	262	4200	0.66	149.0[s]	2.32[a]	1.33	0.754	0.830
Owen [99]	102	203	53		238	4200	0.99	262	4200	0.99	197.4[s]	3.3[a]	1.23	0.697	0.767
Owen [99]	102	203	53		238	4200	1.32	262	4200	1.32	259.0[s]	4.17[a]	1.3	0.737	0.811
Owen [99]	152	305	47.9		238	4200	1.32	262	4200	0.165	65.4	0.9	1.28	0.725	0.798
Owen [99]	152	305	47.9		238	4200	1.32	262	4200	0.33	96.2	1.69	1.4	0.793	0.873
Owen [99]	152	305	47.9		238	4200	1.32	262	4200	0.66	121.1	2.04	1.28	0.725	0.798
Picher et al. [101]	152	304	39.7		83	1266	0.9	230	3400	0.33	56	1.07	0.84	0.551	0.568
Piekarczyk et al. [102]	47	112	55	0.7	113	1420	0.82	240	4810		189	2.8			
Piekarczyk et al. [102]	47	112	55	0.7	110	1150	0.51	240	4810		120	2.0			
Pon et al. [103]	450	900	7.1						4410	0.22	15.5				
Pon et al. [103]	450	900	7.1						4410	0.33	21.2				
Pon et al. [103]	300	600	7.2						4410	0.22	21.1				
Pon et al. [103]	300	600	7.2						4410	0.33	26.8				
Pon et al. [103]	600	1200	7.4						4410	0.22	12.8				
Pon et al. [103]	600	1200	7.4						4410	0.33	16.7				
Pon et al. [103]	150	300	9.6						4410	0.22	34.1[s]				
Pon et al. [103]	150	300	9.6						4410	0.33	44.9[s]				
Rochette and Labossiére [104]	100	200	42		82.7	1265	0.6	230	3400	0.22	73.5	1.60	0.89	0.582	0.602
Rochette and Labossiére [104]	100	200	42		82.7	1265	0.6	230	3400	0.22	73.5	1.57	0.95	0.621	0.643
Rochette and Labossiére [104]	100	200	42		82.7	1265	0.6	230	3400	0.22	67.6	1.35	0.80	0.523	0.541
Rousakis et al. [26]	150	300	20.4	0.26				234	4493	0.17	41.3	0.96			0.417^
Rousakis et al. [26]	150	300	20.4	0.26				234	4493	0.34	57.2	1.42[a]			0.333^
Rousakis et al. [26]	150	300	20.4	0.26				234	4493	0.51	63.1[s]	1.42[a]			0.302^
Rousakis et al. [26]	150	300	49.2	0.17				234	4493	0.17	79.0	0.39[a]			0.229^
Rousakis et al. [26]	150	300	49.2	0.17				234	4493	0.34	83.9	0.35[a]			0.135^
Rousakis et al. [26]	150	300	49.2	0.17				234	4493	0.51	100.6	0.62[a]			0.250^
Saenz and Pantelides [106]	152	304	41.8		86.8[p]	1220[p]	1				83.7	1.18	0.92	0.655	
Saenz and Pantelides [106]	152	304	47.5		86.8[p]	1220[p]	1				81.5	0.88	0.93	0.662	
Saenz and Pantelides [106]	152	304	40.3		86.8[p]	1220[p]	2				108.1	2.04	0.92	0.655	
Saenz and Pantelides [106]	152	304	41.7		86.8[p]	1220[p]	2				109.5	1.76	1.08	0.768	
Santarosa et al. [107]	150	300	28.1					230	3400	0.11	38.6				
Santarosa et al. [107]	150	300	15.3					230	3400	0.11	33.6	0.45[a]			
Santarosa et al. [107]	150	300	15.3					230	3400	0.22	46.7	1.30			
Shahawy et al. [16]	152.5	305	19.4	0.33	82.7	2275	0.36	207	3654	0.5	33.8[s]	1.59[a]			
Shahawy et al. [16]	152.5	305	19.4	0.33	82.7	2275	0.58	207	3654	1	46.4[s]	2.21[a]			
Shahawy et al. [16]	152.5	305	19.4	0.33	82.7	2275	0.81	207	3654	1.5	62.6[s]	2.58[a]			
Shahawy et al. [16]	152.5	305	19.4	0.33	82.7	2275	1.03	207	3654	2	75.7[s]	3.56[a]			
Shahawy et al. [16]	152.5	305	19.4	0.33	82.7	2275	1.25	207	3654	2.5	80.2[s]	3.42[a]			
Shahawy et al. [16]	152.5	305	49	0.29	82.7	2275	0.36	207	3654	0.5	59.1[s]	0.62[a]			
Shahawy et al. [16]	152.5	305	49	0.29	82.7	2275	0.58	207	3654	1	76.5[s]	0.97[a]			
Shahawy et al. [16]	152.5	305	49	0.29	82.7	2275	0.81	207	3654	1.5	98.8[s]	1.26[a]			
Shahawy et al. [16]	152.5	305	49	0.29	82.7	2275	1.03	207	3654	2	112.7[s]	1.90[a]			
Shehata et al. [109]	150	300	29.8	0.21				235	3550	0.165	57.0	1.23	1.23		0.814
Shehata et al. [109]	150	300	29.8	0.21				235	3550	0.330	72.1	1.74	1.19		0.788
Shehata et al. [109]	150	300	25.6					235	3550	0.165	43.9				
Shehata et al. [109]	150	300	25.6					235	3550	0.330	59.6				
Shehata et al. [110]	225	450	34	0.2				235	3550	0.165	43.7	0.62			
Shehata et al. [110]	225	450	34	0.2				235	3550	0.330	62.9	1.09			
Shehata et al. [110]	150	300	34	0.2				235	3550	0.165	61.2	0.91			
Shehata et al. [110]	150	300	34	0.2				235	3550	0.330	82.1	1.10			
Smith et al. [36]	250	500	35		210.52[t]	3182[t]				0.262	50		0.893	0.591	
Smith et al. [36]	250	500	35		210.52[t]	3182[t]				0.262	57		1.218	0.806	
Smith et al. [36]	250	500	35		210.52[t]	3182[t]				0.262	59		1.311	0.867^	
Smith et al. [36]	250	500	35		210.52[t]	3182[t]				0.262	56		1.149	0.760	
Song et al. [112]	100	300	22.4					237	4073	0.13	56.2	0.903	0.874		0.509
Song et al. [112]	100	300	22.4					237	4073	0.26	78.2	1.762	0.937		0.545
Song et al. [112]	100	300	22.4					237	4073	0.39	118.7[s]	3.313	1.070		0.623
Song et al. [112]	150	450	22.4					237	4073	0.13	45.7	1.217	1.117		0.650
Song et al. [112]	150	450	22.4					237	4073	0.26	65.4	2.000	1.179		0.686
Song et al. [112]	150	450	22.4					237	4073	0.39	85.0	2.564	1.207		0.702
Song et al. [112]	100	300	40.9					237	4073	0.13	71.1	1.984[a]	0.920		0.535
Song et al. [112]	100	300	40.9					237	4073	0.26	97.6	1.646	1.039		0.605
Song et al. [112]	100	300	40.9					237	4073	0.39	125.0	2.180	1.030		0.599
Song et al. [112]	150	450	40.9					237	4073	0.13	57.1	0.868	1.238		0.720
Song et al. [112]	150	450	40.9					237	4073	0.26	78.4	1.415	1.074		0.625
Song et al. [112]	150	450	40.9					237	4073	0.39	100.4	1.894	1.164		0.677
Stanton and Owen [30]	152.5	305	49.0		262[t]	4200[t]		238	4200	0.165	68.97	1.0			
Stanton and Owen [30]	152.5	305	49.0		262[t]	4200[t]		238	4200	0.330	103.45	1.8			
Stanton and Owen [30]	152.5	305	49.0		262[t]	4200[t]		238	4200	0.660	151.72	2.3			
Stanton and Owen [30]	152.5	305	49.0		262[t]	4200[t]		238	4200	0.990	213.79[s]	3.7			
Stanton and Owen [30]	152.5	305	49.0		262[t]	4200[t]		238	4200	1.320	275.86[s]	4.6			
Suter and Pinzelli [113]	150	300	44.7					240	3800	0.234	68.31	0.856			
Tamuzs et al. [114]	150	300	20.8	0.241	231	2390		234	4500	0.34	37.49[s]	1.076[a]	0.316	0.305^	0.164^
Tamuzs et al. [114]	150	300	20.8	0.241	231	2390		234	4500	0.34	42.26[s]	1.321[a]	0.551	0.533	0.287^
Tamuzs et al. [114]	150	300	48.8	0.251	231	2390		234	4500	0.34	72.08	0.806	0.449	0.434^	0.233^
Tamuzs et al. [114]	150	300	48.8	0.251	231	2390		234	4500	0.34	72.55	0.902	0.373	0.361^	0.194^
Thériault et al. [116]	51	102	18			549		230	3481	0.165	70				
Thériault et al. [116]	152	304	37			549		230	3481	0.330	64				
Thériault et al. [116]	304	608	37			549		230	3481	0.660	66				
Valdmanis et al. [27]	150	300	40.0	0.17	200.5	1906	0.17	234	4500	0.17	66.0	0.63	0.89	0.936^	0.463^
Valdmanis et al. [27]	150	300	40.0	0.17	231.0	2389	0.34	234	4500	0.34	87.2	1.07	0.84	0.812	0.437^
Valdmanis et al. [27]	150	300	40.0	0.17	236.0	2661	0.51	234	4500	0.51	96.0	1.36	0.69	0.612	0.359^

