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Tensile Property Characterization of Fiber-Reinforced Polymer as an External Strengthening Material for Reinforced Concrete Columns

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Abstract

The strengthening of existing reinforced concrete columns requires materials that can improve structural performance without significantly increasing member dimensions and self-weight. Fiber-Reinforced Polymer (FRP) offers a lightweight and high-strength alternative; however, its tensile properties must be experimentally characterized to establish reliable material parameters for external strengthening applications. This study aims to characterize and compare the tensile properties of Tyfo SCH 7UP and SCH-7UP FRP materials for potential application in reinforced concrete column strengthening. Tensile testing was conducted at the BRIN Polymer Laboratory, Serpong, Indonesia, in accordance with ASTM D3039/D3039M-17, using five specimens from each material group. The test data were analyzed based on tensile strength, nominal strain at break, coefficient of variation, and statistical comparison using Welch's t-test and the Mann–Whitney test. The results showed that Tyfo SCH 7UP (R24080341) achieved a higher mean tensile strength of 1,384.37 ± 102.30 MPa, approximately 13.4% higher than SCH-7UP (R24080342), which recorded 1,220.77 ± 141.17 MPa. Conversely, SCH-7UP exhibited a higher mean nominal strain at break of 4.44 ± 1.15%, compared with 2.68 ± 0.32% for Tyfo SCH 7UP. The tensile-strength difference was not statistically significant ($p = 0.072$), whereas the strain-at-break difference was statistically significant ($p = 0.024$). These findings indicate distinct strength–deformation characteristics between the two FRP

materials and provide initial material parameters for subsequent reinforced concrete column strengthening studies.

Keywords : *Fiber-Reinforced Polymer, CFRP, Tensile Strength, Reinforced Concrete Column, External Strengthening.*

INTRODUCTION

Strengthening reinforced concrete columns in existing buildings can be carried out using the concrete jacketing method, which involves increasing the column cross-sectional dimensions by adding concrete and reinforcement to enhance its structural capacity. Demonstrated that this method can serve as an alternative when existing columns do not satisfy the required strength criteria, particularly under seismic loading, with one strengthening option involving the addition of a 50 mm-thick concrete jacket. However, the addition of concrete, reinforcement, and formwork increases material requirements as well as the dimensions and self-weight of the structural elements (Herarkhi et al., 2025). This condition has encouraged the development of lighter and more efficient external strengthening alternatives, one of which involves the use of carbon fiber-reinforced polymer (CFRP).

The use of CFRP as an external strengthening material has been investigated extensively because of its high strength-to-weight ratio, corrosion resistance, and ease of installation compared with conventional strengthening systems. Golias et al. demonstrated that externally applied CFRP ropes can improve the hysteretic response, load capacity, stiffness, and energy dissipation of reinforced concrete beam–column joints under cyclic loading, while also providing a relatively simple strengthening procedure (Golias et al., 2021). Similarly, Aman et al. reported that externally bonded CFRP sheets can improve the structural resistance of reinforced concrete members, with increasing numbers of CFRP layers contributing to higher resistance and reduced deformation (Aman et al., 2020). These findings indicate that the effectiveness of externally applied CFRP is strongly associated with the mechanical properties and configuration of the strengthening material.

For reinforced concrete columns, CFRP is particularly beneficial when applied as an external jacket because the material can provide lateral confinement to the concrete core and thereby enhance its compressive performance. Karouche et al. experimentally investigated more than 150 CFRP-confined concrete cylinders and found that the strengthening effectiveness was influenced by concrete strength, CFRP orientation, confinement ratio, and the bond characteristics between the composite and concrete (Karouche et al., 2022). In a practical retrofit application, Hassen et al. demonstrated through experimental and finite element analyses that CFRP confinement could substantially increase the compressive strength and ductility-related response of existing reinforced concrete columns (Hassen et al., 2023). Therefore, the performance of CFRP-strengthened columns cannot be evaluated solely from the strengthening configuration, but must also consider the mechanical characteristics of the CFRP material itself.

