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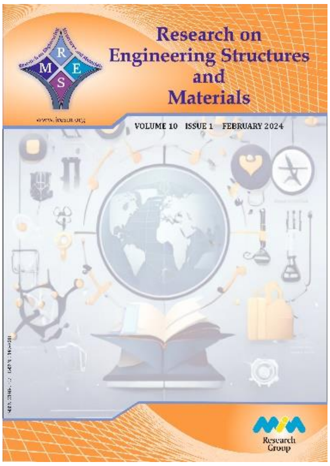

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Research Article

Effects of sugarcane bagasse ash as partial replacement of cement in the compressive strength and light transmissibility of Litracon blocks

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Abstract

Living up to a culture of sustainability and efficiency, the Light Transmitting Concrete or Litracon came to its prominence recently. Aside from that, the increase in the production of cement for building structures to facilitate various social dynamics has contributed to the world's exponentially increasing carbon emissions. Thereby, this study acts upon both phenomena by partially replacing the cement in the concrete mix for producing Litracon blocks using an agricultural waste material called Sugarcane Bagasse Ash or SCBA while aiming to improve their structural performance. The study used five (5) mix designs of 2.5%, 5%, 7.5%, and 10% replacements, and a controlled mix with no replacement. Three (3) cubic samples of 150 mm side dimension for each mix were subjected to the light transmissibility test before the compressive strength test. Results showed that the illumination values in lux of 103 to 120 were at par with the Philippine illumination guidelines for interior rooms, from 100 to 150. Moreover, the highest recorded compressive strength result with SCBA percentage replacement was the 5% design mix at 28.81 MPa, and the 2.5% design mix had the lowest recorded compressive strength of 23.51 MPa. The results further showed that even with no significant relationship between the percentage replacements and compressive strength values from the two-tailed T-test, no significant difference between such strength values was found using the One-way ANOVA test. Thus, this supports the claim that SCBA can partially replace the cement used for the concrete mix of Litracon blocks.

1. Introduction

The world is recently aiming for producing innovative materials and practicing efficient energy consumption. Heeding such a call is an important step towards building a sustainable future. This is in line with the Sustainable Development Goal (SDG) 9 of the United Nations, which focuses on promoting the use of renewable sources, efficient use of energy, and reducing pollution, when it comes to constructing structures [1]. This is due to the need to create healthy environments and spaces upon which people can thrive and foster conducive areas of innovation for continuous social development. In this regard, Litracon has the potential to encapsulate what the SDG stands for. The Light Transmitting Concrete or Litracon is a concrete block with optic fibers that span its entire thickness. It can be stacked together as blocks that become a light-transmitting load-bearing partition, with the purpose of increasing the illumination of a room upon which it is contained. With

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this, it aims to reduce the amount of lighting and the resulting energy required to light up habitable spaces [2], [3].

Since this concrete block can reduce energy consumption, the study conducted by Navabi et al. [4] supported the idea of developing light transmitting concrete. Consequently, their study analyzed the light transmittance and energy efficiency of using Litracon blocks as partitions in structures that were built in some of the world's highly urbanized cities. Hence, the Canadian City of Vancouver has reported an almost 30% savings for structures with Litracon partitions compared to the global average. Similarly, the state capital of Arizona, USA, City of Phoenix and the capital of Iran, City of Tehran, despite being on opposite sides of the world, recorded an almost 46% reduction in electricity cost upon utilizing Litracon partitions compared to regular structures. These findings imply that Litracon supports the fulfillment of the aforementioned SDG by being an innovative construction material that promotes efficient energy consumption for illumination purposes.

Having recently been invented in the year 2001, the concrete block has left some gaps unaddressed, particularly in the need to improve its performance in terms of compressive strength. The study of Navabi [5] found that there was an inversely proportional relationship between the volume of optic fibers used and the resulting compressive strength. The addition of optic fibers reduced the compression area in which concrete showed greater resistance. Aside from that, various studies arrived at a consensus that calls for the improvement of the compressive strength of Litracon [6]-[8]. This is because it can be subjected to compressive stress when used as materials for exterior walls which carry loads from beams and slabs [9]. Hence, the conventional Litracon blocks can achieve a compressive strength of 15 MPa [10] or up to 19 MPa [11], which makes the block suitable only for use in architectural partition walls.

Moreover, since Litracon is composed of cement, the production of this block also aimed to lessen the cement usage in the construction industry, apart from attempting to solve the problem of excessive energy consumption from illumination. Various construction projects globally, particularly in the Philippines that used reinforced concrete structures, have been a common sight, which has led to an increase in cement production [12]. In an article by Mangi et al. [13], it was stated that cement production was accountable for almost 5% of the total metric tons of human-induced carbon dioxide pollution annually. This implied that for every ton of cement produced, a tenth of a ton of carbon dioxide was released. Given the essence of cement, it would be important to note that its production needs not to be eliminated; rather, there should be efforts to not contribute to its pollution.

In addressing the aforementioned problems, it is where the use of Sugarcane Bagasse Ash (SCBA) as partial cement replacement had been drawn from. In the province of Cotabato, Philippines, it has a thriving sugar industry that is also involved in tropical fruits, vegetables, and livestock. The province is hailed as Mindanao's Food Basket and is one of the major sugar-producing provinces in the Philippines [14]. Henceforth, the province is home to numerous sugarcane production facilities, where burning of the bagasse, from which sugarcane juice is extracted, is a necessary step to facilitate the reduction of such extracted concentration to produce raw sugar [15]. It was said that for every bagasse, the resulting volume of ash would be equivalent to around 8% of the original bagasse volume [16]. This in turn, leaves behind a lot of SCBA, which can consume valuable spaces and be harmful to the environment through polluting water bodies and affecting the air quality [17]. This has been a recurring concern for those facilities, especially the Philippine Department of Environment and Natural Resources (DENR) through its Solid Waste Management Act and Clean Water Act [18]. Thus, the problems implied the need for initiatives to lessen its accumulation while maximizing its use. For this reason, the study came up with the idea of utilizing it to partially replace cement in the production of Litracon. Not only did it lessen the amount of cement to be used, but it also reduced the cost required to produce cement [15]. In addition, the pozzolanic nature of SCBA can be used as an advantage which improved Litracon blocks' structural performance.