Valdmanis et al. [27]	150	300	44.3	0.17	200.5	1906	0.17	234	4500	0.17	73.3	0.58	0.74	0.778	0.385^
Valdmanis et al. [27]	150	300	44.3	0.17	231.0	2389	0.34	234	4500	0.34	82.6	0.54[a]	0.43	0.416^	0.224^
Valdmanis et al. [27]	150	300	44.3	0.17	236.0	2661	0.51	234	4500	0.51	115.1	0.94	0.78	0.692	0.406^
Vincent and Ozbakkaloglu [117]	152	305	35.5					240	3800	0.117	44.0	0.77	1.20		0.758
Vincent and Ozbakkaloglu [117]	152	305	35.5					240	3800	0.117	43.9	0.82	1.10		0.695
Vincent and Ozbakkaloglu [117]	152	305	35.5					240	3800	0.117	43.1	0.82	1.10		0.695
Vincent and Ozbakkaloglu [117]	152	305	38.0					240	3800	0.234	63.5	1.51	1.17		0.739
Vincent and Ozbakkaloglu [117]	152	305	38.0					240	3800	0.234	66.1	1.65	1.17		0.739
Vincent and Ozbakkaloglu [117]	152	305	36.1					240	3800	0.234	58.6	1.27	1.11		0.701
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.165	53.8		1.24	0.622	0.821
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.165	61.2		1.24	0.622	0.821
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.165	52.3		1.24	0.622	0.821
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.330	88.2		1.32	0.662	0.874
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.330	85.6		1.32	0.662	0.874
Wang and Wu [33]	150	300	30.9	0.24	219[t]	4364[t]		230.5	3482	0.330	80.6		1.32	0.662	0.874
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.165	68.0		1.57	0.935^	1.032^
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.165	69.2		1.57	0.935^	1.032^
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.165	66.5		1.57	0.935^	1.032^
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.330	100.0		1.56	0.929^	1.025^
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.330	94.9		1.56	0.929^	1.025^
Wang and Wu [33]	150	300	52.1	0.27	225.7[t]	3788[t]		230	3500	0.330	103		1.56	0.929^	1.025^
Watanabe et al. [28]	100	200	30.2		224.6[t]	2716[t]		235	3432	0.167	46.6	1.51	0.94	0.777	0.644
Watanabe et al. [28]	100	200	30.2		224.6[t]	2873[t]		235	3432	0.501	87.2	3.11	0.82	0.641	0.561
Watanabe et al. [28]	100	200	30.2		224.6[t]	2658[t]		235	3432	0.668	104.6	4.15	0.76	0.642	0.520
Wu and Jiang [121]	150	300	28.7		254	4192	0.167	230	3400	0.167	59.34	2.534[a]			
Wu and Jiang [121]	150	300	28.7		254	4192	0.167	230	3400	0.167	54.82	2.140[a]			
Wu and Jiang [121]	150	300	30.1		254	4192	0.334	230	3400	0.334	88.14[s]	3.887[a]			
Wu and Jiang [121]	150	300	30.1		254	4192	0.334	230	3400	0.334	90.40[s]	3.798[a]			
Wu and Jiang [24]	150	300	20.6		242	4441	0.167	242	4059	0.167	50.35		1.41	0.768	0.841
Wu and Jiang [24]	150	300	20.6		242	4441	0.167	242	4059	0.167	52.95		1.56	0.850^	0.930^
Wu and Jiang [24]	150	300	20.6		242	4441	0.167	242	4059	0.167	53.23		1.43	0.779	0.853
Wu and Jiang [24]	150	300	20.6		242	4441	0.334	242	4059	0.334	83.72[s]		1.84	1.003^	1.097^
Wu and Jiang [24]	150	300	20.6		242	4441	0.334	242	4059	0.334	86.55[s]		1.86	1.014^	1.109^
Wu and Jiang [24]	150	300	20.6		242	4441	0.334	242	4059	0.334	88.76[s]		2.26	1.232^	1.347^
Wu and Jiang [24]	150	300	20.6		242	4441	0.501	242	4059	0.501	110.20[s]		1.79	0.975^	1.067^
Wu and Jiang [24]	150	300	20.6		242	4441	0.501	242	4059	0.501	108.11[s]		1.37	0.747	0.817
Wu and Jiang [24]	150	300	20.6		242	4441	0.501	242	4059	0.501	109.97[s]		1.73	0.943^	1.031^
Wu and Jiang [24]	150	300	20.6		242	4441	0.668	242	4059	0.668	127.74[s]		1.92	1.046^	1.145^
Wu and Jiang [24]	150	300	20.6		242	4441	0.668	242	4059	0.668	132.54[s]		1.85	1.008^	1.103^
Wu and Jiang [24]	150	300	20.6		242	4441	0.668	242	4059	0.668	140.58[s]		1.71	0.932^	1.020^
Wu and Jiang [24]	150	300	24.8		242	4441	0.167	242	4059	0.167	61.66		1.81	0.986^	1.079^
Wu and Jiang [24]	150	300	24.8		242	4441	0.167	242	4059	0.167	56.68		1.56	0.850	0.930^
Wu and Jiang [24]	150	300	24.8		242	4441	0.167	242	4059	0.167	56.91		2.04	1.112^	1.216^
Wu and Jiang [24]	150	300	24.8		242	4441	0.334	242	4059	0.334	87.23[s]		1.87	1.019^	1.115^
Wu and Jiang [24]	150	300	24.8		242	4441	0.334	242	4059	0.334	87.80[s]		1.71	0.932^	1.020^
Wu and Jiang [24]	150	300	24.8		242	4441	0.334	242	4059	0.334	88.25[s]		1.65	0.899^	0.984^
Wu and Jiang [24]	150	300	24.8		242	4441	0.501	242	4059	0.501	118.63[s]		1.73	0.943^	1.031^
Wu and Jiang [24]	150	300	24.8		242	4441	0.501	242	4059	0.501	114.67[s]		1.75	0.954^	1.043^
Wu and Jiang [24]	150	300	24.8		242	4441	0.501	242	4059	0.501	114.55[s]		2	1.090^	1.192^
Wu and Jiang [24]	150	300	24.8		242	4441	0.668	242	4059	0.668	133.79		1.36	0.741	0.811
Wu and Jiang [24]	150	300	24.8		242	4441	0.668	242	4059	0.668	135.03		1.44	0.785	0.859
Wu and Jiang [24]	150	300	24.8		242	4441	0.668	242	4059	0.668	139.05		1.51	0.823	0.900^
Wu and Jiang [24]	150	300	36.7		242	4441	0.167	242	4059	0.167	61.89		1.52	0.828	0.906^
Wu and Jiang [24]	150	300	36.7		242	4441	0.167	242	4059	0.167	71.56		1.91	1.041^	1.139^
Wu and Jiang [24]	150	300	36.7		242	4441	0.167	242	4059	0.167	65.51		1.6	0.872	0.954^
Wu and Jiang [24]	150	300	36.7		242	4441	0.334	242	4059	0.334	92.38		1.6	0.872	0.954^
Wu and Jiang [24]	150	300	36.7		242	4441	0.334	242	4059	0.334	97.64		1.68	0.915^	1.002^
Wu and Jiang [24]	150	300	36.7		242	4441	0.334	242	4059	0.334	95.66		1.71	0.932^	1.020^
Wu and Jiang [24]	150	300	36.7		242	4441	0.501	242	4059	0.501	121.23		1.52	0.828	0.906^
Wu and Jiang [24]	150	300	36.7		242	4441	0.501	242	4059	0.501	128.64[s]		1.54	0.839	0.918^
Wu and Jiang [24]	150	300	36.7		242	4441	0.501	242	4059	0.501	116.53		1.7	0.926^	1.014^
Wu and Jiang [24]	150	300	36.7		242	4441	0.668	242	4059	0.668	141.77		1.62	0.883	0.966^
Wu et al. [31]	150	300	23.0		243[t]	4234[t]		230	3400	0.167	45.0				
Wu et al. [35]	150	300	23.1	0.260	243[t]	4234[t]		230	3400	0.167	44.9	2.01			
Wu et al. [35]	150	300	23.1	0.267	243[t]	4234[t]		230	3400	0.167	45.9	2.15			
Wu et al. [35]	150	300	23.1	0.267	243[t]	4234[t]		230	3400	0.334	82.0[s]	3.75			
Xiao and Wu [15]	152	305	33.7		105	1577	0.381				47.9	1.20	0.84	0.559	
Xiao and Wu [15]	152	305	33.7		105	1577	0.381				49.7	1.40	1.15	0.766	
Xiao and Wu [15]	152	305	33.7		105	1577	0.381				49.4	1.24	0.87	0.579	
Xiao and Wu [15]	152	305	33.7		105	1577	0.762				64.6	1.65	0.91	0.606	
Xiao and Wu [15]	152	305	33.7		105	1577	0.762				75.2	2.25	1.00	0.666	
Xiao and Wu [15]	152	305	33.7		105	1577	0.762				71.8	2.16	1.00	0.666	
Xiao and Wu [15]	152	305	33.7		105	1577	1.143				82.9	2.45	0.82	0.546	
Xiao and Wu [15]	152	305	33.7		105	1577	1.143				86.2	3.03[a]	0.90	0.599	
Xiao and Wu [15]	152	305	33.7		105	1577	1.143				95.4				
Xiao and Wu [15]	152	305	43.8		105	1577	0.381				54.7	0.98	0.81	0.539	
Xiao and Wu [15]	152	305	43.8		105	1577	0.381				52.1	0.47	0.76	0.506	
Xiao and Wu [15]	152	305	43.8		105	1577	0.381				48.7	0.37[a]	0.28	0.186^	
Xiao and Wu [15]	152	305	43.8		105	1577	0.762				84.0	1.57	0.92	0.613	
Xiao and Wu [15]	152	305	43.8		105	1577	0.762				79.2	1.37	1.00	0.666	
Xiao and Wu [15]	152	305	43.8		105	1577	0.762				85.0	1.66	1.01	0.672	
Xiao and Wu [15]	152	305	43.8		105	1577	1.143				96.5	1.74	0.79	0.526	
Xiao and Wu [15]	152	305	43.8		105	1577	1.143				92.6	1.68	0.71	0.473^	
Xiao and Wu [15]	152	305	43.8		105	1577	1.143				94.0	1.75	0.84	0.559	
Xiao and Wu [15]	152	305	55.2		105	1577	0.381				57.9	0.69	0.70	0.466^	
Xiao and Wu [15]	152	305	55.2		105	1577	0.381				62.9	0.48	0.62	0.413^	
Xiao and Wu [15]	152	305	55.2		105	1577	0.381				58.1	0.49	0.19	0.127^	
Xiao and Wu [15]	152	305	55.2		105	1577	0.762				74.6	1.21	0.74	0.493	
Xiao and Wu [15]	152	305	55.2		105	1577	0.762				77.6	0.81	0.83	0.553	
Xiao and Wu [15]	152	305	55.2		105	1577	0.762				77.0				
Xiao and Wu [15]	152	305	55.2		105	1577	1.143				106.5	1.43	0.76	0.506	
Xiao and Wu [15]	152	305	55.2		105	1577	1.143				108.0	1.45	0.85	0.566	

Xiao and Wu [15]	152	305	55.2		105	1577	1.143				103.3	1.18	0.70	0.466^	
Yan et al. [123]	305	610	15.0	0.200	86.9	1220	1				37.8	1.1			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	5.840				125.80	2.813			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	5.840				126.39	2.914			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	5.840				127.01	2.801			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	3.504				83.05	1.492			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	3.504				88.68	1.621			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	2.336				64.78	1.155			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	2.336				62.09	1.112			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	2.336				67.47	1.199			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	1.168				45.95	0.647			
Youssef et al. [53]	406.4	812.8	29.4	0.24	103.84	1246	1.168				45.78	0.615			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	2.336				124.08	2.847			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	2.336				129.17	2.792			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	2.336				138.72	2.844			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.752				94.24	1.996			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.752				95.02	1.999			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.752				100.52	1.979			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.168				85.96	1.706			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.168				88.14	2.003			
Youssef et al. [53]	152.4	304.8	44.6	0.20	103.84	1246	1.168				84.23	1.996			
Zhang et al. [124]	150	300	34.3		$91^{p,m}$	$753^{p,m}$	1	240	3800	0.33	59.4	2.1			

p *denotes fiber tensile strength and elastic modulus are given in N/mm-ply*
t *denotes FRP properties calculated based on total nominal ply thickness of fiber sheet*
m *denotes FRP material properties that differ significantly from the reference properties of the corresponding material*
d *denotes ultimate axial stress values that are lower than the unconfined concrete strength*
s *denotes inconsistent axial stress when compared with overall trend in the database*
a *denotes inconsistent axial strain when compared with overall trend in the database*
^ *denotes inconsistent k_ε values when compared with overall trend in the database*