Among the mechanical properties of FRP, tensile strength, elastic modulus, and tensile strain at failure are fundamental parameters because externally applied CFRP primarily develops tensile stresses when it provides confinement or additional reinforcement. Kadhim et al. characterized unidirectional CFRP laminates using tensile coupon tests in accordance with ASTM D3039 and reported an ultimate tensile strength of 1397.8 MPa, a tensile strain at failure of 0.01404, and a longitudinal elastic modulus of 105.3 GPa (Kadhim et al., 2019). In another study, Hosseini et al. reported a nominal tensile strength of 2800 MPa and a measured elastic modulus of 156 GPa for S&P 150/2000 CFRP plates, demonstrating that the mechanical properties may vary substantially depending on the CFRP product and material configuration (Hosseini et al., 2018). Such differences emphasize the importance of experimentally determining the tensile properties of the specific FRP material used for structural strengthening rather than relying solely on generalized or manufacturer-reported values.

The importance of accurately characterizing CFRP tensile behavior is further demonstrated by numerical and experimental investigations of strengthened reinforced concrete columns. El Youbi et al. showed that the number of CFRP plies and loading eccentricity affect the response of CFRP-confined high-strength concrete columns, while their numerical model required the mechanical properties and failure criteria of the FRP

composite as essential input parameters (El Youbi et al., 2022). Kalogeropoulos and Tsonos also emphasized that FRP has a predominantly linear-elastic and brittle response, meaning that rupture or debonding of the strengthening jacket can govern the behavior of a strengthened column if the material is not properly designed (Kalogeropoulos & Tsonos, 2021). Consequently, reliable tensile-property data are essential for defining the constitutive behavior of CFRP, predicting its failure, and assessing the structural effectiveness of external strengthening systems.

Although numerous studies have demonstrated the effectiveness of CFRP for strengthening reinforced concrete members, much of the existing research has focused primarily on the structural response of beams, slabs, and columns rather than on the experimental characterization of the tensile properties of the CFRP material itself. Abd reported that different CFRP strip configurations can significantly influence the strength and failure behavior of reinforced concrete members, indicating that the response of the strengthened structure is closely related to the characteristics and application of the CFRP system (Abd, 2021). Likewise, Mallikarjuna et al. demonstrated that the strengthening technique and CFRP configuration affect the load-carrying behavior of reinforced concrete members, with externally bonded and near-surface-mounted systems exhibiting different structural responses (Mallikarjuna et al., 2023). Therefore, a systematic characterization of tensile strength, elastic modulus, and tensile strain at failure of the FRP material is necessary to establish reliable material parameters for its application as an external strengthening material for reinforced concrete columns, which forms the focus of the present study.

METHODS

The tensile properties of the Fiber-Reinforced Polymer (FRP) were experimentally evaluated at the National Research and Innovation Agency (BRIN), Indonesia, using the Tensile Test method in accordance with ASTM D3039/D3039M-17. Two FRP specimens were prepared, namely Tyfo SCH 7UP and SCH-7UP, with each specimen tested to determine its tensile strength and deformation response under uniaxial tensile loading. The specimens were prepared according to the dimensions and testing requirements

specified in ASTM D3039/D3039M-17 and installed in the testing machine using appropriate grips to ensure axial loading.

During the test, tensile load and specimen deformation were continuously recorded until failure occurred. The experimental data were used to determine the ultimate tensile strength, tensile strain at failure, and elastic modulus of each FRP specimen based on the resulting stress–strain relationship. The tensile properties obtained from the Tyfo SCH 7UP and SCH-7UP specimens were subsequently compared to evaluate their mechanical characteristics and suitability as external strengthening materials for reinforced concrete columns.

RESULTS AND DISCUSSION

Characteristics of the Experimental Data

Tensile testing was conducted on Tyfo SCH 7UP/SCH-7UP material at the BRIN Polymer Laboratory, Serpong. Both reports employed ASTM D3039/D3039M-17 with five specimens in each group. The grip separation was 150 mm and the crosshead speed was 2 mm/min. The specimens were conditioned at 23 ° C and 50% relative humidity (RH) for more than 40 h, while the testing-room condition was recorded as 22.6 ° C and 53.4% RH. The principal reported parameters were tensile strength and nominal strain at break.