One theory that supported the potentiality of using SCBA as partial cement replacement is its silica content and how it aids in the compressive strength performance of concrete. It can be noted that it consists of a lot of silica, which is an important component of cement that aided in binding the compositions of the concrete mix and created better bonds during the concrete hardening process. The use of SCBA was promoted in the study of Mangi et al. [13], wherein cylindrical concrete blocks having concrete mixtures with 5% and 10% replacements using SCBA, exhibited a better compressive strength performance compared to a regular concrete sample with no SCBA replacement. Another study by Hussien & Oan [19] revealed that the 5% cement replacement using SCBA for a cylindrical concrete block showed the optimum compressive strength that was beyond that of the controlled sample, as well as those with 7.5% and 10% replacements. Other studies, such as the one conducted by Bahurudeen et al. [20] used cubic samples of 150 mm side dimension with 5%, 10%, 15%, 20%, and 25% cement replacement percentages with SCBA. They found out that even with just marginal differences in compressive strength values, such differences were insignificant, which implied that concrete with SCBA can compete with the controlled sample.

Delving deeper into the performance of concrete blocks with SCBA replacements, another study by Garrett et al. [21] incorporated the SCBA with another pozzolanic material using Rice Husk Ash (RHA). It investigated the compressive strength of the samples when cured using seawater for 28^{th} days and 6^{th} months. Such a study found out that all samples, with 10%, 20%, and 30% replacements each of SCBA and RHA, exhibited minimal variance in terms of the resulting compressive strength. This meant that the controlled and uncontrolled samples have insignificant differences in the compressive strength. Also, the study of Kumar Reddy et al. [22] investigated the impact of sulfate attack for concrete blocks with SCBA as partial cement replacement by curing the samples in a 5% magnesium sulfate solution. It was found that the samples with SCBA fared better than the controlled sample in the compressive strength performance.

Contextualizing the idea in those existing literatures [13], [19]-[22], it can be implied that the use of SCBA for partial replacement of cement in Litracon blocks further enhanced the sustainability by lessening the use of cement. Hence, no partial replacement of cement in the existing studies pertaining to the concrete mix has been conducted to produce Litracon blocks. Thus, this study particularly sought to address the need to improve its compressive strength performance, from the conventional strength as specified in the study of Swain et al. [10] and Loganayagan et al. [11], since the SCBA is abundant in silica content and has a pozzolanic nature. This also lessened the buildup of agricultural waste that otherwise would have consumed valuable spaces, harmed surrounding ecosystems, and contributed to the exponentially increasing carbon emissions caused by the production of cement. Conversely, light transmissibility was further investigated to enhance the light transmittance considering the improvement of compressive strength of the Litracon block. Thus, it aspired to turn Litracon blocks into a more innovative and sustainable construction material that responded to the call for climate action to benefit the environment and people and helped the sugar industry deal with SCBA waste accumulation.

This present study aimed to determine the compressive strength and light transmissibility of Litracon blocks with partial replacement of cement using SCBA. The study specifically aimed to develop such blocks using five (5) cement replacement percentages by mass which are 2.5%, 5%, 7.5%, and 10%, including 0% as controlled replacement using SCBA, which were subjected to compressive strength and light transmissibility tests. With those tests, the study determined the compressive strength and light transmissibility of the Litracon blocks, subsequently comparing the results with standard illumination ranges as per the Philippine Department of Energy guidelines [21]. It also discussed how optic fibers were bonded with the concrete mix and how their placement was secured through the Scanning Electron Microscopy (SEM) Interpretation. Lastly, the study also determined the significant difference in the results of the compressive strength test and their correlation through two (2) statistical tools, namely, One-way ANOVA (Analysis of Variance) and two-tailed T-test.

2. Methodology

2.1. Cement, Coarse Sand, Sugarcane Bagasse Ash, Plastic Optic Fiber, and Cubic Mold Materials

The quantity of materials, particularly cement and coarse sand, had adopted the mortar-based concrete ratio as concrete block samples in this study [24]. The design of Litracon blocks has uniform dimensions with a side measurement of 150 mm for all samples, as shown in Figure 1. The use of the 150 mm thickness followed the minimum architectural convention regarding the thickness of exterior and interior walls, which was the recommended use as a product of this study.

Fig. 1. Litracon samples before failure stage

Generally, Ordinary Portland Cement of grade 33 was used in making the Litracon samples for this study. It was commercially sourced from a local supplier in Tugbok District, Davao City, Philippines using bags that contain 40 kilograms (kg). To ensure the use of good quality cement, the test procedures included the determination of specific gravity through ASTM C188 [25] and unit weight through ASTM C138 [26]. It was carried out at the laboratory of the Civil Engineering Department at Ateneo de Davao University, Davao City, Philippines, wherein a unit weight of 1090 kilograms per cubic meter (kg/cu.m) and a specific gravity of 3.15 were found. Table 1 shows the properties of the Ordinary Portland Cement.

Table 1. Properties of ordinary portland cement

Materials	Grade	Weight (kg/bag)	Unit Weight (kg/cu.m)	Specific Gravity (SSD)
Cement	33	40	1090	3.15

The coarse sand aggregates were quarried from Matalam, Cotabato Province, Philippines. The purpose behind using this kind of aggregate was to explore its potential for being used in Litracon blocks. Most of the related literature pertaining to Litracon involved either the use of only fine sand for mortar-based ones [5], [6], [27] or fine sand and gravel [28] for structural concrete. Hence, this present study intended to contribute new knowledge by exploring the possibilities of using coarse sand for Litracon blocks. Apart from washing these aggregates, these test procedures were conducted to determine if the material was at par with ASTM standards in ensuring the production of good quality Litracon samples. The coarse sand material underwent tests which involved sieve analysis and fineness modulus with ASTM D2487 [29] as the reference standard, as well as specific gravity, water absorption, and unit weight based on the ASTM C128 [30]. The mentioned tests were performed at the laboratory of the Civil Engineering Department at Ateneo de Davao University, Davao City, Philippines. Table 2 shows the results of the conducted quality tests for coarse sand to determine its properties.

Table 2. Properties of coarse sand

Materials	Specific Gravity (SSD)	Unit Weight (kg/cu.m)	Water Absorption (%)	Fineness Modulus
Coarse Sand	2.80	27.47	1.43	6.30

The Sugarcane Bagasse Ash (SCBA), as shown in Figure 2, was sourced out from the Cotabato Sugar Central Company, Incorporated at the town of Matalam, Cotabato Province, Philippines. Similar to the coarse sand used in this study, this material also underwent test procedures to determine the specific gravity, unit weight, water absorption, and fineness modulus. Investigating those properties was of prime importance, as this material would be the main subject of this study. Besides, it is common knowledge in the field of Civil Engineering that cement also contains Silica, which usually ranges from a fifth to a quarter of its mass [24]. The study theorized that SCBA aided in introducing better bonds between the components of the concrete mix while the samples were being cured, as implied by the study of Bahurudeen et al. [20].