Table 4. Test database of GFRP-wrapped concrete specimens

Paper	Specimen Dimensions		Concrete Properties		FRP Properties			Fiber Properties			Measured Ultimate Conditions			Hoop Rupture Strain Reduction Factors	
	D (mm)	H (mm)	f'_{co} (MPa)	ε_{co} (%)	E_{frp} (GPa)	f_{frp} (MPa)	t_{frp} (mm)	E_f (GPa)	f_f (MPa)	t_f (mm)	f'_{cc} (MPa)	ε_{cu} (%)	$\varepsilon_{h,rup}$ (%)	$k_{\varepsilon,frp}$	$k_{\varepsilon,f}$
Aire et al. [56]	150	300	42					65	3000	0.149	41[s]	0.73[a]	0.55		0.119^
Aire et al. [56]	150	300	42					65	3000	0.447	61[s]	1.74[a]	1.3		0.282^
Aire et al. [56]	150	300	42					65	3000	0.894	85[s]	2.5[a]	1.1		0.238^
Abdollahi et al. [54]	150	300	14.8	0.24	26.49	537	0.508	24.59	504		30.0	1.85			
Abdollahi et al. [54]	150	300	25.1	0.23	26.49	537	0.508	24.59	504		34.2	1.40			
Abdollahi et al. [54]	150	300	41.7	0.28	26.49	537	0.508	24.59	504		51.9	0.43[a]			
Abdollahi et al. [54]	150	300	25.1	0.23	26.49	537	1.016	24.59	504		55.5	1.96			
Abdollahi et al. [54]	150	300	25.1	0.23	26.49	537	2.032	24.59	504		83.3[s]	2.77			
Ahmad et al. [55]	102	203	39.0		48.3	2070	0.88				115.3				
Ahmad et al. [55]	102	203	50.5		48.3	2070	0.88				135.1				
Almusallam [58]	150	300	47.7	0.308	27	540	1.3				56.7	1.485	0.849	0.425^	
Almusallam [58]	150	300	47.7	0.308	27	540	3.9				100.1	2.723	0.800	0.400^	
Almusallam [58]	150	300	50.8	0.294	27	540	1.3				55.5	0.970	1.007	0.504	
Almusallam [58]	150	300	50.8	0.294	27	540	3.9				90.8	0.970	0.802	0.401^	
Au and Buyukozturk [59]	150	375	24.2	0.360	26.1	575	1.2				43.8	2.230	1.480	0.672	
Berthet et al. [61]	160	320	25					74	2500	0.330	42.8	1.698	1.655		0.490^
Berthet et al. [61]	160	320	25					74	2500	0.330	42.3	1.687	1.643		0.486^
Berthet et al. [61]	160	320	25					74	2500	0.330	43.1	1.711	1.671		0.495^
Berthet et al. [61]	160	320	40					74	2500	0.220	44.8	0.526	1.369		0.405^
Berthet et al. [61]	160	320	40					74	2500	0.220	46.3	0.467[a]	1.246		0.369^
Berthet et al. [61]	160	320	40					74	2500	0.220	49.8	0.496[a]	1.075		0.318^
Berthet et al. [61]	160	320	40					74	2500	0.330	50.8	0.632[a]	0.900		0.266^
Berthet et al. [61]	160	320	40					74	2500	0.330	50.8	0.582[a]	1.281		0.379^
Berthet et al. [61]	160	320	40					74	2500	0.330	51.8	0.635[a]	1.197		0.354^
Berthet et al. [61]	160	320	40					74	2500	0.550	66.7	1.050	1.546		0.458^
Berthet et al. [61]	160	320	40					74	2500	0.550	68.2	1.240	1.817		0.538
Berthet et al. [61]	160	320	40					74	2500	0.550	67.7	1.168	1.582		0.468^
Berthet et al. [61]	160	320	52					74	2500	0.495	64.7	0.529[a]	1.190		0.352^
Berthet et al. [61]	160	320	52					74	2500	0.495	75.1	1.132	1.265		0.374^
Berthet et al. [61]	160	320	52					74	2500	0.495	76.1	1.132	1.274		0.377^
Bullo [64]	150	300	32.54	0.248				65	1700	0.46	72.43	3.727[a]	2.145		0.820
Bullo [64]	150	300	32.54	0.248				65	1700	0.46	73.56	3.928[a]	2.171		0.830
Bullo [64]	150	300	32.54	0.248				65	1700	0.46	75.83	2.853	2.048		0.783
Bullo [64]	150	300	32.54	0.248				65	1700	1.15	118.84	4.280	1.961		0.750
Bullo [64]	150	300	32.54	0.248				65	1700	1.15	130.15[s]	4.038	1.918		0.733
Bullo [64]	150	300	32.54	0.248				65	1700	1.15	135.81[s]	4.844	1.816		0.694
Comert et al. [67]	150	300	39					65	1700	0.56	64	2.3			
Comert et al. [67]	150	300	39					65	1700	0.56	61	2.1			
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	1.25				59.1	1.35	2.020	0.874^	
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	1.25				59.8	1.15	2.143	0.928^	
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	2.5				88.9	2.21	2.032	0.880^	
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	2.5				88.0	2.21	2.114	0.915^	
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	3.75				113.2	2.85	2.112	0.914^	
Cui and Sheikh [68]	152	305	47.8	0.222	22	508.2	3.75				112.5	2.80	2.110	0.913^	
Demers and Neale [69]	152	305	32.2		10.5[p]	220[p]	1				31.0[d]				
Demers and Neale [69]	152	305	32.2		10.5[p]	220[p]	1				30.8[d]				
Demers and Neale [69]	152	305	32.2		10.5[p]	220[p]	3				48.3	2.04			
Demers and Neale [69]	152	305	32.2		10.5[p]	220[p]	3				48.3	1.97			
Green et al. [73]	152	305	54.0					8.8[p]	182[p]	2	62				
Harries and Carey [8]	152	305	31.8	0.28	4.9[p]	75[p]	3	10.3[p]	154[p]		37.3	0.65	1.216	0.794	0.813
Harries and Carey [8]	152	305	31.8	0.28	4.9[p]	75[p]	9	10.3[p]	154[p]		53.2[S]	0.95[a]	1.438	0.939^	0.962^
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	1	10.3[p]	154[p]		36.8	0.44			
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	2	10.3[p]	154[p]		36.6	0.40			
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	3	10.3[p]	154[p]		36.6	0.50	1.20	0.784	0.803
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	6	10.3[p]	154[p]		37.6	0.57[a]	1.03	0.673	0.689
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	9	10.3[p]	154[p]		46.7	0.68[a]	1.11	0.725	0.742
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	12	10.3[p]	154[p]		50.2	0.82[a]	1.09	0.712	0.729
Harries and Kharel [75]	152	305	32.1	0.28	4.9[p]	75[p]	15	10.3[p]	154[p]		60	0.87[a]	1.11	0.725	0.742
Jiang and Teng [32]	152	305	33.1	0.309	80.1[t]	1826[t]				0.17	42.4	1.303	2.08	0.912^	
Jiang and Teng [32]	152	305	33.1	0.309	80.1[t]	1826[t]				0.17	41.6	1.268	1.758	0.771	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.17	40.5	0.813	1.523	0.668	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.17	40.5	1.063	1.915	0.84	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.34	52.8	1.203	1.639	0.719	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.34	55.2	1.254	1.799	0.789	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.51	64.6	1.554	1.594	0.699	
Jiang and Teng [32]	152	305	45.9	0.243	80.1[t]	1826[t]				0.51	65.9	1.904	1.940	0.851	
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	1.27	56.2		1.849	0.795	0.923^
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	1.27	51.9	1.315	1.442	0.62	0.72
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	1.27	58.3	1.459	1.885	0.811	0.941^
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	2.54	75.7	2.457	1.762	0.758	0.879^
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	2.54	77.3	2.188	1.674	0.72	0.836
Lam and Teng [18]	152	305	38.5	0.223	21.8[t]	506.9[t]		22.46	450	2.54	75.2		1.772	0.762	0.884^
Li et al. [87]	152.4	305	45.6		15.1	320.2	0.738	70	3000	0.4	49.4[s]				
Lin and Chen [38]	120	240	32.7		32.9	743.9	0.9				62.2				
Lin and Chen [38]	120	240	32.7		32.9	743.9	0.9				61.4				
Lin and Chen [38]	120	240	32.7		32.9	743.9	0.9				66.3				
Lin and Chen [38]	120	240	32.7		32.9	743.9	1.8				101.3				
Lin and Chen [38]	120	240	32.7		32.9	743.9	1.8				88.0				
Lin and Chen [38]	120	240	32.7		32.9	743.9	1.8				104.5				
Mandal et al. [92]	103	200	30.7	0.270	26.1	575	1.3				54.5	1.54[a]			
Mandal et al. [92]	105	200	30.7	0.270	26.1	575	2.6				79.3	2.75[a]			
Mandal et al. [92]	103	200	46.3	0.230	26.1	575	1.3				58.5	0.90[a]			
Mandal et al. [92]	105	200	46.3	0.230	26.1	575	2.6				83.8	1.48			
Mandal et al. [92]	103	200	54.5	0.240	26.1	575	1.3				63.5	0.32[a]			
Mandal et al. [92]	105	200	54.5	0.240	26.1	575	2.6				84.1	0.80[a]			