Table 1. Main testing conditions for the two specimen groups

Parameter	R24080341	R24080342
Test standard	ASTM D3039/D3039M-17	ASTM D3039/D3039M-17
Number of specimens	5	5
Grip separation	150 mm	150 mm
Crosshead speed	2 mm/min	2 mm/min
Conditioning	23 ° C; 50% RH; >40 h	23 ° C; 50% RH; >40 h
Reported parameters	Tensile strength; strain at break	Tensile strength; strain at break

Source: BRIN test reports R24080341 and R24080342, 2025

The R24080341 report recorded a mean tensile strength of 1,384.37 ± 102.30 MPa and a nominal strain at break of 2.68 ± 0.32%. The R24080342 report recorded a tensile

strength of 1,220.77 ± 141.17 MPa and a nominal strain at break of 4.44 ± 1.15%. The reported values are expressed as mean ± standard deviation.

The individual data presented on page 3 of each report were used as the basis for additional statistical analysis. This analysis was performed to evaluate data dispersion, between-group differences, and the degree of variability in the test results.

Specimen Data and Descriptive Statistical Analysis

Table 2. Individual tensile strength and nominal strain-at-break data

Specimen	R24080341 – Stress (MPa)	R24080341 – Strain (%)	R24080342 – Stress (MPa)	R24080342 – Strain (%)
Specimen 1	1280.16	2.41047	1123.35	3.50528
Specimen 2	1381.87	2.53536	1054.15	3.11690
Specimen 3	1334.28	2.40619	1250.36	4.75321
Specimen 4	1552.75	2.94956	1421.97	4.83279
Specimen 5	1372.79	3.08875	1254.00	5.98828

Source: BRIN test reports R24080341 and R24080342, 2025

For R24080341, tensile strength ranged from 1,280.16 to 1,552.75 MPa, with a median of 1,372.79 MPa. For R24080342, the range was 1,054.15–1,421.97 MPa, with a median of 1,250.36 MPa. The wider range indicates greater dispersion in tensile strength for the second group.

For strain at break, R24080341 ranged from 2.40619–3.08875%, whereas R24080342 ranged from 3.11690–5.98828%. The range of the second group was substantially wider, which is consistent with its larger standard deviation.

Table 3. Descriptive statistics and 95% confidence intervals

Group	Tensile strength mean ± SD (MPa)	95% CI mean (MPa)	Strain mean ± SD (%)	95% CI mean (%)
R24080341	1384.37 ± 102.30	1257.35–1511.39	2.68 ± 0.32	2.28–3.07
R24080342	1220.77 ± 141.17	1045.48–1396.05	4.44 ± 1.15	3.01–5.87

Source: BRIN test reports R24080341 and R24080342, 2025

The confidence intervals were calculated using the t distribution with four degrees of freedom because each group consisted of five specimens. Given the small sample size, the intervals are relatively wide; therefore, the results should be interpreted as an initial material characterization rather than as a highly precise population estimate.

