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Experimental Study on the Mechanical Properties of Concrete with Pyrolyzed Spent Coffee Grounds

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Abstract: *This study explores the use of pyrolyzed spent coffee grounds (SCG) as a partial sand replacement in concrete. The mechanical performance of SCG-modified concrete is evaluated to address the negative consequences of improper SCG disposal and sand mining. SCG biochar was included in concrete mixes at weight replacement percentages of 0%, 10%, 15%, and 20% after being pyrolyzed at 350°C. Mechanical testing, including compressive and split tensile strength, was done at 28 and 56 days of curing. The results consistently showed a drop in both strengths as the SCG content increased because of the biochar's lower specific gravity and higher water absorption. Although the modified concrete may not be suitable for structural applications, it shows strong potential for use in non-load bearing applications, offering a sustainable alternative for construction needs. Furthermore, a significant relationship between compressive and tensile strength was observed, which supports SCG utilization in sustainable concrete.*

Keywords: coffee ground; biochar; pyrolysis; concrete; waste utilization

1. INTRODUCTION

Concrete is a necessary building material. However, its conventional production, particularly cement manufacturing and natural sand extraction, has significant environmental effects, including high carbon emissions and ecological damage. Many studies have concentrated on finding sustainable alternative materials, especially abundant and categorized as waste, for use as partial substitutes for conventional concrete constituents in support of the United Nations Sustainable Development Goals (UN SDGs). Among the substitutes investigated in earlier studies have been organic materials. Using organic materials does, however, provide several challenges, including susceptibility to decomposition, high water absorption, possible adverse chemical reactions, and variation in physical and chemical properties. Some organic materials can be utilized in sustainable concrete applications with appropriate pre-treatment, including pyrolysis, chemical stabilization, and careful mix design and proportioning. Biochar is the final product obtained from the pyrolysis process. It is produced through the thermochemical conversion of organic waste biomass and is characterized by several unique properties, including high carbon content, a porous structure, and a large specific surface area [1]. Pine wood biochar at 5% (w/w) improved soil physico-chemical properties, such as increasing plant available water by up to 22% in clay loam and 37% in sandy soil, suggesting its potential use in drought-prone areas [2]. Biochar derived from durian husk, mangosteen shell, and banana peel can effectively reduce nickel concentrations in wastewater, with removal efficiencies of 93.89%, 88.33%, and 86.11%, respectively, highlighting their potential as sustainable biofilters [3].
Rising coffee consumption in the Philippines produces large volumes of spent coffee grounds, usually disposed of in landfills, which cause methane emissions and aggravation of environmental problems. Recent research has identified pyrolyzed SCGs, especially those processed at 350°C, as a promising sustainable alternative to sand in concrete. SCG incorporated with other agricultural waste, such as coffee husk ash and eggshell powder, was tested as a sustainable partial replacement for cement and sand in concrete [4]. Using 75% eggshell powder and 25% coffee husk ash, 10% cement replacement produced the highest 28-day compressive strength. A 17.75% strength increase was observed at a 0.4 water-cement ratio without sand replacement. These findings highlight the value of agricultural waste in enhancing concrete performance while promoting sustainable construction. This material improves concrete's mechanical performance, especially its compressive strength, while addressing waste disposal issues. SCG biochar is a good, environmentally friendly additive for sustainable concrete since it allows the construction sector to lower its carbon footprint, slow down resource depletion, and support circular economy practices by sand replacement.
Two main environmental issues are highlighted in this research: the continuous depletion of natural sand resources for concrete manufacture [5] and the improper disposal of SCGs, which fuels leachate generation in landfills [6, 7]. Severe environmental damage, including soil erosion, limited water availability, and habitat destruction, results from excessive sand mining [5, 8]. Comparably, the worldwide disposal of more than 60 million tons of SCGs yearly generates greenhouse gases and acidic leachate [9, 10]. Only a small portion of this waste is repurposed into products like biochar, bio-oil, fertilizers, filters, and bricks.

Given these environmental issues, finding sustainable substitutes for natural sand and encouraging the valorization of SCGs in construction is necessary. The limited prior research on using pyrolyzed SCGs as fine aggregate replacements, combined with the importance of validating their environmental benefits, highlights the need for this study. Thus, the main goal of this work is to assess the performance of pyrolyzed SCGs as a partial sand replacement in concrete and ascertain their potential as a green building material.