Mastrapa [10]	152.5	305	29.8		19.19	565	0.61	55.85	1800	0.330	33.7			
Mastrapa [10]	152.5	305	31.2		19.19	565	1.84	55.85	1800	0.991	67.5	3.01	2.26	0.767	0.701
Mastrapa [10]	152.5	305	31.2		19.19	565	1.84	55.85	1800	0.991	64.67	3.13	1.99	0.676	0.617
Mastrapa [10]	152.5	305	31.2		19.19	565	3.07	55.85	1800	1.651	91.01	5.27	1.83	0.621^	0.568^
Mastrapa [10]	152.5	305	31.2		19.19	565	3.07	55.85	1800	1.651	96.87	6.25[a]	1.80	0.611^	0.559^
Mastrapa [10]	152.5	305	37.2		19.19	586	4.06	55.85	1800	2.311	111.0				
Micelli et al. [93]	102	204	32.0	0.14				72	1520	0.35	51.6	1.25	1.25		0.592^
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.275	31.03	1.0			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.275	34.06	1.3			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.275	35.58	1.5			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.826	63.02	2.7			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.826	49.02	1.8			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	0.826	58.68	3.3			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	1.376	86.81	3.3			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	1.376	88.32	3.6			
Mirmiran et al. [9]	152.5	305	29.8					55.85	1800	1.376	93.63	3.8			
Mirmiran et al. [9]	152.5	305	31.2					55.85	1800	0.826	63.09	3.1			
Mirmiran et al. [9]	152.5	305	31.2					55.85	1800	0.826	65.43	3.1			
Mirmiran et al. [9]	152.5	305	31.2					55.85	1800	1.376	91.91	4.3			
Mirmiran et al. [9]	152.5	305	31.2					55.85	1800	1.376	89.01	5.0			
Modarelli et al. [96]	150	300	28.35	0.49	86	1957	0.23	65	1700	0.23	53.27	1.9[a]			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.3	72.59	3240	0.215	46.00	2.292[a]			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.3	72.59	3240	0.215	41.20	1.889			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	60.52	3.079			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	59.23	3.405[a]			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	59.77	2.744			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	60.16	2.887			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	69.02	3.100			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	55.75	2.489			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	0.6	72.59	3240	0.43	56.41	2.968			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	0.86	84.88	3.145			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	0.86	84.33	4.150			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	0.86	79.64	4.100			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	1.72	106.87[s]	5.242[a]			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	1.72	104.94[s]	5.453[a]			
Nanni and Bradford [97]	150	300	36.3		52	583[m]	1.2	72.59	3240	1.72	107.91[s]	4.509[a]			
Shao et al. [108]	152	305	40.2		26.13	610	1.02	72.4	2275	0.358	49.6				
Shao et al. [108]	152	305	40.2		26.13	610	2.03	72.4	2275	0.716	71.4				
Silva and Rodrigues [111]	150	300	31.1	0.240	21.3	464.3	2.54	26.1	575	2.6	91.6	2.61	1.985	0.911	0.901
Silva and Rodrigues [111]	150	300	29.6	0.240	21.3	464.3	2.54	26.1	575	2.6	89.4	2.72			
Silva and Rodrigues [111]	150	300	31.1	0.240	21.3	464.3	2.54	26.1	575	2.6	87.5	2.28	1.890	0.867	0.858
Silva and Rodrigues [111]	150	450	31.1	0.240	21.3	464.3	2.54	26.1	575	2.6	91.9	2.34	1.865	0.856	0.847
Silva and Rodrigues [111]	150	450	29.6	0.240	21.3	464.3	2.54	26.1	575	2.6	89.8	2.32			
Silva and Rodrigues [111]	150	450	31.2	0.240	21.3	464.3	2.54	26.1	575	2.6	91.9	2.31	1.925	0.883	0.874
Silva and Rodrigues [111]	250	750	31.2	0.240	21.3	464.3	2.54	26.1	575	2.6	55.8	1.09	1.160	0.532^	0.527^
Suter and Pinzelli [113]	150	300	44.7					73	2300	0.308	52.69	0.232[a]			
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.17	37.2[d]	0.942	1.609	0.706	
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.17	38.8[d]	0.825	1.869	0.820	
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.34	54.6	2.130	2.040	0.895^	
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.34	56.3	1.825	2.061	0.904^	
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.51	65.7	2.558	1.955	0.858	
Teng et al. [115]	152.5	305	39.6	0.263	80.1[t]	1826[t]				0.51	60.9	1.792	1.667	0.731	
Thériault et al. [116]	152	304	37			642		27.6	552	3.9	90				
Thériault et al. [116]	51	102	18			642		27.6	552	1.3	64				
Wong et al. [34]	152.5	305	46.7	0.287	80.1[t]	1826[t]				0.34	58.0	1.77			
Wong et al. [34]	152.5	305	36.7	0.274	80.1[t]	1826[t]				0.34	53.1	1.53			
Wong et al. [34]	152.5	305	36.5	0.256	80.1[t]	1826[t]				0.34	53.8	1.54			
Wong et al. [34]	152.5	305	36.5	0.256	80.1[t]	1826[t]				0.51	63.1	2.15			
Wu et al. [31]	150	300	23.0		80.5[t]	1794[t]		73	1500	0.354	45.0				
Wu et al. [35]	150	300	23.1	0.267	80.5[t]	1794[t]		73	1500	0.354	46.4	2.49			
Wu et al. [35]	150	300	23.1	0.267	80.5[t]	1794[t]		73	1500	0.354	45.0	2.36			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	7.267				70.77	1.527[a]			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	7.267				71.78	1.445[a]			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	7.267				76.78	1.387[a]			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	4.472				49.53	1.345			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	4.472				54.90	1.003			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	4.472				61.19	1.189			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	3.354				49.30	0.971			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	3.354				51.19	0.897			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	3.354				47.88	0.912			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	1.677				44.14	0.781			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	1.677				42.96	0.695			
Youssef et al. [53]	406.4	812.8	29.4	0.24	18.47	424.7	1.677				45.11	0.715			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	3.354				94.10	2.013			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	3.354				91.87	2.014			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	3.354				89.29	2.011			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	2.236				80.39	1.518			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	2.236				80.04	1.488			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	2.236				81.13	1.530			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	1.677				66.20	1.298			
Youssef et al. [53]	152.4	304.8	44.1	0.24	18.47	424.7	1.677				66.60	1.357			
Youssef et al. [53]	152.4	304.8	44.1	0.240	18.47	424.7	1.677				63.62	1.295			

p   *denotes fiber tensile strength and elastic modulus are given in N/mm-ply*
t   *denotes FRP properties calculated based on total nominal ply thickness of fiber sheet*
m   *denotes FRP material properties that differ significantly from the reference properties of the corresponding material*
d   *denotes ultimate axial stress values that are lower than the unconfined concrete strength*
a   *denotes inconsistent axial strain when compared with overall trend in the database*
^   *denotes inconsistent k_c values when compared with overall trend in the database*

Table 5. Test database of AFRP -wrapped concrete specimens

Paper	Specimen Dimensions		Concrete Properties		FRP Properties			Fiber Properties			Measured Ultimate Conditions			Hoop Rupture Strain Reduction Factors	
	D (mm)	H (mm)	f'_{co} (MPa)	ε_{co} (%)	E_{frp} (GPa)	f_{frp} (MPa)	t_{frp} (mm)	E_f (GPa)	f_f (MPa)	t_f (mm)	f'_{cc} (MPa)	ε_{cu} (%)	$\varepsilon_{h,rup}$ (%)	$k_{\varepsilon,frp}$	$k_{\varepsilon,f}$
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.169	61.4	2.33	3.16	0.975	1.053^
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.169	62.7	2.33	3.13	0.966	1.043^
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.169	55.8	2.07	3.21	0.991	1.070^
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.338	90.1	3.80[a]	2.89	0.892	0.963
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.338	88.3	3.45	3.05	0.941	1.017^
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.338	83.3	3.68[a]	2.96	0.914	0.987
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.507	113.2	4.39	2.74	0.846	0.913
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.507	116.3	4.6[a]	2.46	0.759	0.820
Dai et al. [40]	152	305	39.2		115.2[t]	3732[t]		78[f]	2400[f]	0.507	118	4.78	2.97	0.917	0.990
Nanni and Bradford [97]	150	300	35.6		62.2	1150	3.8	127.5	2640	2.16	192.21[s]	9.628[a]			
Nanni and Bradford [97]	150	300	35.6		62.2	1150	3.8	127.5	2640	2.16	186.35[s]	6.778[a]			
Ozbakkaloglu and Akin [39]	152	305	39					120	2900	0.4	69.2	2.32	1.71		0.684
Ozbakkaloglu and Akin [39]	152	305	39					120	2900	0.4	67.1	2.30	1.56		0.624
Ozbakkaloglu and Akin [39]	152	305	39					120	2900	0.6	87.6	3.11	1.84		0.736
Ozbakkaloglu and Akin [39]	152	305	39					120	2900	0.6	85.0	2.86	1.66		0.664
Rochette and Labossiére [104]	150	300	43		13.6	230	1.27				47.3	1.11	1.55	0.917	
Rochette and Labossiére [104]	150	300	43		13.6	230	2.56				58.9	1.47	1.39	0.822	
Rochette and Labossiére [104]	150	300	43		13.6	230	3.86				71.0	1.69	1.33	0.786	
Rochette and Labossiére [104]	150	300	43		13.6	230	5.21				74.4	1.74	1.18	0.698	
Suter and Pinzelli [113]	150	300	44.7		31.2	602.2	0.7	120	2900	0.193	52.23	0.238[a]			
Suter and Pinzelli [113]	150	300	44.7		31.2	602.2	1.4	120	2900	0.386	76.85	1.136			
Suter and Pinzelli [113]	150	300	44.7		31.2	602.2	2.1	120	2900	0.579	103.45	1.300			
Suter and Pinzelli [113]	150	300	44.7		31.2	602.2	2.8	120	2900	0.772	136.89	1.784			
Suter and Pinzelli [113]	150	300	36.2		31.2	602.2	0.7	120	2900	0.193	48.15	0.664			
Suter and Pinzelli [113]	150	300	36.2		31.2	602.2	1.4	120	2900	0.386	75.30	1.006			
Suter and Pinzelli [113]	150	300	36.2		31.2	602.2	2.1	120	2900	0.579	98.46	1.304			
Suter and Pinzelli [113]	150	300	33.3		31.2	602.2	0.7	120	2900	0.193	50.28	0.790			
Suter and Pinzelli [113]	150	300	33.3		31.2	602.2	1.4	120	2900	0.386	78.59	1.302			
Suter and Pinzelli [113]	150	300	33.3		31.2	602.2	2.1	120	2900	0.579	103.90	1.502			
Suter and Pinzelli [113]	150	300	54		31.2	602.2	0.7	120	2900	0.193	61.56	0.342[a]			
Suter and Pinzelli [113]	150	300	54		31.2	602.2	1.4	120	2900	0.386	84.24	0.638[a]			
Suter and Pinzelli [113]	150	300	54		31.2	602.2	2.1	120	2900	0.579	111.24	0.816[a]			
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	109.0	3.73	2.54		1.016^
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	103.4	3.40	2.10		0.839
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	105.3	3.37	2.08		0.831
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	107.7	3.41	2.18		0.873
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	104.0	3.22	2.12		0.848
Vincent and Ozbakkaloglu [118]	152	305	49.4					120	2900	0.6	110.1	3.48	2.22		0.888
Wang and Wu [119]	70	210	51.63	0.248				118	2060	0.057	65.97	0.403[a]			
Wang and Wu [119]	70	210	51.63	0.248				118	2060	0.095	72.63	0.530[a]			
Wang and Wu [119]	70	210	51.63	0.248				118	2060	0.191	111.43	0.567[a]			
Wang and Wu [119]	105	315	50.64	0.244				118	2060	0.072	59.48	0.331[a]			
Wang and Wu [119]	105	315	50.64	0.244				118	2060	0.143	62.69	0.387[a]			
Wang and Wu [119]	105	315	50.64	0.244				118	2060	0.286	96.02	0.423[a]			
Wang and Wu [119]	194	582	44.92	0.260				118	2060	0.143	44.00	0.358[a]			
Wang and Wu [119]	194	582	44.92	0.260				118	2060	0.286	58.75	0.387[a]			
Wang and Wu [119]	194	582	44.92	0.260				118	2060	0.572	106.03	0.460[a]			
Wang and Wu [119]	70	210	29.37	0.203				118	2060	0.095	49.64	0.537[a]			
Wang and Wu [119]	70	210	29.37	0.203				118	2060	0.057	41.80	0.360[a]			
Wang and Wu [119]	70	210	29.37	0.203				118	2060	0.191	86.07[s]	0.953[a]			
Wang and Wu [119]	105	315	28.79	0.202				118	2060	0.072	41.20	0.363[a]			
Wang and Wu [119]	105	315	28.79	0.202				118	2060	0.143	47.77	0.583[a]			
Wang and Wu [119]	105	315	28.79	0.202				118	2060	0.286	87.42[s]	1.147			
Wang and Wu [119]	194	582	23.98	0.207				118	2060	0.143	33.84	0.383[a]			
Wang and Wu [119]	194	582	23.98	0.207				118	2060	0.286	43.90	0.513[a]			
Wang and Wu [119]	194	582	23.98	0.207				118	2060	0.572	80.86[s]	0.933[a]			
Wang and Zhang [120]	150	450	47.3					118	2060	0.572	84.30	1.619			
Wang and Zhang [120]	150	450	51.1					118	2060	0.572	88.65	1.446			
Watanabe et al. [28]	100	200	30.2	0.23	97.1[t]	2589[t]		73	3432	0.145	39.0	1.58	2.36	0.885	0.502^
Watanabe et al. [28]	100	200	30.2	0.23	87.3[t]	2707[t]		73	3432	0.290	68.5	4.74[a]	3.09	0.997	0.657
Watanabe et al. [28]	100	200	30.2	0.23	87.3[t]	2667[t]		73	3432	0.430	92.1	5.55[a]	2.65	0.867	0.564
Wu et al. [31]	150	300	23.0		115[t]	2324[t]		120	2000	0.286	53.0				
Wu et al. [35]	150	300	23.1	0.267	115[t]	2324[t]		120	2000	0.286	45.2	2.31			
Wu et al. [35]	150	300	23.1	0.267	115[t]	2324[t]		120	2000	0.286	50.7	3.03[a]			
Wu et al. [35]	150	300	23.1	0.267	115[t]	2324[t]		120	2000	0.286	53.7	3.29[a]			
Wu et al. [122]	100	300	46.4	0.255				118	2060	0.286	78.26	0.903			
Wu et al. [122]	100	300	46.4	0.255				118	2060	0.572	128.49	1.879			