Comparison of Tensile Strength

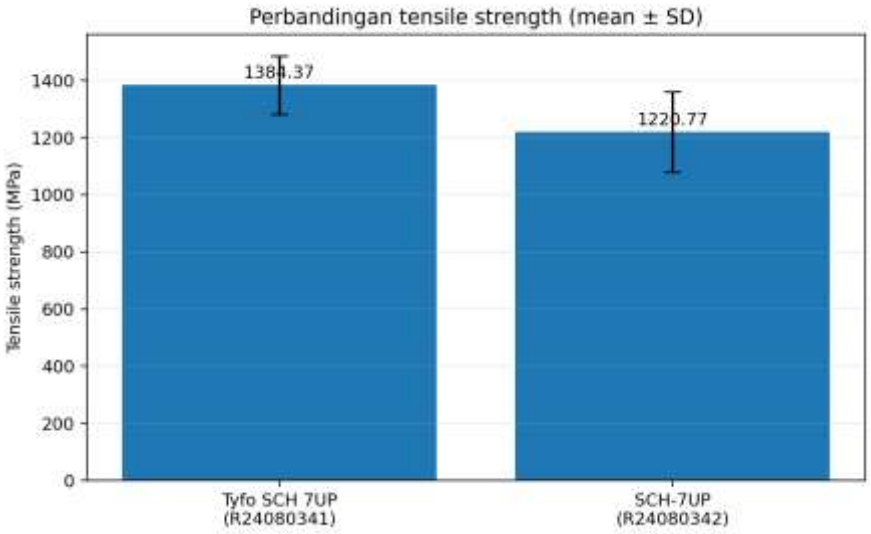


Figure 1. Comparison of tensile strength between the two material groups
Error bars represent ±1 standard deviation.

Figure 1 shows a mean tensile strength of 1,384.37 MPa for R24080341 and 1,220.77 MPa for R24080342. The mean difference was 163.60 MPa, corresponding to approximately 13.4% higher tensile strength for R24080341.

This difference does not necessarily indicate that one material group is statistically stronger at the population level. Welch's t-test produced $t = 2.098$, $df = 7.29$, and $p = 0.072$. At the 5% significance level, $p > 0.05$; therefore, the difference in tensile strength cannot be considered statistically significant based on five specimens per group.

The Mann–Whitney test, used as a non-parametric approach, yielded $p = 0.095$, which also does not reach the 5% significance level. Accordingly, the most appropriate interpretation is that R24080341 shows a higher mean tensile strength, while the available

statistical evidence is insufficient to generalize this difference to the broader material population.

From an engineering perspective, the result remains important because both groups exhibit tensile strength on the gigapascal scale. For structural strengthening research, this parameter can serve as an initial material characteristic; however, the selection of design values should consider the relevant design standards, reduction factors, force-transfer mechanisms, and structural element test results.

Comparison of Nominal Strain at Break

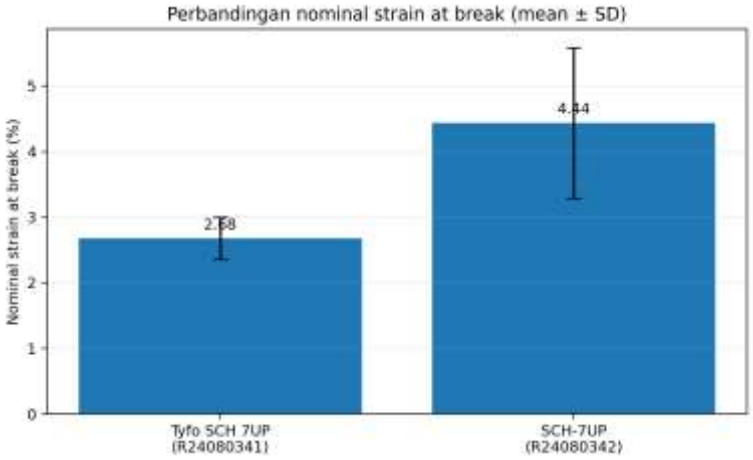


Figure 2. Comparison of nominal strain at break between the two material groups
Error bars represent ±1 standard deviation.

R24080341 had a mean nominal strain at break of 2.68%, whereas R24080342 reached 4.44%. Thus, R24080342 exhibited a mean value approximately 65.8% higher. This represents the most pronounced difference between the two datasets.

Welch's t-test yielded t = -3.304, df = 4.62, and p = 0.024. Thus, at the 5% significance level, the evidence for a difference in mean strain at break is stronger than that for tensile strength. The Mann–Whitney test yielded p = 0.008, which is also below 0.05.

Nevertheless, the statistical interpretation should be made cautiously because the sample size was only five specimens per group. The large difference in strain may also be

influenced by individual variability, specimen geometry, material condition, or local material characteristics. The test reports do not provide sufficient information to establish the specific cause of this difference.