The objectives of this study are to: (1) assess the mechanical characteristics, specifically the compressive strength and split tensile strength of concrete with pyrolyzed SCG as a partial replacement for sand, and (2) determine the best percentage of pyrolyzed SCGs that can be practically used as a sand substitute in concrete mixtures. The succeeding sections of this paper outline the methodology, detailing the SCG pyrolysis process, material preparation, and testing procedures, followed by the presentation of results, conclusions, and recommendations for future research. It is important to note that *pyrolyzed SCG* refers to the process by which spent coffee grounds are thermally treated, while *SCG biochar* denotes the resulting material from this pyrolysis process. For clarity and consistency, these terms are used interchangeably throughout this paper.

2. METHODOLOGY

This section outlines the procedures followed to prepare the materials essential for the study. It covers the pyrolysis of SCGs to produce biochar, material preparation, casting, and testing of concrete specimens.

2.1 Pyrolysis of SCG

The pyrolysis of SCGs plays a central role in this study, as it enables the conversion of organic waste into biochar, which is then evaluated as a partial sand replacement in concrete. The pyrolysis process used a Vecstar Model AF2 Laboratory Tube Furnace.

Pyrolysis involves subjecting SCGs to high temperatures in a low-oxygen environment, causing thermal decomposition that separates the material into volatile gases and solid biochar. The resulting biochar, a carbon-rich substance, holds potential for enhancing the sustainability and performance of concrete. The process began with the collection of SCGs from a single coffee shop. These were sun-dried for approximately 48 hours to eliminate moisture, which is essential for effective pyrolysis. Once thoroughly dried, the SCGs were stored in airtight plastic bags and sealed in plastic containers to prevent contamination and moisture ingress.
The dried SCGs were then placed in a metal pot, and their initial weight was recorded (Fig. 1 (a)). The pot was covered with a lid and inserted into the electric furnace preheated to 350°C (Fig. 1 (b)). The SCGs were pyrolyzed at this constant temperature for three hours.

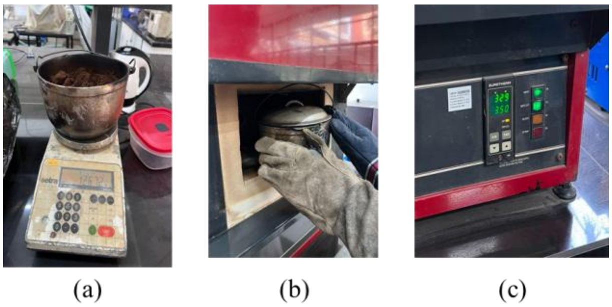

Fig. 1. SCG Pyrolysis Equipment: (a) Weighing of dried SCG prior to pyrolysis; (b) Insertion of lidded metal pot into the electric furnace; (c) Setting the furnace temperature to 350°C.

After heating, the pot was removed and transferred to a fume hood for cooling, as shown in Fig. 2a. The lid was kept closed throughout the cooling process to prevent oxidation and burning of the biochar. The material inside was stirred every five minutes to prevent ember formation and ensure uniform cooling. Once cooled, the biochar was transferred to a separate container, weighed, and compared to the initial SCG weight to confirm an approximate yield of 50% (Fig. 2b and 2c).

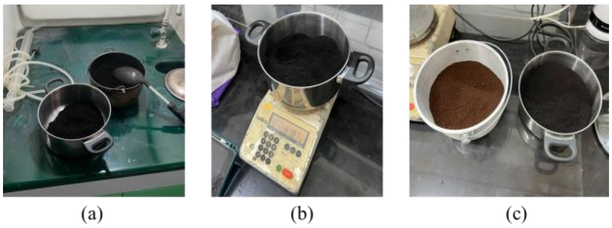

Fig. 2. Post-Pyrolysis Handling and Output: (a) Cooling of biochar inside a covered pot to prevent combustion; (b) Weighing of biochar after pyrolysis, with an expected yield of approximately 50%; (c) Visual comparison between raw SCG and resulting SCG biochar.

2.2 Material Preparation

The biochar obtained from pyrolysis was later incorporated into concrete mixtures to evaluate their mechanical properties.