Fig. 2. Bagasse Ash used for this study

As previously discussed, a lot of studies have supported the use of SCBA to partially replace cement due to its Silica content and pozzolanic nature. Thereby, its silica content was also determined, and it was done using Gravimetry Analysis. The Gravimetry Analysis was performed in the Chemistry Analytical and Research Laboratory at Ateneo de Davao University, Davao City, Philippines, and the determination of SCBA properties was still conducted in the Civil Engineering Laboratory at Ateneo de Davao University, Davao City, Philippines. The study of Norsuraya et al. [31] stated that the silica content of some agricultural waste materials such as SCBA typically ranged from 50% to 95%, but a 95% result was highly suggested for studies that aimed to take advantage of its silica content. However, this entailed burning them in a furnace to a thousand degrees Celsius (1000 °C) for four (4) hours, apart from outsourcing them as ashes from factories. With the study aiming to help the sugarcane industry in the Cotabato Province of the Philippines to eliminate the accumulation of SCBA, it was decided that the ashes would be outsourced as is. It did not undergo another type of process for this study to determine if such state of the SCBA would still be deemed enough to partially replace cement and act upon the accumulation of ashes. Table 3 shows the results of the properties of SCBA with 59.78% silica content.

Table 3. Properties of Sugarcane Bagasse Ash

Materials	Specific Gravity (SSD)	Unit Weight (kg/cu.m)	Water Absorption (%)	Fineness Modulus	Silica Content (%)
SCBA	2.14	21.02	366.67	2.95	59.78

Furthermore, optic fibers as light illumination materials were purchased from a local hardware store in Davao City, Philippines. The fibers used were 3 mm diameter, each measuring 200 mm in length, shown in Figure 3. With each sample containing 36 fibers, the total length used for one sample was 7.2 m. The use of 36 fibers was in accordance with the limitations set by this study regarding the percentage of fibers (POF) being limited to one percent of the sample's surface area. The excess length had been accounted for in this measurement, with the purpose of having an allowance for gripping them to eliminate potential sag and straightening them during concrete pouring and tamping. This also highlighted the reason behind using only 36 optic fibers per sample, as it made it easier to manage their placement inside the mold. The said excess length was cut with the use of a cable cutter after the samples were removed from their molds, being a variable of light transmissibility.

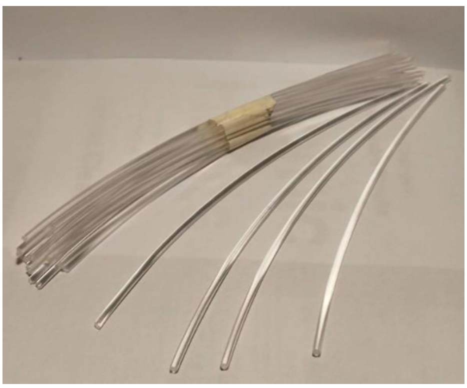

Fig. 3. Optic Fibers used for this study

The verification and legitimacy of the locally purchased optic fibers were supported by the Scanning Electron Microscopy-Energy Dispersive X-Ray or SEM-EDX Analysis. After samples were subjected to the compressive strength test, a portion of one of them was analyzed through a microscope. This was to have a detailed and magnified view as to how the optic fibers bonded with the concrete mix after it had reached the failure stage. Simultaneously, the elemental composition of the sample was determined while the SEM images were being produced. The elements occupying each pixel were identified to determine their respective percentage. Of the entire image, 37.44% of it was identified as an element of optic fiber. Table 4 shows such composition, with the three rows showing elements that verified the legitimacy of the optic fibers procured for this study. The analysis was conducted in the Chemistry Analytical and Research Laboratory at the Ateneo de Davao University, Davao City, Philippines.

Table 4. Elements of optic fiber

Elements	App. Con	Intensity	Weight (%)	Weight (%) Sigma	Atomic Percent
Fluorine (F K)	332319.50	0.2013	44.25	1.35	36.54
Aluminum (Al K)	11170.29	0.6598	0.45	0.05	0.26
Silicon (Si K)	32979.42	0.7702	1.15	0.07	0.64

Lastly, the Litracon samples were of uniform dimensions, with a side dimension of 150 mm and were molded in a half-of-an-inch thick phenolic board, as shown in Figure 4. Using such material for casting the concrete mix for this study provided a smooth surface for the blocks produced. Since Litracon blocks were stacked into partitions, plumbness or straightness was achieved when the blocks were mortared and installed by adhesion. Furthermore, compared to other ordinary casting materials, its durability and moisture resistance make a good formwork material to ensure that no external factors can affect the concrete block hardening process [32].

Fig. 4. Molds using phenolic board

2.2. Litracon Block Samples and Design Mixtures

This study produced twenty (20) Litracon blocks, which were then grouped into five (5) based on the design mixtures. To determine the structural performance of each design mixture, three (3) repetitions of tests were conducted [32]. Additionally, the researchers included one (1) extra sample for each design mix, as a precaution in case any samples from the three (3) test repetitions were exposed to unforeseen conditions. Thus, of the 20 samples, only fifteen (15) were subjected to the tests and statistical analysis. Moreover, the design mixture used in every Litracon block employed a 1:2 ratio of cement-coarse sand materials. This ratio was based on class-A mortar-based concrete with a mix ratio of one part cement to two parts coarse sand. This study used 0.45 water-cement (W/C) ratio for every volume of concrete block sample in each design mixture [24], as shown in Table 5.