From a material-behaviour perspective, a combination of high tensile strength and greater strain at break is generally attractive for strengthening systems. However, the present study did not test the material after application to concrete; therefore, a direct relationship between material strain and column ductility cannot be established from tensile-test data alone.

Coefficient of Variation (CV) Analysis

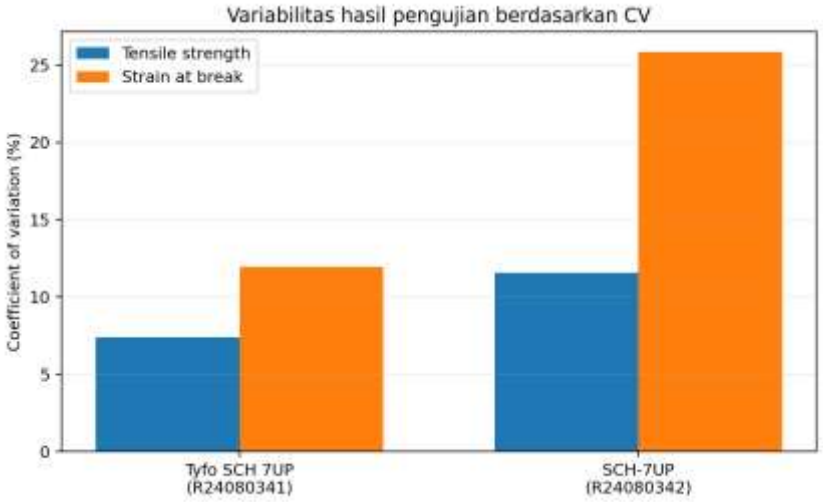


Figure 3. Coefficients of variation for tensile strength and strain at break

The coefficient of variation (CV) for tensile strength was 7.39% for R24080341 and 11.56% for R24080342. For strain at break, the CV values were 11.93% and 25.87%, respectively. CV was calculated as the ratio of the standard deviation to the mean multiplied by 100%.

The results show that tensile strength was relatively more consistent than strain at break in both groups. R24080341 exhibited the lowest dispersion for both parameters, whereas R24080342 had the greatest variation in strain at break. Numerically, the strain-at-break CV for R24080342 was approximately twice that of R24080341.

Table 4. Coefficients of variation of the test results

Parameter	R24080341 CV (%)	R24080342 CV (%)	Interpretation
Tensile strength	7.39	11.56	Lower variability in R24080341
Nominal strain at break	11.93	25.87	Higher variability in R24080342

Source: BRIN test reports R24080341 and R24080342, 2025

The higher variability should be considered when the material parameters are used for numerical modelling or design calculations. In future research, a larger number of specimens and testing across multiple material batches would provide a stronger statistical basis.

Inferential Statistical Analysis and Strength–Strain Relationship

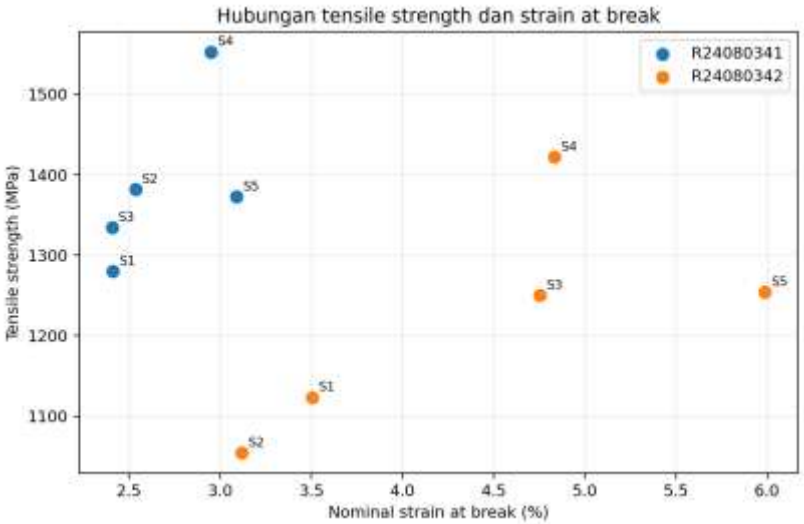


Figure 4. Relationship between tensile strength and nominal strain at break for each specimen

Figure 4 indicates that tensile strength and strain at break do not exhibit a simple positive relationship across all specimens. In R24080341, strain at break remained within a relatively narrow range of approximately 2.41–3.09%, while tensile strength varied from

about 1,280 to 1,553 MPa. In R24080342, strain at break increased to nearly 6%, but tensile strength did not increase proportionally.