The primary binding material used in this study was ordinary Portland cement (Type I). The cement, coarse aggregates, and fine aggregates were prepared and tested in accordance with the relevant standards set by the American Society for Testing and Materials (ASTM). The applicable ASTM standards and corresponding values from each test are summarized in Table 1.

A significant difference in the specific gravity can be observed when comparing the physical properties of sand and SCG biochar. SCG biochar has a value of 0.770, considerably lower than sand at 2.222. This lower specific gravity indicates that incorporating SCG biochar into concrete will reduce its overall density, contributing to developing lightweight concrete. It also reflects the more porous and less compact nature of SCG biochar.

Table 1. Material Properties

Material	ASTM Standard	Values
Cement	Specific Gravity (ASTM C188)	3.152
Coarse Aggregates (gravel)	Moisture Content (%) (ASTM C566)	0.017
	Fineness Modulus (ASTM C136)	7.594
	Specific Gravity (ASTM C127)	2.800
	Absorption (%) (ASTM C127)	2.000%
	Unit Weight (kg/m^3) (ASTM C29)	1558.000
Fine Aggregates (sand)	Moisture Content (%) (ASTM C566)	1.010
	Fineness Modulus (ASTM C136)	2.350
	Specific Gravity (ASTM C128)	2.222
	Absorption (%) (ASTM C128)	3.513
	Unit weight (kg/m^3) (ASTM C29)	1516.000
SCG biochar	Fineness Modulus (ASTM C136)	2.965
	Specific Gravity (ASTM C128)	0.770
	Absorption (ASTM C128)	24.260%

The absorption rate further confirms the porosity, where SCG biochar recorded 24.260%, compared to just 3.513% for sand. The significantly higher absorption rate suggests that SCG biochar retains much more water, which could influence mix design considerations such as water content and workability. Previous studies found that water content in concrete mix influences the resulting concrete strength [11].

In terms of fineness modulus, SCG biochar showed a higher value of 2.965 compared to 2.350 for sand. This indicates that SCG biochar has a coarser particle size distribution overall. While both materials contain a range of particle sizes, sand is finer on average. These findings are visually supported in the grain size distribution curves in Fig. 3.

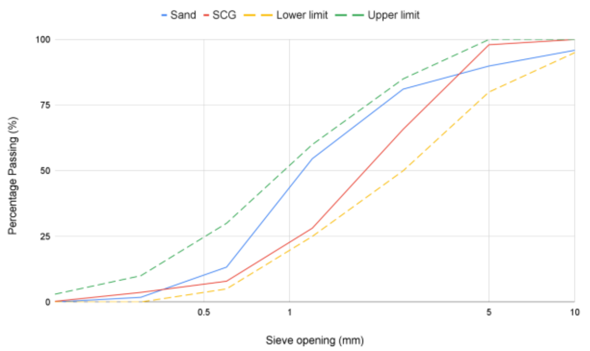

Fig. 3. Grain size distribution curve of sand and SCG biochar

The concrete proportioning procedure followed the guidelines of the American Concrete Institute (ACI), ACI 211.1, or the Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. The concrete constituents used in this study were carefully sourced and measured in precise quantities based on the specified mix proportions from the concrete mix design. Pyrolyzed SCG was incorporated into the concrete mix as a partial replacement for fine aggregates. Replacement percentages were set at 0% (control), 10%, 15%, and 20%, in accordance with the experimental design. The mixing process was conducted systematically to ensure uniform distribution of materials, resulting in concrete samples that were consistent, replicable, and suitable for the subsequent mechanical testing phases of the study. The slump test was conducted according to ASTM C143.

2.3 Mechanical Testing

The concrete specimens underwent mechanical testing once the prescribed curing times were completed. Every specimen was weighed and measured for average diameter and height with a caliper prior to testing. ASTM C39 was followed for the compressive strength test, while ASTM C496 was followed for the split tensile test.

3. RESULTS AND DISCUSSION

3.1 Slump Test

Table 2 presents the results of the concrete slump test, which clearly show an inverse relationship between the workability of the concrete mix and the percentage of pyrolyzed SCG used as a sand replacement. With no SCG replacement, the control sample attained a slump of 70 mm, indicating medium workability and matching with the target slump based on the mix design. However, when 5% pyrolyzed SCG was used in place of sand (by weight), the slump dropped noticeably to 40 mm, suggesting a marked decrease in workability. This downward trend continued with increasing replacement levels: 30 mm at 10%, 20 mm at 15%, and 15 mm at 20% SCG replacement, representing the lowest workability among all tested mixes.