t   *denotes FRP properties calculated based on total nominal ply thickness of fiber sheet*

f   *denotes fiber properties established to be inaccurate based on the analysis of the database*

a   *denotes inconsistent axial strain when compared with overall trend in the database*

^   *denotes inconsistent k_ε values when compared with overall trend in the database*

Table 6. Test database of HM and UHM CFRP-wrapped concrete specimens

Paper	Specimen Dimensions		Concrete Properties		FRP Properties			Fiber Properties			Measured Ultimate Conditions			Hoop Rupture Strain Reduction Factors	
	D (mm)	H (mm)	f'_{co} (MPa)	ε_{co} (%)	E_{frp} (GPa)	f_{frp} (MPa)	t_{frp} (mm)	E_f (GPa)	f_f (MPa)	t_f (mm)	f'_{cc} (MPa)	ε_{cu} (%)	$\varepsilon_{h,rup}$ (%)	$k_{\varepsilon,frp}$	$k_{\varepsilon,f}$
Bullo [64]	150	300	32.54	0.248				390	3000	0.165	52.63	0.833	0.467		0.607
Bullo [64]	150	300	32.54	0.248				390	3000	0.165	56.59	0.928	0.52		0.676
Bullo [64]	150	300	32.54	0.248				390	3000	0.165	61.11	0.833	0.421		0.547
Bullo [64]	150	300	32.54	0.248				390	3000	0.495	97.33	1.817	0.639		0.831^
Bullo [64]	150	300	32.54	0.248				390	3000	0.495	83.75	1.265	0.439		0.571
Bullo [64]	150	300	32.54	0.248				390	3000	0.495	100.16	1.687	0.539		0.701
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.16	67.5	1.11[a]	0.789		1.038^
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.16	64.1	1.03[a]	0.769		1.012^
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.33	84.2	1.33	0.642		0.845^
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.33	83.1	1.23	0.634		0.834^
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.49	99.7	1.56	0.603		0.793^
Cui and Sheikh [68]	152	305	45.7	0.243				436	3314	0.49	94.9	1.43	0.546		0.718^
Hosotani et al. [76]	200	600	41.7	0.34	439	3972	0.676	392	2943	0.652	90	1.5			
Lin and Chen [38]	120	240	32.7		157.54	770	0.5				51.0				
Lin and Chen [38]	120	240	32.7		157.54	770	0.5				49.6				
Lin and Chen [38]	120	240	32.7		157.54	770	1.0				77.3				
Lin and Chen [38]	120	240	32.7		157.54	770	1.0				68.9				
Rousakis [105]	150	300	25.2	0.311				377	4410	0.17	41.6	1.437	0.695		0.594
Rousakis [105]	150	300	25.2	0.311				377	4410	0.17	38.8	1.206	0.581		0.497
Rousakis [105]	150	300	25.2	0.311				377	4410	0.34	60.1	1.881	0.641		0.548
Rousakis [105]	150	300	25.2	0.311				377	4410	0.34	55.9	2.097	0.551		0.471
Rousakis [105]	150	300	25.2	0.311				377	4410	0.51	67.0	2.452	0.449		0.384
Rousakis [105]	150	300	25.2	0.311				377	4410	0.51	67.3	2.432	0.368		0.315
Rousakis [105]	150	300	47.4	0.308				377	4410	0.17	72.3	1.085	0.772		0.660
Rousakis [105]	150	300	47.4	0.308				377	4410	0.17	64.4	0.866	0.513		0.439
Rousakis [105]	150	300	47.4	0.308				377	4410	0.34	82.4	1.399	0.656		0.561
Rousakis [105]	150	300	47.4	0.308				377	4410	0.34	82.4	1.350	0.537		0.459
Rousakis [105]	150	300	47.4	0.308				377	4410	0.51	96.3	1.585	0.443		0.379
Rousakis [105]	150	300	47.4	0.308				377	4410	0.51	95.2	1.687	0.578		0.494
Rousakis [105]	150	300	51.8	0.298				377	4410	0.17	78.7	0.748	0.543		0.464
Rousakis [105]	150	300	51.8	0.298				377	4410	0.17	72.8	0.663	0.398		0.340
Rousakis [105]	150	300	51.8	0.298				377	4410	0.34	95.4	1.047	0.551		0.471
Rousakis [105]	150	300	51.8	0.298				377	4410	0.34	90.7	1.001	0.364		0.311
Rousakis [105]	150	300	51.8	0.298				377	4410	0.51	110.5	1.292	0.438		0.374
Rousakis [105]	150	300	51.8	0.298				377	4410	0.51	103.6	1.203	0.310		0.265^
Rousakis [105]	150	300	51.8	0.298				377	4410	0.85	112.7	1.593	0.289		0.247^
Rousakis [105]	150	300	51.8	0.298				377	4410	0.85	126.7	1.612	0.360		0.308
Matthys et al. [11]	150	300	34.9	0.21	480	1100		640	2650	0.235	41.3[s]	0.40	0.19	0.829^	0.459
Suter and Pinzelli [113]	150	300	44.7					640	2650	0.38	91.98	0.534			
Watanabe et al. [28]	100	200	30.2	0.23	628[t]	1579[t]		637	2452	0.14	41.7	0.57	0.23	0.916^	0.598
Watanabe et al. [28]	100	200	30.2	0.23	629[t]	1824[t]		637	2452	0.28	56.0	0.88	0.22	0.759^	0.572
Watanabe et al. [28]	100	200	30.2	0.23	576[t]	1285[t]		637	2452	0.42	63.3	1.30	0.22	0.987^	0.572
Wu et al. [31]	150	300	23.0		563[t]	2544[t]		540	1900	0.286	50.0				
Wu et al. [35]	150	300	23.1	0.267	563[t]	2544[t]		540	1900	0.286	50.5	1.27[a]			
Wu et al. [35]	150	300	23.1	0.267	563[t]	2544[t]		540	1900	0.286	48.9	1.20[a]			

t *denotes FRP properties calculated based on total nominal ply thickness of fiber sheet*

^ *denotes inconsistent k_ε values when compared with overall trend in the database*