Table 5. Summary of statistical analyses

Statistical parameter	Result
Shapiro–Wilk tensile strength R24080341	W=0.887; p=0.341
Shapiro–Wilk tensile strength R24080342	W=0.956; p=0.777
Shapiro–Wilk strain R24080341	W=0.835; p=0.151
Shapiro–Wilk strain R24080342	W=0.942; p=0.680
Welch tensile strength	t=2.098; df=7.29; p=0.072
Welch strain at break	t=-3.304; df=4.62; p=0.024
Mann–Whitney tensile strength	U=21.0; p=0.095
Mann–Whitney strain at break	U=0.0; p=0.008

Source: BRIN test reports R24080341 and R24080342, 2025

The Shapiro–Wilk test for each group produced $p > 0.05$, providing no sufficient evidence to reject the normality assumption. However, because $n = 5$, the normality test has limited statistical power, and graphical inspection remains important.

Welch's test was selected because it does not require equal variances between the two groups. The results show that the difference in tensile strength was not significant at $\alpha = 0.05$, whereas the difference in strain at break showed stronger evidence. The non-parametric Mann–Whitney test provided a consistent conclusion for both parameters.

These statistical findings should be regarded as supporting analysis. The data came from two laboratory test reports with a limited number of specimens and were not explicitly designed as a controlled experiment to test the effect of a particular treatment variable. Therefore, differences between the reports should not be directly interpreted as effects of composition, batch, or treatment without additional experimental information.