Table 5. Quantities and Ingredients of Litracon Block

Mix Designs	Volume (m^3)	W/C Ratio	Water (kg)	Cement (kg)	Coarse Sand (m^3)	SCBA (kg)	Optic Fibers (m)
Control Mix (0% SCBA)	0.003375	0.45	1.094	2.43	0.003375	0	7.2
Design Mix - A (2.5% SCBA)	0.003375	0.45	1.094	2.369	0.003375	0.0675	7.2
Design Mix - B (5% SCBA)	0.003375	0.45	1.094	2.308	0.003375	0.1215	7.2
Design Mix - C (7.5% SCBA)	0.003375	0.45	1.094	2.248	0.003375	0.1822	7.2
Design Mix - D (10% SCBA)	0.003375	0.45	1.094	2.187	0.003375	0.243	7.2

This study employed five (5) varied replacement percentages of cement based on its mass. The following were 2.5%, 5%, 7.5%, and 10%; however, the design mixture also included 0% replacement as controlled design mixture. In the study of Mangi et al. [13] and Hussien & Oan [19], the percentages ranged from 0% to 10%, with the 5% sample exhibiting the optimum compressive strength. For this reason, this present study wanted to investigate the results if a 2.5% increment would be implemented, hence the inclusion of the 2.5% and 7.5% replacement percentages. Moreover, tap water that was free from objectionable matter was used to mix the dry materials of Litracon blocks. The partial cement replacement took place by subtracting the percentage to be replaced by SCBA. Also in Table 5 were the calculated quantities of design mixtures used for each one (1) concrete block sample which also considered the multipliers to quantify each mixture. The volume of the sample was taken as the volume of the coarse sand used while the multiplier of 18 and the 40-kilogram constant were multiplied with the volume to get the required mass for cement.

2.3. Litracon Blocks Making, Curing Procedure, and Series of Tests

2.3.1. Production of Litracon Blocks and Workability Test

After preparing all the materials needed to make Litracon blocks, the sample-making process proceeded by following all the provided design mixtures listed in Table 5. Subsequently, all the materials were mixed and blended in a 500-liter capacity one-bagger mixer. Generally, the mixing process of concrete involved blending the bagasse ash with cement and coarse sand based on its percentage of replacement, which was often added to make a uniform and cohesive mixture. All samples were produced in only one (1) batch of mixture for each design mix to ensure adequate results for the series of tests conducted. The sample-making was performed at Tugbok District, Davao City, Philippines.

Thereafter, each batch of mixes after mixing all materials was subjected to the slump test in compliance with the ASTM C143 [33] to determine its workability. Once the workability in each design mixture was determined, the mixes were poured onto their respective molds, shown in Figure 5. The samples were then left undisturbed for twenty-four (24) hours before being submerged in a water bath for curing, which lasted for twenty-eight (28) days. The curing procedure was in accordance with ASTM C31 [33], and all samples were submerged in a curing pond where the sample-making was conducted.

Fig. 5. Samples casted on the molds

2.3.2. Light Transmissibility Test

When the curing period for the 28th day was over, samples were tested for light transmissibility before they were subjected to the compressive strength test. This study adopted the light transmissibility test performed in the study of Tahwia et al. [34]. In this test, the illumination values in lux were recorded using a lux meter, as presented in Figure 6. The study tested the light transmissibility of one (1) sample per percentage replacement of Litracon block and compared it to the standard illumination ranges provided by the Department of Energy (DOE) illumination guidelines in the Philippines [23].

A clear image of the entire setup has not been captured because it was conducted in a dark area for accurate results. With this, Figure 7 is presented to show the setup of the light transmissibility test, which was performed in Tugbok District, Davao City, Philippines. In the study conducted by Tahwia et. al [34], about the translucent self-compacting concrete (TSCC), Litracon block samples were subjected to light transmittance test using a Light-Dependent Resistor (LDR) setup as an electrical circuit to measure the current corresponding to the total amount of light passing throughout the specimens. The electrical circuit was set with a 100-ohm resistance and a uniform DC voltage of ten volts (V), but only in the event of voltage variation did the 10V uniform voltage had become 20V and 30V, respectively. Three (3) incandescent lights with wattages (W) of 9W, 20W, and 35W were placed in the middle of each Litracon block sample to demonstrate the fluctuation in light source to attain the desired degree of light intensity. In this present study, a lux meter was used to measure the intensity of light transmittance.

Fig. 6. Lux meter used for the Light Transmissibility Test

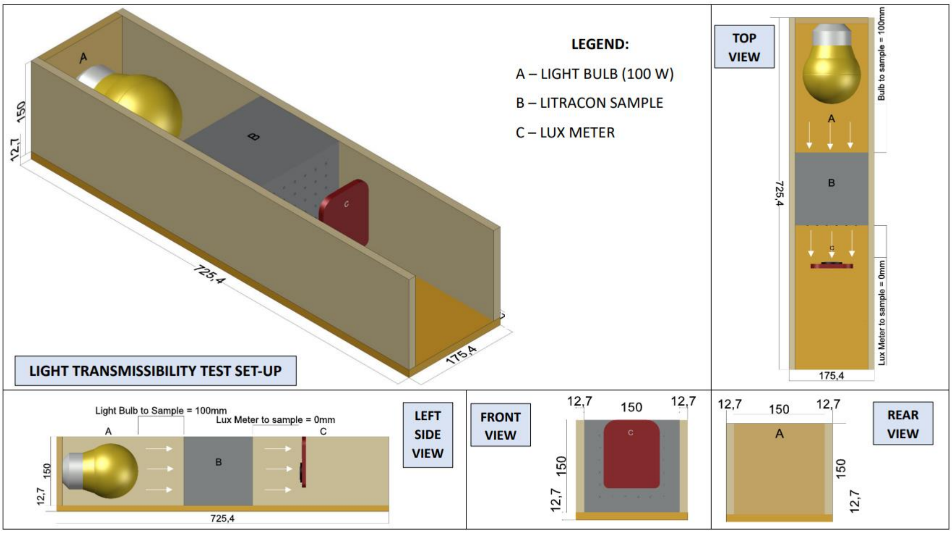

Fig. 7. Illustration of the Light Transmissibility Test setup

It is important to note that a reference standard cannot be found when it comes to this specific test, which is why this study resorted to following the setup of the study by Tahwia et al. [34]. Hence, such setup was set forth for optimum light transmittance during light transmissibility test. Furthermore, the dimensions were restricted to encapsulate the sample, light bulb, and lux meter only. It was made out of phenolic board of the same thickness similar to the formwork material molds used to cast the samples. The actual setup is presented in Figure 8.

Fig. 8. Light transmissibility test setup without the sample, cover, and lux meter

To commence the test, the researchers placed each sample 100 mm from the light source as presented in Figure 9. Afterwards, the sample was covered with another phenolic board, leaving a small hole to insert the lux meter, and recorded the reading when the values have no longer fluctuated. With this, the test needs not to be conducted at a time or place with lighting that can be deemed sufficient to affect the readings from the lux meter. Thereby, the test took place in a dark area at night, around 7 in the evening, with the hole for inserting the lux meter further covered with paper and cloth to eliminate the passage of external light rays that would have otherwise affected the data.