Table 7. Test database of unbonded-wrap or tube encased concrete specimens

Paper	FRP type	Specimen Dimensions		Concrete Properties		FRP Properties			Fiber Properties			Measured Ultimate Conditions			Hoop Rupture Strain Reduction Factors	
		D (mm)	H (mm)	f'_{co} (MPa)	ε_{co} (%)	E_{frp} (GPa)	f_{frp} (MPa)	t_{frp} (mm)	E_f (GPa)	f_f (MPa)	t_f (mm)	f'_{cc} (MPa)	ε_{cu} (%)	$\varepsilon_{h,rup}$ (%)	$k_{\varepsilon,frp}$	$k_{\varepsilon,f}$
Hong and Kim [13]	CFRP[fm]	300	600	17.5		137	2058	2	235	3920		75.6	2.88[a]			
Hong and Kim [13]	CFRP[fm]	300	600	17.5		137	2058	3	235	3920		80.2[s]	2.23[a]			
Karantzikis et al. [84]	CFRP[ub]	200	350	12.1	0.22				230	3500	0.12	21.54	1.16			
Matthys et al. [11]	CFRP[ub]	150	300	34.9	0.21	200	2600	0.117	240	3900	0.117	42.2	0.72	1.08	0.831	0.665
Ozbakkaloglu and Vincent [14]	CFRP	74	152	43.0					240	3800	0.117	67.4	1.35	1.07		0.676
Ozbakkaloglu and Vincent [14]	CFRP	74	152	43.0					240	3800	0.117	71.0	1.44	1.32		0.834
Ozbakkaloglu and Vincent [14]	CFRP	74	152	43.0					240	3800	0.117	61.1	0.92	0.91		0.575
Ozbakkaloglu and Vincent [14]	CFRP	74	152	47.8					240	3800	0.117	60.9	0.84	0.83		0.524^
Ozbakkaloglu and Vincent [14]	CFRP	74	152	55.0					240	3800	0.117	56.5[d]	0.80	0.72		0.455^
Ozbakkaloglu and Vincent [14]	CFRP	74	152	55.0					240	3800	0.234	96.0	1.43	1.13		0.714
Ozbakkaloglu and Vincent [14]	CFRP	74	152	50.3					240	3800	0.234	98.1	1.71	0.95		0.600
Ozbakkaloglu and Vincent [14]	CFRP	74	152	52.0					240	3800	0.234	105.7	2.41	1.07		0.675
Ozbakkaloglu and Vincent [14]	CFRP	152	305	37.3					240	3800	0.117	42.0	0.79	1.20		0.758
Ozbakkaloglu and Vincent [14]	CFRP	152	305	34.6					240	3800	0.117	41.6	0.66	0.77		0.486^
Ozbakkaloglu and Vincent [14]	CFRP	152	305	35.5					240	3800	0.234	59.1	1.43	1.32		0.834
Ozbakkaloglu and Vincent [14]	CFRP	152	305	36.3					240	3800	0.234	60.9	1.53	1.36		0.859
Ozbakkaloglu and Vincent [14]	CFRP	152	305	37.3					240	3800	0.234	61.7	1.45	1.23		0.777
Ozbakkaloglu and Vincent [14]	CFRP	302	600	36.3					240	3800	0.234	38.6	0.80	1.08		0.682
Ozbakkaloglu and Vincent [14]	CFRP	302	600	36.3					240	3800	0.468	57.0	1.52	1.17		0.739
Harries and Carey [8]	GFRP[ub]	152	305	31.8	0.28	4.9[p]	75[p]	3	10.3[p]	154[p]		33.6		1.29	0.843	0.863^
Harries and Carey [8]	GFRP[ub]	152	305	31.8	0.28	4.9[p]	75[p]	9	10.3[p]	154[p]		48.4		1.13	0.738	0.756
Li et al. [88]	GFRP	150	300	47.5	0.4				73	1800	0.3	50.9	0.9	1.5		0.608
Li et al. [88]	GFRP	150	300	47.5	0.4				73	1800	0.3	85.7[s]	2.1	2.4		0.973^
Mastrapa [10]	GFRP[ub]	152.5	305	37.2		19.19	586	4.06	55.85	1800	2.311	112[s]				
Mastrapa [10]	GFRP[ub]	152.5	305	37.2		19.19	586	4.06	55.85	1800	2.311	110[s]				
Mastrapa [10]	GFRP[ub]	152.5	305	29.8		19.19	565	0.61	55.85	1800	0.330	26.68[d]	1.50	1.10	0.374^	0.341^
Mastrapa [10]	GFRP[ub]	152.5	305	31.2		19.19	565	1.84	55.85	1800	0.991	63.09	3.12	2.25	0.764	0.698
Mastrapa [10]	GFRP[ub]	152.5	305	31.2		19.19	565	1.84	55.85	1800	0.991	65.43	3.11	2.22	0.754	0.689
Mastrapa [10]	GFRP[ub]	152.5	305	31.2		19.19	565	3.07	55.85	1800	1.651	91.91	4.27	1.97	0.669	0.611
Mastrapa [10]	GFRP[ub]	152.5	305	31.2		19.19	565	3.07	55.85	1800	1.651	89.01	5.03	1.75	0.594	0.543
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.275	33.65	1.0			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.275	33.16	2.3[a]			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.275	33.23	2.0[a]			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.826	63.02	2.7			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.826	65.16	3.0			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	0.826	65.23	2.8			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	1.376	93.70	4.3			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	1.376	92.26	3.9			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	29.8					55.85	1800	1.376	96.46	4.4			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	31.2					55.85	1800	0.826	67.50	3.0			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	31.2					55.85	1800	0.826	64.68	3.1			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	31.2					55.85	1800	1.376	91.01	5.3			
Mirmiran et al. [9]	GFRP[ub]	152.5	305	31.2					55.85	1800	1.376	96.87	6.3[a]			
Park et al. [100]	GFRP	150	300	32		39.59	321	1				54.2	1.50[a]			
Park et al. [100]	GFRP	150	300	32		39.59	321	1				55.3				
Park et al. [100]	GFRP	150	300	32		39.59	321	1				56.7	1.70[a]			
Park et al. [100]	GFRP	150	300	54		56.12	530	3				95.5				
Park et al. [100]	GFRP	150	300	54		56.12	530	3				114.7	2.36			
Park et al. [100]	GFRP	150	300	54		56.12	530	3				111.7				
Park et al. [100]	GFRP	150	300	54		56.99	607	5				206.4	3.88			
Park et al. [100]	GFRP	150	300	54		56.99	607	5				198.9				
Park et al. [100]	GFRP	150	300	54		56.99	607	5				189.1				
Park et al. [100]	GFRP	150	450	54		56.12	530	3				115.3	3.14[a]			
Park et al. [100]	GFRP	150	450	54		56.12	530	3				113.4	3.42[a]			
Park et al. [100]	GFRP	150	450	54		56.12	530	3				108.5	3.64[a]			
Saafi et al. [12]	GFRP[fs]	152	435	35	0.25	32	450	0.8				52.8	1.90[a]			
Saafi et al. [12]	GFRP[fs]	152	435	35	0.25	34	505	1.6				66.0	2.47			
Saafi et al. [12]	GFRP[fs]	152	435	35	0.25	36	560	2.4				83.0	3.00			
Ozbakkaloglu and Vincent [14]	AFRP	100	200	37					120	2900	0.2	70.6	2.06	2.22		0.888
Ozbakkaloglu and Vincent [14]	AFRP	100	200	35.5					120	2900	0.2	65.5	1.75	2.08		0.832
Ozbakkaloglu and Vincent [14]	AFRP	100	200	34					120	2900	0.2	62.8	1.88	2.25		0.900
Ozbakkaloglu and Vincent [14]	AFRP[fm]	100	200	37.2					99	2930	0.3	89.1	3.10	2.11		0.713
Ozbakkaloglu and Vincent [14]	AFRP[fm]	100	200	37.2					99	2930	0.3	91.9	3.31	2.39		0.808
Ozbakkaloglu and Vincent [14]	AFRP[fm]	100	200	35.4					99	2930	0.3	86.7	3.04	2.21		0.747
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	104.6	3.15	2.19		0.876
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	107.9	3.55	2.42		0.968
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	106.3	3.47	2.38		0.952
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	109.9	3.01	2.11		0.843
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	109.9	3.18	2.33		0.930
Vincent and Ozbakkaloglu [118]	AFRP	152	305	49.4					120	2900	0.6	110.7	2.98	2.80		1.120^
Saafi et al. [12]	HM CFRP	152	435	35.0	0.25	367	3300[t]	0.11[t]				55	1.0			
Saafi et al. [12]	HM CFRP	152	435	35.0	0.25	390	3550[t]	0.23[t]				68	1.6			
Saafi et al. [12]	HM CFRP	152	435	35.0	0.25	415	3700[t]	0.55[t]				97	2.2			
Ozbakkaloglu and Vincent [14]	UHM CFRP	152	305	36.3					640	2650	0.190	46.4	0.28[a]	0.12		0.290
Ozbakkaloglu and Vincent [14]	UHM CFRP	152	305	36.3					640	2650	0.190	46.0	0.30[a]	0.11		0.266
Ozbakkaloglu and Vincent [14]	UHM CFRP	152	305	36.3					640	2650	0.190	43.3	0.25[a]	0.18		0.435
Matthys et al. [11]	UHM CFRP[ub]	150	300	34.9	0.21	420	1100[m]	0.235	640	2650	0.235	40.7[s]	0.36[a]	0.18	0.687	0.435

p — *denotes fiber tensile strength and elastic modulus are given in N/mm-ply*
t — *denotes FRP properties calculated based on total nominal ply thickness of fiber sheet*
m — *denotes FRP material properties that differ significantly from the reference properties of the corresponding material*
d — *denotes ultimate axial stress values that are lower than the unconfined concrete strength*
s — *denotes inconsistent axial stress when compared with overall trend in the database*
a — *denotes inconsistent axial strain when compared with overall trend in the database*
^ — *denotes inconsistent k_ε values when compared with overall trend in the database*
fm — *denotes tubes fabricated using automated manufacturing method*
fs — *denotes tubes suppiled by manufacturer*
ub — *denotes unbonded-wrap specimen*

Table 8. Average hoop rupture strain reduction factor (k_ε) with FRP type and confinement technique

Specimens	$k_{\varepsilon,f}$			$k_{\varepsilon,frp}$		
	Number	SD	Average	Number	SD	Average
All	201	0.135	0.675	150	0.125	0.709
All wrapped	186	0.134	0.675	146	0.126	0.707
CFRP wrapped	131	0.115	0.680	116	0.127	0.682
GFRP wrapped	25	0.084	0.793	23	0.059	0.803
AFRP wrapped	8	0.087	0.732	7	0.066	0.809
HM CFRP wrapped	22	0.115	0.493	-	-	-
UHM CFRP wrapped	-	-	-	-	-	-
All tube-encased	15	0.157	0.675	4	0.047	0.775
CFRP tube-encased	4	0.033	0.690	-	-	-
GFRP tube-encased	5	0.094	0.723	4	0.047	0.775
AFRP tube-encased	4	0.055	0.775	-	-	-
HM CFRP tube-encased	-	-	-	-	-	-
UHM CFRP tube-encased	2	0.051	0.326	-	-	-

Table 9. Variation of strength enhancement coefficients (k_1) with FRP type and confinement technique

Specimens	k_1		
	Number	R^2	*Average*
All	753	0.799	3.22
All wrapped	684	0.806	3.26
CFRP wrapped	426	0.870	3.67
GFRP wrapped	149	0.759	2.49
AFRP wrapped	67	0.889	3.30
HM CFRP wrapped	34	0.772	4.96
UHM CFRP wrapped	8	-	-
All tube-encased	69	0.759	2.94
CFRP tube-encased	14	0.907	2.87
GFRP tube-encased	36	0.731	2.92
AFRP tube-encased	12	0.811	2.95
HM CFRP tube-encased	3	-	-
UHM CFRP tube-encased	4	-	-

Table 10. Variation of strain enhancement coefficients (k_2) with FRP type and confinement technique

Specimens	All, k_2			AS, k_2			AFL, k_2			AML, k_2		
	Number	R^2	*Average*	Number	R^2	*Average*	Number	R^2	*Average*	Number	R^2	*Average*
All	511	0.786	0.271	53	0.583	0.270	179	0.831	0.297	215	0.723	0.261
All wrapped	462	0.753	0.266	50	0.564	0.271	134	0.809	0.296	215	0.723	0.261
CFRP wrapped	282	0.682	0.267	48	0.546	0.269	53	0.677	0.296	143	0.660	0.259
GFRP wrapped	109	0.820	0.262	-	-	-	40	0.719	0.281	60	0.765	0.249
AFRP wrapped	36	0.613	0.265	2	1.000	0.339	15	0.847	0.355	8	0.981	0.334
HM CFRP wrapped	30	0.688	0.320	-	-	-	26	0.714	0.320	4	0.863	0.321
UHM CFRP wrapped	5	-	-	-	-	-	-	-	-	-	-	-
All tube-encased	49	0.883	0.298	3	0.433	0.258	45	0.870	0.299	-	-	-
CFRP tube-encased	12	0.959	0.268	-	-	-	11	0.965	0.272	-	-	-
GFRP tube-encased	22	0.862	0.298	3	0.433	0.258	19	0.797	0.300	-	-	-
AFRP tube-encased	12	0.351	0.302	-	-	-	12	0.351	0.302	-	-	-
HM CFRP tube-encased	3	-	-	-	-	-	3	-	-	-	-	-
UHM CFRP tube-encased	-	-	-	-	-	-	-	-	-	-	-	-

Specimen instrumentation notes:
AS *denotes axial strains were determined from axial axial strain gauges mounted on the surface of the specimens at mid-height of specimens*
AFL *denotes axial strains were determined from LVDTs or dial gauges mounted on loading platens to measure deformations along the full height of specimens*
AML *denotes axial strains were determined from LVDTs or dial gauges mounted on the specimens to measure deformations within a gauge length along the height of specimens*

Table 11. Statistics of strength enhancement ratio (f'_{cc}/f'_{co}) predictions of best performing models

Model	Prediction of f'_{cc}/f'_{co}			
	Test data	Average Absolute Error (%)	Mean (%)	Standard Deviation (%)
Proposed model	753	11.2	99.6	13.7
Teng et al. [48]	753	11.8	98.8	14.5
Lam and Teng [3]	753	12.4	99.4	15.3
Wu and Zhou [52]	753	12.4	102.1	15.5
Wu and Wang [51]	753	12.7	101.4	15.7
Wei and Wu [50]	753	12.7	101.5	15.7
Al-Salloum and Siddiqui [45]	753	12.7	101.7	15.8
Realfonzo and Napoli [7]	753	12.7	103.2	15.8
Bisby et al. [5]	753	12.8	101.9	15.8
Jiang and Teng [32]	753	12.9	93.9	14.6