Among the mixes, only the control sample achieved the design slump, which explains the adverse effect of SCG biochar on concrete workability. The progressive decline in slump values with higher SCG content reflects the material's physical characteristics compared to natural sand. Specifically, SCG biochar has a significantly lower specific gravity (0.770) than sand (2.22), resulting in a lower overall mix density. Moreover, the high-water absorption rate of SCG biochar (24.260%) compared to sand (3.513%) reduces the available free water in the mix. This increased absorption leads to a drier mix and, consequently, lower workability. These findings suggest that while SCG biochar can serve as a sand replacement, its effects on concrete consistency must be carefully managed, potentially requiring adjustments in water content or the use of admixtures to maintain desired workability.

Table 2. Concrete Slump Test Results

Pyrolyzed SCG Weight Replacement (%)	Slump Test Result (mm)	Degree of Workability
0%	70	Medium
5%	40	Low
10%	30	Low
15%	20	Very Low
20%	15	Very Low

3.2 Compressive Strength

To assess the impact of incorporating pyrolyzed SCGs in concrete, a compressive strength test of concrete mixes containing varying percentages of pyrolyzed SCGs was conducted after 28 and 56 days of curing. The compressive strength of concrete at 28 days, the nominal curing period, is a key indicator of its early-age performance and provides a baseline for evaluating the effectiveness of SCG biochar as a partial sand replacement. To gain further understanding of the material's long-term performance, compressive strength was also measured at 56 days of curing, which extends beyond the standard testing period and offers a more comprehensive understanding of strength development over time.

Concrete samples containing pyrolyzed SCG replacements at 0% (control), 5%, 10%, 15%, and 20% by weight of sand were tested for compressive strength. Explicitly included in this study was a 5% weight replacement level to compare it with the conclusions in [12]. Volume-based replacement was employed in the mix design of [12]. This study, on the other hand, used weight-based replacement. A 29.3% increase in compressive strength at a 15% volume replacement of sand with pyrolyzed SCGs was reported. Including a 5% weight replacement in this work enables a proper comparison with their work and supports the evaluation of the validity of SCG biochar's possible additive strength-enhancing capacity in concrete.

Examining Fig. 4 clearly shows that the compressive strength of concrete falls as the percentage of pyrolyzed SCG replacement by weight increases. This pattern indicates that higher replacement levels of pyrolyzed SCG have an adverse effect on the compressive strength of the concrete.

For the 28-day compressive strength test, the control samples, with no SCG replacement, exhibited an average compressive strength of 31.35 MPa, serving as the baseline. At 5% SCG replacement, strength dropped sharply to 15.65 MPa, representing a 50.08% reduction compared to the control. This substantial decrease indicates the adverse impact of SCG biochar at even low replacement levels. At 10% replacement, the strength further decreased to 13.87 MPa, a 55.76% reduction, while 15% replacement yielded 13.30 MPa, reflecting a 57.59% decline. The 20% replacement level showed the lowest strength at 9.50 MPa, marking a drastic 69.70% reduction from the control.

For the 56-day curing period, a similar trend was observed. The control samples achieved an average compressive strength of 33.70 MPa. With 5% SCG replacement, the strength decreased to 17.30 MPa, a 48.67% reduction. At 10% replacement, the average strength was 15.35 MPa, a 54.44% decrease, while the 15% replacement yielded 15.01 MPa, corresponding to a 55.47% reduction. The most significant decrease was again observed at 20% replacement, with a strength of 10.44 MPa, reflecting a 69.03% reduction compared to the control.

The observed reduction in compressive strength across both curing periods can be primarily attributed to the physical characteristics of SCG biochar relative to sand. With its lower specific gravity and higher water absorption rate, SCG biochar contributes to a less dense concrete mix, and its absorptive nature reduces the amount of free water available for cement hydration, thereby compromising strength development.