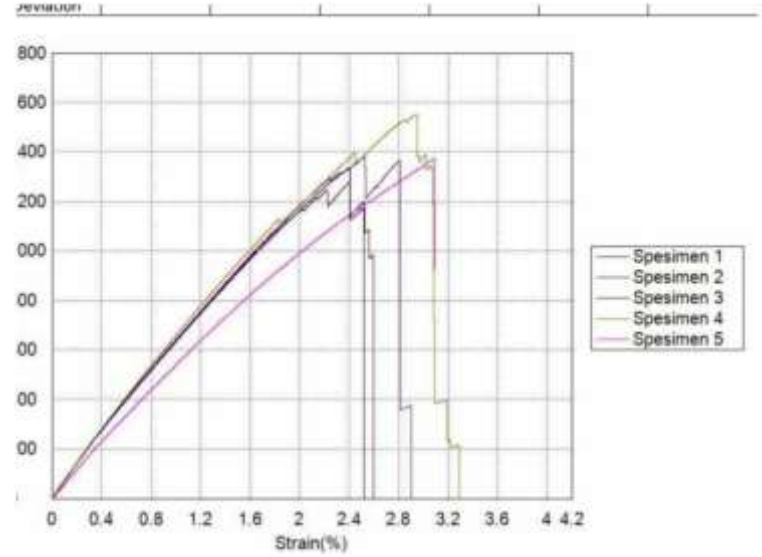


Figure 5. Stress–strain curves for R24080341 from the BRIN test report

Image source: BRIN test report R24080341

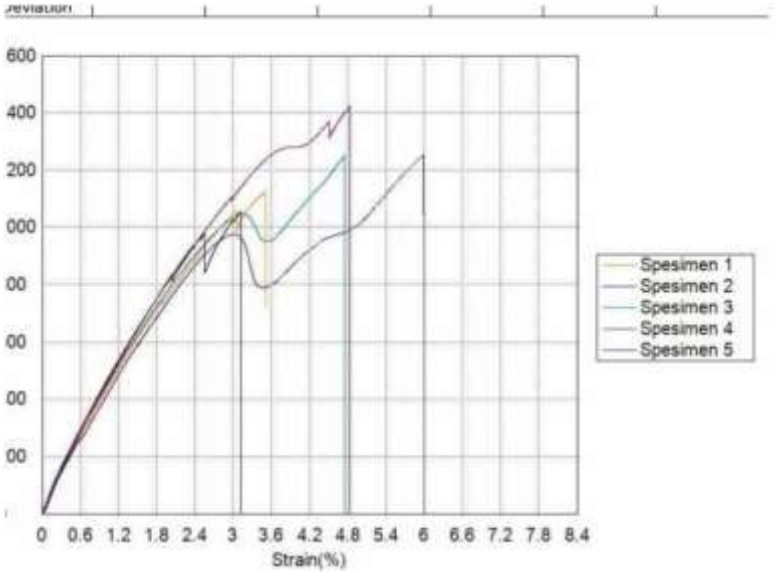


Figure 6. Stress–strain curves for R24080342 from the BRIN test report

Image source: BRIN test report R24080342

The curves in both reports show the tensile response of each specimen up to failure. R24080341 exhibits relatively high peak stress with a narrower strain-to-failure range, whereas R24080342 shows a longer strain range and greater specimen-to-specimen variation.

In the context of reinforced concrete column strengthening, these tensile-test results can be used as an initial material characterization before structural element testing. Tensile strength represents the material's capacity to resist tensile stress, while strain at break provides information on deformation capacity up to failure. However, the actual contribution to column axial capacity and ductility is also governed by material–concrete interaction, strengthening configuration, number of layers, fiber orientation, development length, and failure mode.

Synthesis of Findings and Directions for Further Research

Overall, both groups exhibited high tensile properties, but with a trade-off between tensile strength and strain at break. R24080341 was superior in terms of mean tensile strength, whereas R24080342 was superior in nominal strain at break. The statistical analysis indicates that the evidence for a difference in strain at break is stronger than that for tensile strength.

To strengthen the scientific contribution of the article, future research can link these material characteristics with reinforced concrete column tests, such as control columns and strengthened columns with variations in the number of layers or strengthening configuration. The parameters to be compared may include axial capacity, load–displacement response, strain, ductility, failure mode, and strengthening efficiency. In this way, the tensile-test data serve not merely as material data but also as a basis for explaining the relationship between strengthening-material properties and structural response.

CONCLUSION

The tensile testing conducted at the BRIN Polymer Laboratory using ASTM D3039/D3039M-17 demonstrated that both FRP material groups exhibited high tensile performance and are potentially suitable for application as external strengthening

materials for reinforced concrete columns. The Tyfo SCH 7UP (R24080341) specimens achieved a higher mean tensile strength of 1,384.37 ± 102.30 MPa, compared with 1,220.77 ± 141.17 MPa for SCH-7UP (R24080342), representing an approximately 13.4% higher tensile strength.

In contrast, SCH-7UP (R24080342) exhibited superior deformation capacity, with a mean nominal strain at break of 4.44 ± 1.15%, compared with 2.68 ± 0.32% for Tyfo SCH 7UP, corresponding to an increase of approximately 65.8%. Statistical analysis indicated that the difference in tensile strength was not statistically significant at the 5% significance level ($p = 0.072$), whereas the difference in nominal strain at break was statistically significant based on both Welch's t-test ($p = 0.024$) and the Mann–Whitney test ($p = 0.008$).

Overall, the results confirm that the two FRP groups possess different combinations of tensile strength and strain capacity, with Tyfo SCH 7UP providing higher tensile strength and SCH-7UP providing greater strain at failure. The results provide an important initial material characterization for subsequent application in reinforced concrete column strengthening; however, the tensile properties alone cannot directly represent the increase in column axial capacity or ductility because these responses are also governed by FRP–concrete interaction, number of layers, fiber orientation, development length, strengthening configuration, and failure mode.

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