Table 12. Statistics of strain enhancement ratio ($\varepsilon_{cu}/\varepsilon_{co}$) predictions of best performing models

Model	Prediction of $\varepsilon_{cu}/\varepsilon_{co}$			
	Test data	Average Absolute Error (%)	Mean (%)	Standard Deviation (%)
Proposed model	511	21.7	100.5	27.2
Tamuzs et al. [43]	511	26.3	108.4	35.0
Wei and Wu [50]	511	28.7	98.0	35.8
Binici [46]	511	29.2	92.3	34.8
Jiang and Teng [42]	511	29.5	116.1	38.5
Youssef et al. [53]	511	30.0	112.5	39.0
Teng et al. [49]	511	30.2	117.6	39.0
Fahmy and Wu [47]	511	30.5	99.5	38.9
Teng et al. [48]	511	30.5	117.0	39.3
De Lorenzis and Tepfers [4]	511	31.3	77.9	27.9

List of Figure Captions

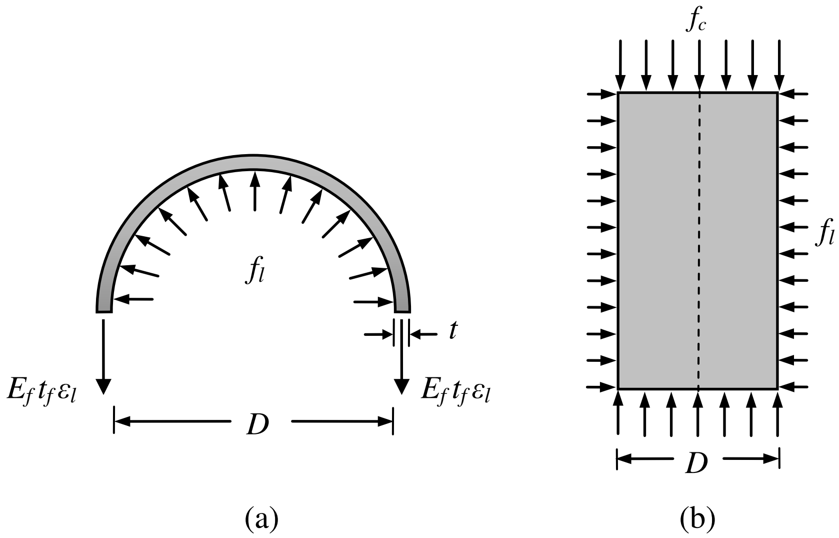


Figure 1. Confining action of FRP shell on concrete core: (a) FRP shell; (b) Concrete core

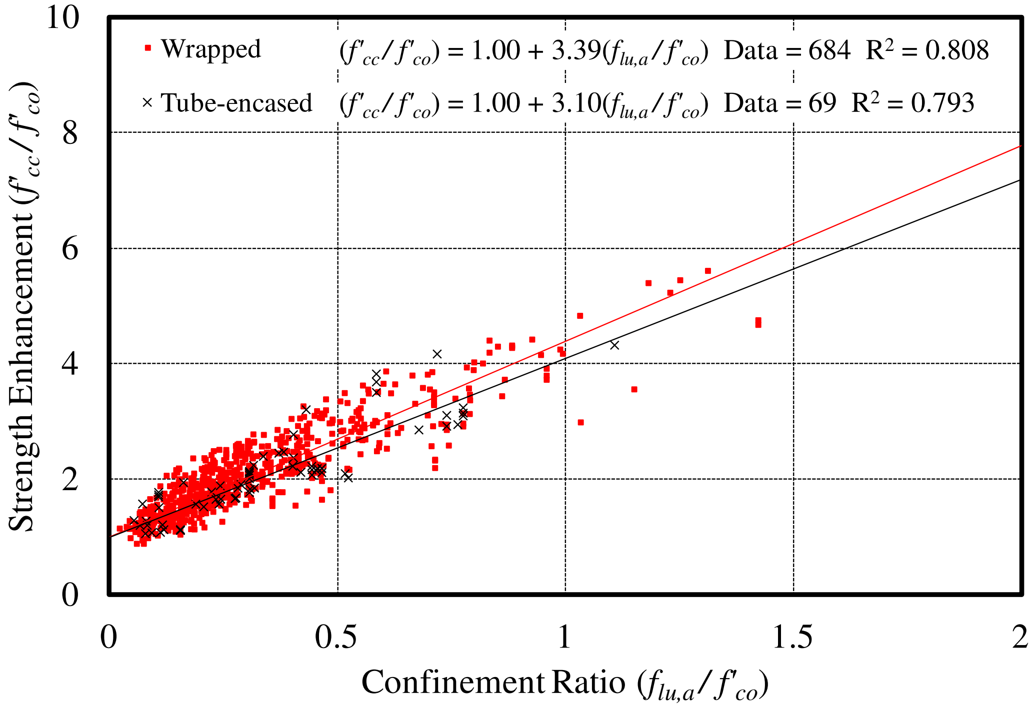


Figure 2. Variation of strength enhancement ratio with confinement ratio

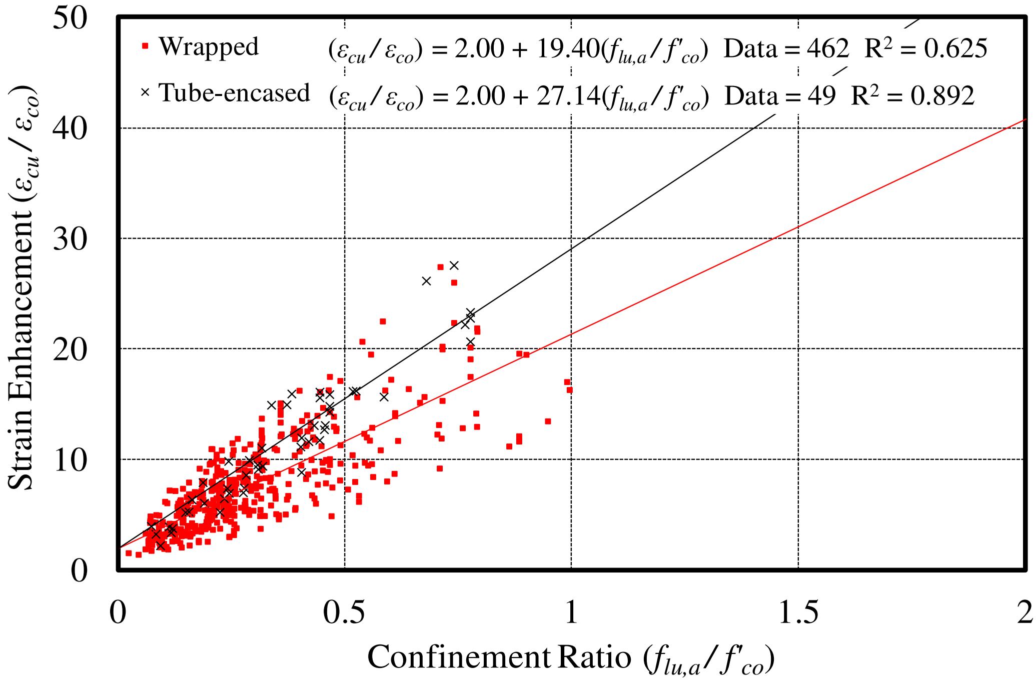
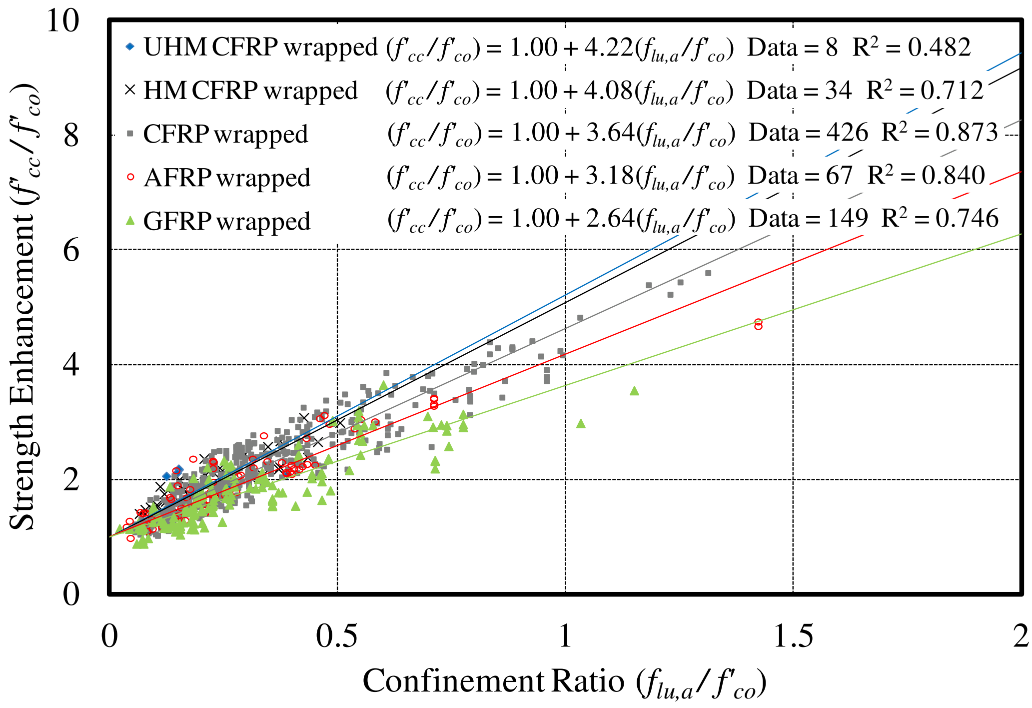
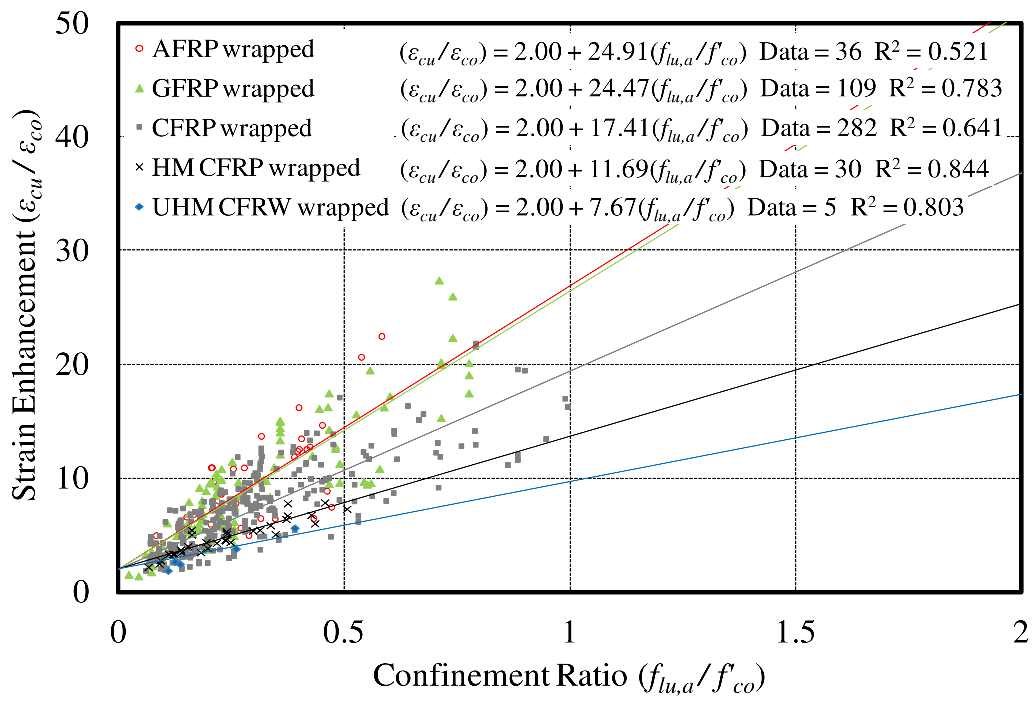