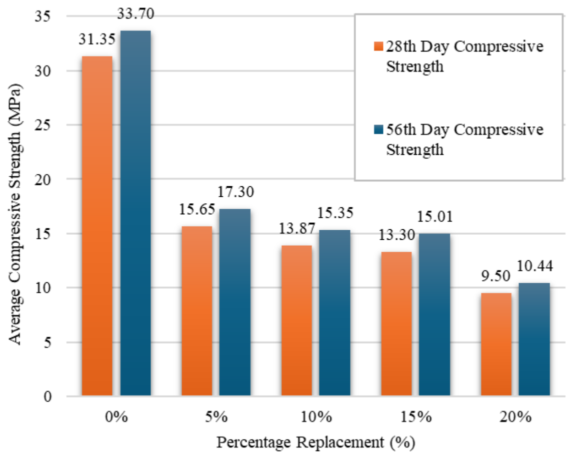

Fig. 4. Compressive strength at 28th and 56th day

Reflecting normal strength gained due to continuous hydration and curing, a 7.49% increase in compressive strength was noted for the control sample between 28 and 56 days [13]. While the 10% replacement gained 10.71%, indicating modest changes in strength over time despite lower initial values, the 5% SCG replacement showed a 10.54% increase. With the highest gain at 12.86%, the 15% replacement indicates improved long-term curing performance among the SCG compositions. Meanwhile, the 20% replacement gained 9.87%, the lowest among the SCG mixes, reinforcing that high SCG content significantly weakens the concrete.

To assess the statistical significance of these results, t-tests were performed with a 0.05 significance level. Results revealed no significant difference between the 5% and 10% replacements, and similarly between the 10% and 15%. However, a significant difference was found between the control and 5%, as well as between the 15% and 20% replacements. This indicates that the control mix performed significantly better, while the 20% SCG mix performed significantly worse. The 5%, 10%, and 15% replacements, on the other hand, showed comparable compressive strengths.

The results also showed that the highest average compressive strength achieved among the SCG biochar concrete specimens was 15.65 MPa, while the lowest was 9.50 MPa. A compressive strength of around 15 MPa is appropriate for low strength blinding concrete, typically used in construction applications requiring a level surface but not carrying structural loads [14]. Similarly, comparable strength levels were recommended for non-load-bearing pavements in [15], while concrete with similar strengths was utilized for non-load-bearing walls in [16].

Furthermore, ASTM C129-06 specifies the minimum compressive strength for non-load-bearing concrete masonry units as 3.45 MPa, a level much exceeded by all SCG biochar concrete specimens examined in this work. Still, the minimum strength needed for non-load-bearing uses depends on design criteria and layout.

Although the compressive strengths obtained in this study satisfy criteria for some non-structural uses, they are insufficient for load-bearing applications, including columns, beams, or footings, which usually demand much higher strength. Based on the mix design, SCG biochar concrete is more appropriate for non-load-bearing building uses.

Differences in aggregate properties, which greatly affect mix design and the computation of volume and weight-based replacements, explain the variations in results relative to earlier studies. The specific gravity of pyrolyzed SCGs and the unit weight of fine aggregates control these variations. For example, volume-based replacement was used, which, given the low specific gravity of SCG biochar, produced a smaller quantity of material (by weight) being added into the mix [12]. This likely contributed to their reported 29.3% increase in compressive strength at a 15% volume replacement level. In contrast, this study employed weight-based replacement, leading to a greater actual mass of SCG biochar being incorporated, which may have contributed to the observed decline in compressive strength with increasing replacement percentages.

3.3 Split Tensile Test

The analysis of split tensile strength for concrete incorporating pyrolyzed SCGs as a partial sand replacement reveals key findings into the material's behavior under tensile stress. As shown in Fig. 5, increasing the percentage of pyrolyzed SCG consistently decreases split tensile strength at both 28-day and 56-day curing periods. This trend indicates that higher levels of SCG replacement have a negative impact on the tensile performance of concrete.

At 28 days, the control sample showed the highest average split tensile strength at 2.82 MPa. With a 10% SCG replacement, the strength dropped to 1.71 MPa, a 39.32% reduction from the control. Further increases to 15% and 20% replacements resulted in strengths of 1.64 MPa and 1.54 MPa, corresponding to 41.88% and 45.41% reductions, respectively.