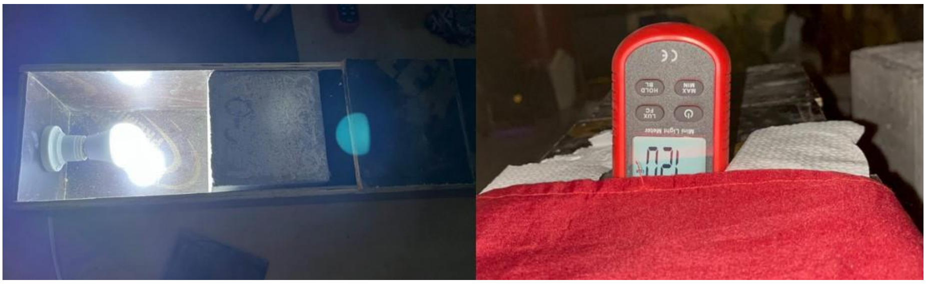

Fig. 9. Light transmissibility test setup without the sample, cover, and lux meter

The results were then compared to the standard illumination ranges by the DOE [23]. However, no statistical analysis was conducted to interpret the results apart from indicating upon which range of values the obtained results fall onto for certain occupancy types such as exterior rooms, tropical public spaces, and interior rooms. The reason behind was that the optic fiber in every sample remained constant, and no variation was made to produce the Litracon blocks in this present study. Moreover, a study about Litracon could not be completed without conducting a light transmissibility test, as its light transmittance was its essence, which made it unique among other types of blocks used for constructing structural partitions.

2.3.3. Compressive Strength Test

After conducting the light transmissibility test, the compressive strength test for each sample was then followed to determine the compressive structural performance of each design mixture. With the recent invention of Litracon in the year 2001, a reference specification for testing its compressive strength was yet to be standardized. The relevant studies cited to have either adopted their country's national standard [35] or used the testing procedures by widely accepted standards such as ASTM C39 [36] and ASTM C109 [8], [37]. In this study, the samples were of uniform measurements with 150 mm side dimension in accordance with IS 516-1959 [38] to conform to the minimum requirement for exterior structural partitions [24]. Thus, the compressive strength test conformed to the procedure outlined in ASTM C109, but the dimensions were in accordance with IS 516-1959. This test was executed at AC JOYO Design and Technical Services in Davao City, Philippines.

2.3.4. Scanning Electron Microscopy (SEM) Interpretation

The Scanning Electron Microscopy (SEM) Interpretation was conducted subsequent to the compressive strength test, where the samples underwent failure. This was meant to demonstrate the placement of the optic fibers and their binding capability with other components of the concrete mix. High-resolution images were provided and interpreted thereafter. The sample with high compressive strength result was selected for further evaluation through SEM analysis. Hence, a small-sized specimen was cut, shown in Figure 10, and the optic fiber was exposed to analyze the bond characteristic within the concrete mix. The standard area of the specimen for SEM Analysis ranges from approximately 1 cm to 5 microns in width, and the specimen was obtained from the samples with the optimum percentage for replacing cement with SCBA. The result was done and interpreted, wherein no parameters were measured or compared, but the images were presented to understand the sample's mode of failure. This test was conducted in the Chemistry Analytical and Research Laboratory at the Ateneo de Davao University, Davao City, Philippines.

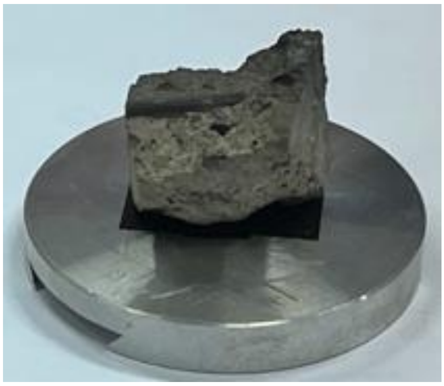

Fig. 10. Portion of the Sample for SEM-EDX Analysis

2.4. Statistical Analysis

The study utilized two (2) statistical tools to evaluate the response of the variables considered. The two-tailed T-test and the One-way Analysis of Variance (ANOVA) were employed with 95% confidence level (p<0.05). For the T-test, the means of the resulting compressive strength results as dependent variable for all design mixtures, as well as their corresponding slump measurement as dependent variable, were compared vis-a-vis the partial cement replacement percentages as independent variable in the design mixture. This test determined whether there is a significant relationship, or there is no significant relationship between the former mentioned dependent variable, and the latter mentioned independent variable. In contrast, for the One-way ANOVA test, it determined if there is a significant difference between the results obtained after all samples were subjected to the compressive strength test.

The T-test formulated two hypotheses in this study. First, the null hypothesis, which stated that there is no significant relationship between the partial cement replacement percentages versus the slump measurement and compressive strength results. Second, the alternative hypothesis, which connoted a significant relationship between those variables. For the One-way ANOVA, the null hypothesis is that there is no significant difference between the compressive strength values, while a significant difference is anticipated for the alternative hypothesis. The statistical analysis was accomplished using the IBM® SPSS® statistics software version 22.0 [39] at the University Information Technology Office in Ateneo de Davao University, Davao City, Philippines.

3. Results and Discussion

3.1. Workability of Design Mixtures

The parameter used to describe the workability of the design mixtures tested in this study was the slump distance in accordance with ASTM C143 [33], with the exception that no coarse aggregate was used in the concrete mix. Table 6 shows the results of the slump test conducted, wherein an increased slump distance was observed as the percentage replacement also increased. The highest value was obtained for the 10% mix design with a slump distance of 6.8 inches. On the other hand, the lowest slump distance was recorded of 2 inches by the controlled mix.

Table 6. Results of the slump test

Mix Designs	Slump Distance (in.)
Control Mix (0% SCBA)	2.00
Design Mix-A (2.5% SCBA)	3.70
Design Mix-B (5% SCBA)	4.50
Design Mix-C (7.5% SCBA)	6.60
Design Mix-D (10% SCBA)	6.80

It was important to note that the results of the slump test were within the limits set forth by ASTM C143 [33]. Regardless of the type, it must neither have too high nor too low slump values, as the compressive strength was inversely proportional to the workability. However, the need for a workable concrete was necessary in this study for the samples to be easily placed and avoid segregation, which attained the desired design strength. For this reason, the slump distance of 2 inches was within the standard limit, which meant that despite being the least workable among the other design mixtures, it still satisfied the need to be easily molded. Similar to that of the 10% mix design with a slump distance of 6.8 inches, it was still covered by the upper limit set forth by the reference standard. It was the most workable, yet it was not to the point that the components of the concrete mix became segregated.