Figure 3. Variation of strain enhancement ratio with confinement ratio



(a)



(b)

Figure 4. Influence of FRP type on ultimate conditions of FRP-confined concrete: (a) compressive strength; (b) ultimate axial strain

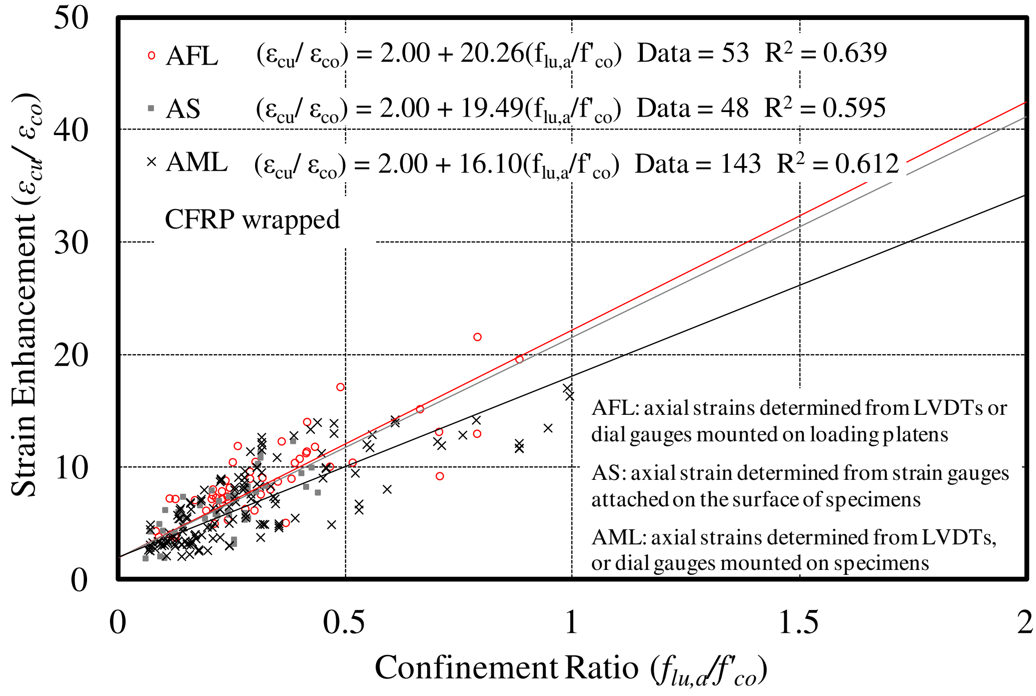
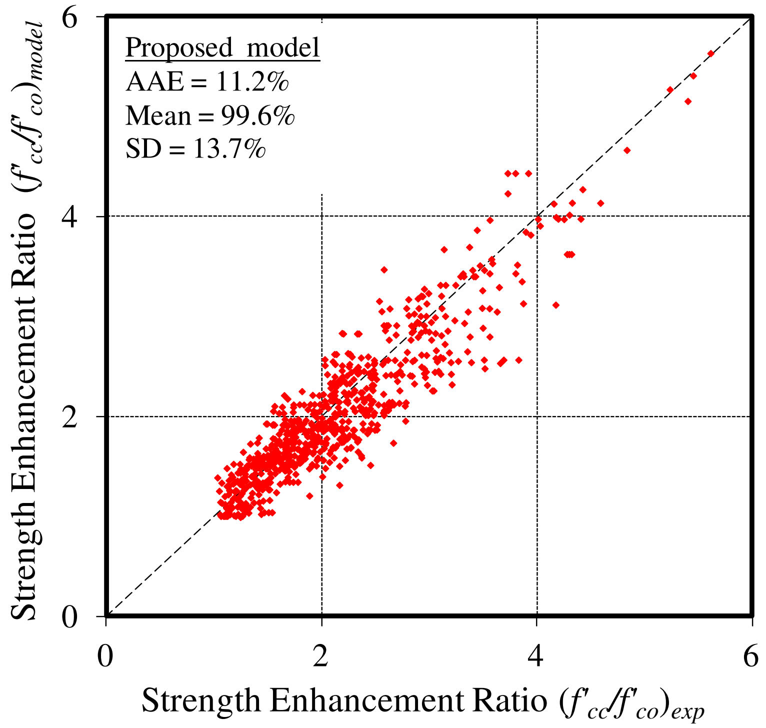


Figure 5. Influence of measurement method on ultimate strain of CFRP-wrapped concrete



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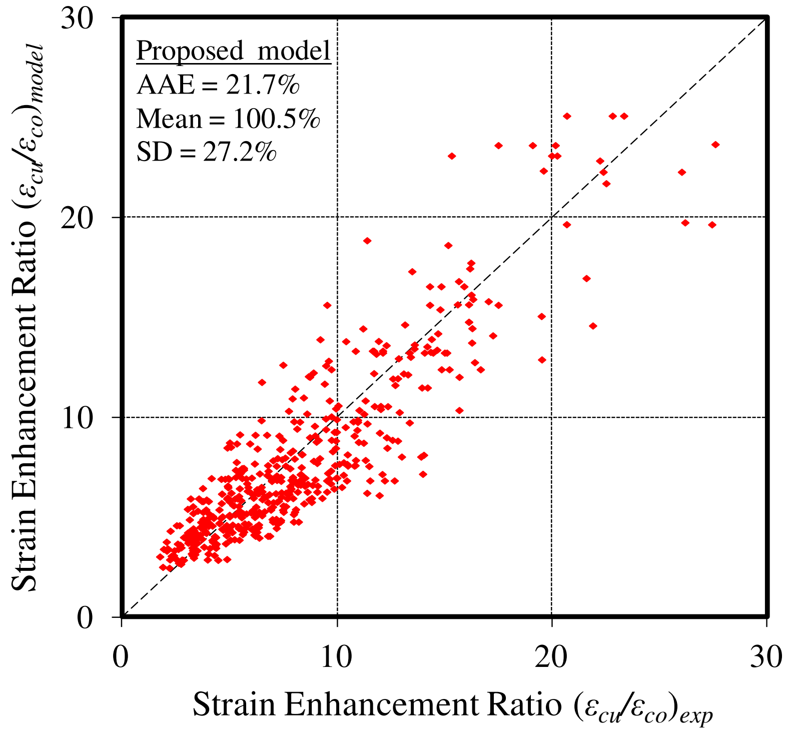
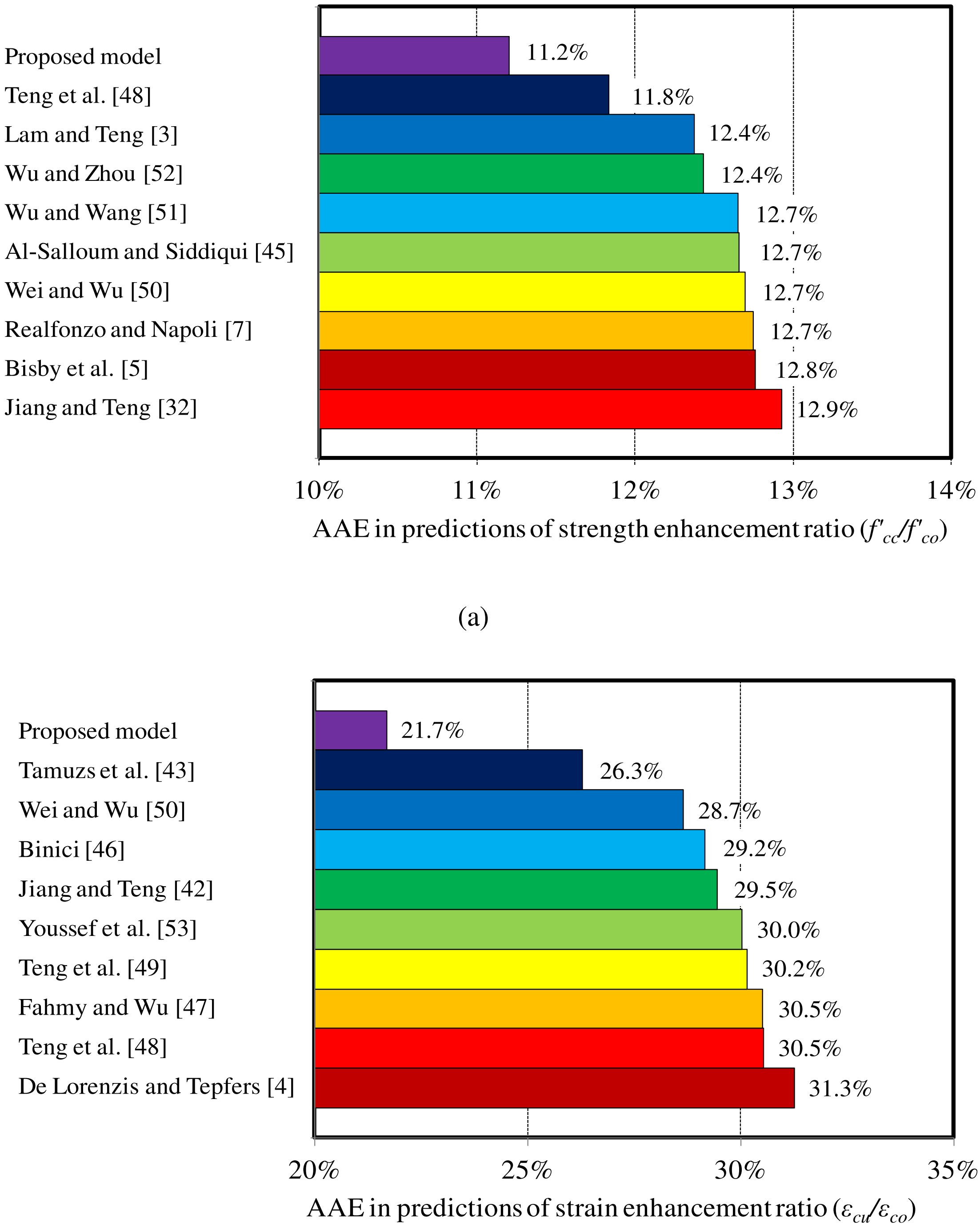


(b)

Figure 6. Comparison of model predictions of: (a) strength enhancement ratios (f'_{cc} / f'_{co}) and (b) strain enhancement ratios ($\varepsilon_{cu} / \varepsilon_{co}$) with experimental data



(a)

(b)

Figure 7. Average absolute error in model predictions of: (a) strength enhancement ratios (f'_{cc}/f'_{co}), (b) strain enhancement ratios ($\varepsilon_{cu}/\varepsilon_{co}$)