At 56 days, the control sample again performed best with a strength of 2.97 MPa. The 10% replacement achieved 1.84 MPa, showing a 38.13% decrease. The 15% and 20% replacements yielded 1.74 MPa and 1.58 MPa, representing 41.55% and 46.95% reductions, respectively.

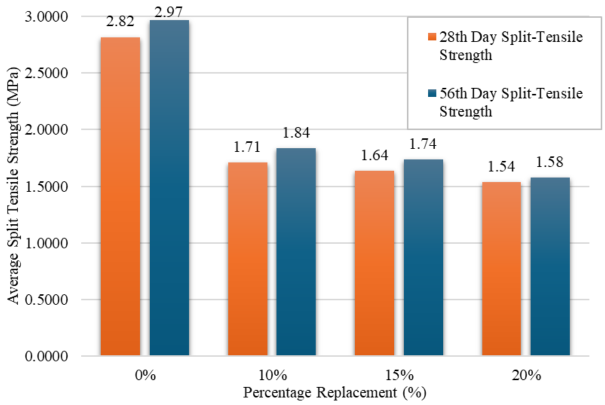

Fig. 5. Compressive strength at 28th and 56th day.

Over 28 to 56 days of curing, the control sample showed a 5.37% increase in split tensile strength. The 15% and 20% replacements had smaller gains of 5.98% and 2.41%, respectively; the 10% SCG replacement group displayed a somewhat higher gain of 7.44%. Though there were small changes over time, the general trend shows that partial sand replacement with pyrolyzed SCG drastically lowers split tensile strength.

Knowing tensile strength is crucial since tensile and compressive forces abound in concrete constructions. Based on ASTM C496, the indirect method known as the split tensile test guarantees structural integrity under various loads and helps evaluate the material's performance under tension. ASTM C496/496M states that although it is less than flexural strength, splitting tensile strength is usually higher than direct tensile strength. The design of structural lightweight concrete to assess its shear resistance depends much on this test.

Although pyrolyzed SCGs could be used in other fields [6, 17], these results reveal that their inclusion in concrete compromises split tensile strength. Consequently, the 0% replacement mix is the most efficient in terms of mechanical performance.

To further evaluate the data, t-tests were performed using a significance level of 0.05. Results showed that the 10%, 15%, and 20% SCG mixes were not significantly different. However, the control mix was statistically higher than the 10% replacement, confirming that pyrolyzed SCG negatively affects split tensile strength.

3.4 Correlation between Compressive and Tensile Strength

Compared to the compressive strength test results, concrete is evident as inherently strong in compression but weak in tension [18]. This characteristic is demonstrated by the consistently lower values of split tensile strength relative to compressive strength across all test samples. A widely recognized relationship between split tensile strength (f_t) and compressive strength (f’c) is described by the empirical formula presented in Eq. 1.

$$f_t = k\,(f'c)^n \qquad \text{(Eq. 1)}$$

Where: k = empirical constant, n = exponent typically ranging from 0.5 to 0.85, with 0.5 commonly adopted as the standard value in ACI 318-2014 [19].

Eq. 2 and Fig. 6 show the best-fit equation developed for this study based on experimental data. The coefficient of determination (R^2) is 0.9802, indicating a strong positive correlation between compressive and split tensile strengths [20, 21]. This high correlation suggests that the factors influencing compressive strength in concrete with SCG biochar as a partial sand replacement likely have a similar effect on tensile strength, reinforcing the interconnected nature of these mechanical properties.