With the results presented in the same table, it can be interpreted that there was a directly proportional relationship between the slump values and the replacement percentages. It was observed that an increase in cement replacement by SCBA had led to a concrete mix that became consolidated and properly placed without segregation while the samples were being cured. The obtained slump values ranged from 2 inches to 6.8 inches and were within the limits of the reference standard. It can be interpreted that all samples, regardless of the design mixture, exhibited the required plasticity and cohesion while they were being poured onto their respective molds.

It was also discussed in the study of Mangi et al. [13] that the partial replacement of cement by SCBA decreased the necessary amount of moisture for the concrete mix. With this, as more SCBA was added to each design mixture, the friction between the components of the mix was minimized, which resulted in an entire mixture behaving more like a fluid. Thus, SCBA provided additional plasticity to the consistency of concrete, and the use of superplasticizers may not be necessary. In addition, the use of a 0.45 W/C ratio, as a constant ratio in all design mixes, also allowed for SCBA to increase the fluidity of the concrete mix, which resulted in a linear increase within the standard range. Thus, the results of the slump test for the workability of concrete used in the Litracon blocks in this study implied that the SCBA contributed to a workable concrete with a watery texture without resistance to shear stress or too stiff that would lead to the formation of honeycombs and air voids in concrete.

3.2. Compressive Strength of Litracon Blocks

Testing the durability of concrete on its compressive strength was an important parameter for the structural performance of the Litracon blocks, as discussed herein. In Table 7, it can be seen that for a 28th-day curing period, the highest strength was attained by the controlled mix with 29.18 MPa, closely followed by the 5% design mix with 28.81 MPa, and the least value was achieved by the 2.5% design mix with 23.51 MPa. It was found that the obtained compressive strength in all mixtures was above the conventional compressive strength of Litracon blocks from 15 MPa [10] to 19 MPa [11], which could be categorized as a partition wall for architectural use. It can also be observed that the obtained compressive strength results for all design mixtures in this study were above the minimum requirement of 21 MPa (3000 psi) for structural concrete as per ACI 318 [40], considering that all Litracon blocks had no coarse aggregate in the design mix; hence it was classified as mortar-based.

Table 7. Results of the compressive strength test

Mix Designs	Sample 1 (MPa)	Sample 2 (MPa)	Sample 3 (MPa)	Average (MPa)
Control Mix (0% SCBA)	24.27	27.06	36.22	29.18
Design Mix-A (2.5% SCBA)	21.42	22.06	27.06	23.51
Design Mix-B (5% SCBA)	25.51	29.23	31.68	28.81
Design Mix-C (7.5% SCBA)	22.49	24.30	26.97	24.59
Design Mix-D (10% SCBA)	21.41	23.87	29.04	24.77

Although the 2.5% design mix exhibited the lowest compressive strength, it managed to attain such a minimum requirement and was still feasible for the concrete mix used to make Litracon blocks. Likewise, the 5% design mix, which was neither the lowest nor highest replacement percentage, exhibited the greatest strength among all mix designs with SCBA replacement. This also indicated that such a percentage was the optimum amount required to replace cement with SCBA for better structural performance in terms of compressive strength. Moreover, the average of all compressive strength per design mix can be understood that no relationship could be drawn from the results.

Noticeably, a differed results in the 0% to 5% samples can also be observed, while there was small variation for the remaining replacement percentages. The results indicated that regardless of whether or not a Litracon block has its cement component partially replaced by SCBA, it still performed as good as its controlled counterpart in terms of compressive strength. It might just be that smaller replacement percentages would have greater advantages in such a parameter, as indicated by Mangi et al. [13] and Hussien & Oan [19]. They mentioned in their respective studies that the 5% replacement exhibited the greatest compressive strength. Their findings were similar to the results of this study, with the only difference being that 5% was the optimum replacement percentage. However, both this present study and the mentioned studies observed a similar decreasing trend for replacement percentages greater than 5%. Hussien & Oan [19] have indicated that the sudden increase of compressive strength on the 5% replacement can be attributed to the pozzolanic interaction of the SCBA between the rest of the components of the concrete mix. They also mentioned that this pozzolanic interaction could be minimized for samples with SCBA replacement percentages greater than 5%. In the Litracon's compressive strength, Dos Henriques et al. [6] stated that the presence of voids in the optic fiber-concrete mix interface was accountable for the eminent compressive failure of Litracon blocks. They mentioned that the addition of optic fibers increased the air-void ratio around that interface.

Contextualizing those statements in the present study also indicated that the SCBA had contributed its pozzolanic ability to introduce pozzolanic interaction during the concrete hardening process. It may just be insufficient to strengthen the cementitious bonds in the optic fiber-concrete mix interface. Thus, it still presented a potential for increasing the compressive strength of any concrete mix for any purpose it may serve. Overall, these compressive strength values indicated that Litracon blocks with SCBA can be an effective partial cement replacement to lessen the amount of accumulated SCBA. Furthermore, understanding each sample's mode of failure mechanism showed similar patterns, as presented in Figure 11. As further noticed, the cracks primarily outlined the placement of the optic fibers. This was supported by the study of Dos Henriques et al. [6], wherein the first areas to crack were usually those that were near the optic fiber-concrete mix interface due to the existence of microscopic air voids enveloping the optic fiber surface. As discussed in the compressive strength test results, the pozzolanic action contributed by SCBA was not enough to counteract such an effect.

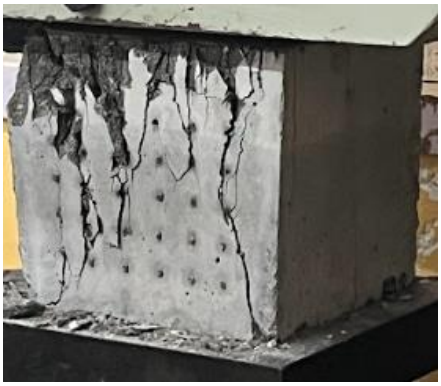

Fig. 11. Litracon block subjected to the compressive strength test

3.3. Light Transmissibility of Litracon Blocks

The results of the light transmissibility test were presented in Table 8, wherein a non-linear and inconclusive values were observed, similar to the results of the compressive strength test. Comparing them became irrational as the fiber optic was kept constant at 1%, with the 36 fibers on one sample placed in the same manner as in the other samples. Thus, results of little to no marginal differences were expected for this parameter. Hence, the obtained results ranged from 103 lux to 120 lux, which were interpreted by comparing them with the standard illumination ranges by the DOE [23]. Based on the guidelines, all the lux values for all samples were within the standard range of illumination. The minimum lux for open public spaces was 50 lux. On the contrary, for interior rooms, it ranged from 100 to 150 lux.