$$f_t = 0.0004\,(f'c)^{0.5501} \qquad \text{(Eq. 2)}$$

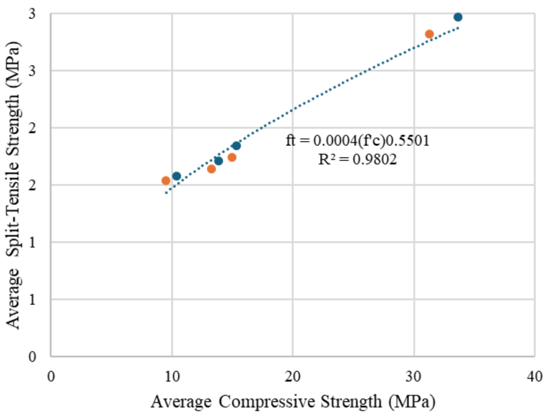

Fig. 6. Correlation between compressive and split tensile strengths

4. CONCLUSION

This study investigated the potential of pyrolyzed SCG (SCG biochar) as a partial replacement for sand in concrete mixtures. The results demonstrated that increasing the percentage of SCG biochar consistently led to reductions in compressive and split tensile strength at 28 and 56 days of curing. This decline in mechanical performance is attributed to the low specific gravity and high-water absorption rate of SCG biochar, which negatively affect the density and hydration of the concrete mix. Despite this, the SCG-modified concrete still met the strength requirements for non-load-bearing applications, such as blinding layers, non-load-bearing walls, and pavements. Furthermore, a strong correlation between compressive and split tensile strengths was established, indicating consistent mechanical behavior.

While the results confirm that SCG biochar is not suitable for structural concrete, its use in non-structural applications offers a promising approach to valorize coffee waste and promote more sustainable concrete practices.

Based on the findings of this study, several recommendations are proposed to guide future research. First, a comparative study should be conducted between volume-based and weight-based replacement of sand with pyrolyzed SCG. This would help identify the more effective replacement method for strength, durability, and sustainability. A deeper investigation into the performance of concrete with 5% SCG replacement by weight is encouraged, as this ratio showed potential in past studies. Second, to address the reduced workability observed in SCG-modified concrete, it is recommended that plasticizers be included in future mix designs. These admixtures may improve slump and workability without compromising strength, and the optimal dosage should be determined. Additionally, the effects of varying pyrolysis temperatures on SCG biochar should be studied, as temperature can influence its structure and performance in concrete. Future studies should also consider testing other important mechanical and durability properties such as flexural strength, modulus of elasticity, impact resistance, chloride penetration, freeze-thaw durability, and acid attack resistance. Since this study used SCG from a single source, it is also recommended that different types of coffee grounds be tested and their chemical composition analyzed to determine their suitability for construction use. Lastly, SCG biochar could also be explored as a cementitious material, not just as a sand replacement. Research in [22] suggests that biochar can help balance moisture and improve cement hydration, opening new opportunities for sustainable concrete applications.

5. REFERENCES

Cite at least two relevant articles from previse IEICES Proceedings (http://www.tj.kyushu-u.ac.jp/en/igses/ieices/proceedings.php)

[1] Bhattacharya, T. Khan, A. Ghosh, T., Kim, J.T., & Rhim, J.W., Advances and prospects for biochar utilization in food processing and packaging applications, Sustainable Materials and Technologies 39 (2024) e00831.

[2] Mishra, A. & Shinogi, Y. Effects of biochar on soil physico-chemical properties, Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 4, pp.102-105, 2018-10-18.

[3] Cerro, F.A., Algo, D.G., Luzorata, J.G., Bocobo, A.E., & Beltran, E.J., Development of Biofilter Using a Biochar from Pericarp of Durian, Mangosteen, and Banana in Reducing Nickel Concentration in Wastewater, pp. Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.347-352, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences.

[4] Mercado, K.O., Cabiltes, J.I., Manese, C.F., Ramos, D.S., & Lejano, B. Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.1212-1218, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences.

[5] Filho, L., Hunt, W., Lingos, J., Platje,A., Vieira, J., Will, L., & Gavriletea, M. (2021). The Unsustainable Use of Sand: Reporting on a Global Problem. Sustainability, 13(6), 3356. https://doi.org/10.3390/su13063356.

[6] Mahmoud, E., Atabani, A. E., & Badruddin, I. A. (2022). Valorization of spent coffee grounds for biogas production: A circular bioeconomy approach