Table 8. Results of the light transmissibility test

Mix Designs	Luminance (Lux)
Control Mix (0% SCBA)	105
Design Mix-A (2.5% SCBA)	103
Design Mix-B (5% SCBA)	103
Design Mix-C (7.5% SCBA)	120
Design Mix-D (10% SCBA)	109

The results showed that the produced Litracon blocks can be good partitions for interior rooms since the results ranged from 103 to 120 lux. It can be noted that the lux meter was placed tangentially (Figure 7) to one sample's exterior surface to generate the readings. Since there was no reference standard for this test, using such a method of recording was deemed enough to represent the light transmissibility of the entire structural partition. Even though the light transmissibility results were not subjected to any statistical procedure, the marginal difference between the values obtained was deemed to be insignificantly different. It was highly attributed to the 1% configuration of optic fibers among all samples.

This marginal difference also indicated that the optic fibers of one sample transmitted light illumination in a similar manner as in the other samples, as demonstrated in Figure 12. Contrary to the study of Navabi et al. [4], sensors were used to record the light transmittance and were placed in multiple areas, not just concentrated in one area that fronted one sample, as compared to the present study. Their light transmittance obtained from 300 lux to 1000 lux was greater compared to this present study, which ranged from 103 lux to 120 lux. Hence, their study also employed varying percentage of optic fiber (POF) ranging from 3% to 15%, compared to this study by only 1%. Nonetheless, this present study provided higher precedence on the structural performance of the compressive strength of the Litracon blocks while lessening the amount of cement to be utilized and acting upon the accumulation of SCBA simultaneously. However, this finding did not imply that the light transmissibility test results were obsolete, as conducting such a procedure would ensure that each produced Litracon block would not have eliminated its light-transmitting nature.

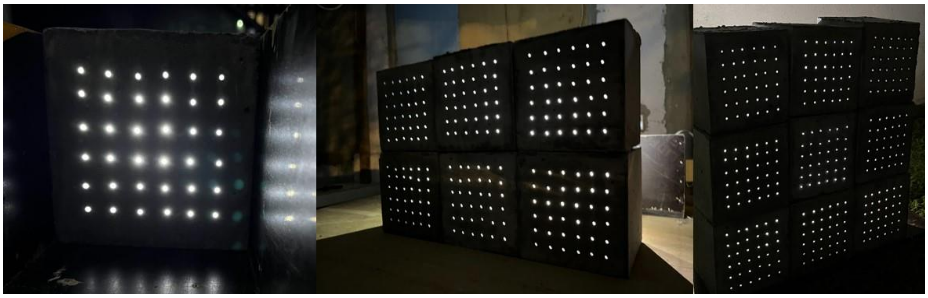

Fig. 12. Litracon block subjected to the compressive strength test

3.4. Interpretation between concrete and optic fiber

The Scanning Electron Microscopy (SEM) Interpretation was used to evaluate the microstructure of the concrete. This test was done after compressing the samples into failure during the compressive strength test. Thereafter, cracks were evident in the samples (Figure 11), and small specimens (Figure 10) were collected from these cracked areas for SEM analysis to investigate the bond between the concrete and optic fiber. Accordingly, it was the design mix with 5% SCBA that obtained the optimum compressive strength results for all design mixes with SCBA replacement.

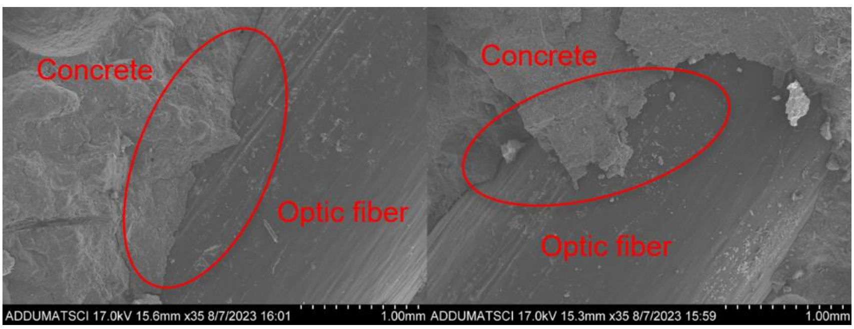

Fig. 13. Micro image of bond between concrete and fiber optic

Interpreting the SEM images for this study involved coming up with inferences pertaining to what was seen in the optic fiber-concrete mix interface. In Figure 13, it showed that the optic fiber had a scratched texture due to the roughness of the concrete. These images demonstrated that the roughness between the fiber optic and the concrete bonded effectively, which obtained in all compressive strength results above the minimum standard for structural concrete. On the other hand, these results had no significant effect on the optic fiber's light transmittance since the results of the light transmissibility test were within the standard range of illumination. Thus, it could still transmit light, considering the scratched texture defining its circumference.

Additionally, the surface area was negligible compared to the abundantly available volume of optic fiber in the Litracon blocks for transmitting light from one face to its opposite. Correspondingly, Figure 14 presented the optic fiber-concrete mix interface, which showed specks of concrete on the optic fiber's surface. The study interpreted this as evidence of some areas wherein concrete was bonded onto the optic fiber's surface. The contribution of SCBA's cement replacement to strengthening the cementitious bonds within that space was very prominent. This finding was also agreed in the study of Hussien & Oan [19]; however, the optic fiber-concrete mix interface provided minimal micro air voids, which potentially affected the compressive strength of the sample. Dos Henriques et al. [6] stated that achieving optimal concrete performance required minimal presence of air voids.