for a biorefinery. Fuel, 328, 125296. https://doi.org/10.1016/j.fuel.2022.125296.
[7] Rivera, X. C. S., Gallego-Schmid, A., Najdanovic-Visak, V., & Azapagic, A. (2020). Life cycle environmental sustainability of valorisation routes for spent coffee grounds: From waste to resources. Resources, Conservation and Recycling, 157, 104751. https://doi.org/10.1016/j.resconrec.2020.104751
[8] Deng, M., Li, Q., Li, W., Lai, G., & Pan, Y. (2022). Impacts of Sand Mining Activities on the Wetland Ecosystem of Poyang Lake (China). Land, 11(8), 1364. https://doi.org/10.3390/land11081364.
[9] Franca, A. S., & Oliveira, L. S. (2022). Potential Uses of Spent Coffee Grounds in the Food Industry. Foods, 11(14), 2064. https://doi.org/10.3390/foods11142064.
[10] Forcina, A., Petrillo, A., Travaglioni, M., di Chiara, S., & De Felice, F. (2023). A comparative life cycle assessment of different spent coffee ground reuse strategies and a sensitivity analysis for verifying the environmental convenience based on the location of sites. Journal of Cleaner Production, 385, 135727. https://doi.org/10.1016/j.jclepro.2022.135727.
[11] Lejano, B., Elevado, K.J., Jarder, S.L., Arion, J.L., Capistrano, N.S., Ongpeng, Z., & Perez, A. (2024). Enhancing compressive strength in concrete with waste ceramic tiles: effects of selected aggregate modification treatments, water-cement ratio, and curing periods for decision tree regression analysis. Journal of Engineering Science & Technology, 19(3), 744-761.
[12] Roychand, R., Kilmartin-Lynch, S., Saberian, M., Li, J., Zhang, G., & Li, C. Q. (2023). Transforming spent coffee grounds into a valuable resource for the enhancement of concrete strength. Journal of Cleaner Production, 419, 138205. https://doi.org/10.1016/j.jclepro.2023.138205.
[13] Singh, V. K. (2023). Hydration and setting of Portland Cement. The Science and Technology of Cement and Other Hydraulic Binders, 423–466. https://doi.org/10.1016/b978-0-323-95080-0.00012-1.
[14] Mas, B., Cladera, A., Olmo, T. del, & Pitarch, F. (2012). Influence of the amount of mixed recycled aggregates on the properties of concrete for non-structural use. Construction and Building Materials, 27(1), 612–622. https://doi.org/10.1016/j.conbuildmat.2011.06.073,
[15] Ali, S. S., Ijaz, N., Aman, N., & Noor, Engr. M. (2017). Feasibility study of low density waste plastic in non load bearing asphalt pavement in District faisalabad. Earth Sciences Pakistan, 1(2), 17–18. https://doi.org/10.26480/esp.02.2017.17.18 .
[16] Pitroda, J., & Bhut, K. (2016). A critical review on Non-Load bearing wall based on different materials. International Journal of Constructive Research in Civil Engineering, 2(4). https://doi.org/10.20431/2454-8693.0204005.
[17] Adelfio, L., La Scalia, G., La Fata, C. M., & Giallanza, A. (2022). Life cycle analysis of innovative building materials based on circular coffee ground supply chain. Transportation Research Procedia, 67, 100–108. https://doi.org/10.1016/j.trpro.2022.12.040.
[18] Wu, S., Chen, X., & Zhou, J. (2012). Tensile strength of concrete under static and intermediate strain rates: Correlated results from different testing methods. Nuclear Engineering and Design, 250, 173–183. https://doi.org/10.1016/j.nucengdes.2012.05.004.
[19] Ahmed, F. B., Ahsan, K. A., Shariff, T., & Meem, S. R. (2021). Formulation of polynomial equation predicting the splitting tensile strength of concrete. Materials Today: Proceedings, 38, 3269–3278. https://doi.org/10.1016/j.matpr.2020.10.017.
[20] Akoglu, H. (2018). User's guide to correlation coefficients. Turkish Journal of Emergency Medicine/TüRkiye Acil Tıp Dergisi, 18(3), 91–93. https://doi.org/10.1016/j.tjem.2018.08.001.
[21] Schober P, Boer C, Schwarte LA. Correlation Coefficients: Appropriate Use and Interpretation. Anesth Analg. 2018 May;126(5):1763-1768. doi: 10.1213/ANE.0000000000002864. PMID: 29481436.
[22] Mensah, R.A.; Shanmugam, V.; Narayanan, S.; Razavi, N.; Ulfberg, A.; Blanksvärd, T.; Sayahi, F.; Simonsson, P.; Reinke, B.; Försth, M.; et al. Biochar-Added Cementitious Materials—A Review on Mechanical, Thermal, and Environmental Properties. Sustainability 2021, 13, 9336. https://doi.org/10.3390/su13169336