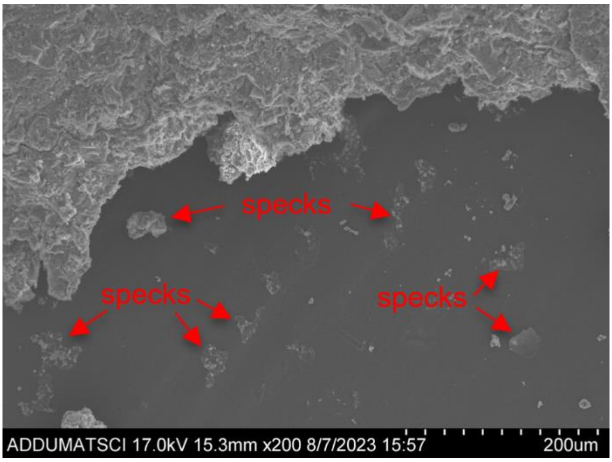

Fig. 14. Specks of concrete on the surface of optic fiber

The results herewith evidently adhered with minimal air voids, which achieved to all design mixes the best concrete performance on its compressive strength. Overall, the optic fibers have greatly provided a medium for transmitting light, which was also bonded on concrete with cement that was partially replaced with SCBA without compromising its integrity and effectiveness. Thus, Litracon blocks were not only aesthetically pleasing, but also a good construction material since there were no gaps or air voids produced when optic fibers and concrete bonded together.

3.5. Implications of the Obtained Slump and Compressive Strength Values

This section determined the true relationship between the incremental increase of cement replacement percentages by SCBA and the slump distance and compressive strength values, as well as the significant differences between the obtained results for both parameters. The IBM® SPSS® statistics software was used to determine the *p*-values and come up with a decision pertaining to the acceptance or rejection of the formulated hypotheses. Table 9 presented the results of the One-way ANOVA and T-test for the incremental increase of cement replacement percentages versus the slump values and compressive strength.

The *p*-value of 0.004 for the first comparison was obtained using the two-tailed T-test, which indicated that it was less than the significance level. Thus, there was a significant relationship between the partial cement replacement percentages and the resulting slump distance. This supported the claim that the addition of SCBA led to higher values for slump. This was also expressed in the study of Hussien & Oan [19] about using sugarcane waste in concrete for cylindrical blocks. What this implied was that adding SCBA led to concrete mixes that were workable and able to be cast onto their molds without impeding segregation between the components of the mix itself.

Table 9. Implications of the Obtained Slump and Compressive Strength Values

Variables	p-value vs. α-value	Remarks
T-Test for Workability Independent: SCBA Percentages Dependent: Obtained Slump Values	p = 0.004 α = 0.05 p< α, reject the null hypothesis in favor of the alternative hypothesis	There is a significant relationship between the increasing cement replacement percentages with SCBA and the resulting slump distance.
T-Test for Compressive Strength Independent: SCBA Percentages Dependent: Compressive Strength	p = 0.4281 α = 0.05 p> α, accept the null hypothesis	There is no significant relationship between the increasing cement replacement percentages with SCBA and the resulting compressive strength.
ANOVA for Compressive Strength Independent: SCBA Percentages Dependent: Compressive Strength	p = 0.3289 α = 0.05 p> α, accept the null hypothesis	There is no significant difference between the resulting compressive strength values.

For the second comparison, the p-value of 0.4281 was attained, which indicated a greater value than the confidence level considering the two-tailed T-test. With this, there was no significant relationship between the partial cement replacement percentages and the resulting compressive strength. This supported the claim about the compressive strength results wherein a nonlinear and inconclusive trend could be drawn from the individual results indicated per cement replacement percentage. However, the same table also showed that a p-value of 0.3289 was obtained in the ANOVA, which also signified that there was no significant difference between the compressive strength values. This also further implied that the marginal differences between each compressive strength value supported the findings that the partial replacement of cement by SCBA would not significantly provide a huge difference on the attained compressive strength on the structural performance of Litracon blocks.

4. Conclusions and Recommendation

The use of SCBA as a partial cement replacement percentage with optic fibers to produce Litracon blocks shows an optimum compressive strength of 28.81 MPa for the 5% design mix. The lowest compressive strength value was attained in the 2.5% design mix of 23.51 MPa. However, all samples were able to achieve above the minimum specified compressive strength of concrete on the 28th day of curing despite not being classified as structural concrete. The results of this study support the idea that using SCBA as partial cement replacement would entail reasonable compressive strength results not just for Litracon blocks but for other structures as well. These findings can also serve as a benchmark for enhancing the compressive strength of Litracon blocks by partially replacing the cement with bagasse ash by burning the bagasse at higher temperatures to achieve 95% pozzolanic materials. Hence, this study only utilized 59.78% silica content of the bagasse ash and has not been conducted to use SCBA with silica content greater than 95%. In addition, it is recommended to open the possibility for further research regarding the use of other pozzolanic agricultural waste materials.

Moreover, the SEM analysis further exhibited that the optic fiber-concrete mix interface had evidently provided an adequate bond, which strengthened the idea that SCBA, as a partial cement replacement, is effective. However, considering the results of the compressive strength, the design mixes have not affected the light transmissibility performance of Litracon blocks since the results have ranged from 103 lux to 120 lux and are within the standard range. The results of this study indicate further that Litracon blocks can be used as a good partition wall, achieving more than the required structural strength for load-bearing blocks. Hence, this result is beneficial to the construction industry by using this block without sacrificing the light transmissibility results. Also, the Litracon block in this study is capable of illuminating lights in living spaces within the Philippine Standard. Similarly, the resulting illumination values from the light transmissibility test fall under the range of illumination guidelines; this study can also be a benchmark for other researchers to explore different methods and mechanisms to better actualize the light-transmitting nature of Litracon blocks.

Overall, this study promoted the use of agricultural waste to produce a structural partition which also aided in the required illumination and energy consumption of habitable spaces. The aim to fulfill the mission of one of the United Nations' SDGs, which is about the innovative infrastructure and materials for construction, has been fulfilled by this study. This is because it produced a concrete block for structural partitions that aided in lessening the accumulation of SCBA. This is particularly important given that the material is a byproduct of the sugar industry in Matalam, Cotabato Province, Philippines, and is otherwise considered as an agricultural waste. By partially replacing cement with bagasse ash, this study shows promising results in terms of reducing both waste and energy consumption while also improving the compressive strength of Litracon blocks. In addition, it can be understood that reducing the use of cement promotes the sustainability of construction materials by dealing with accumulated agricultural waste such as sugarcane bagasse ash. Lastly, this study hopes that further research will be conducted to take advantage of other agricultural waste while building sustainable communities that foster places of innovation and thriving cultures around the world.

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