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OPTIMIZATION OF COMPRESSIVE STRENGTH OF WASTED SOFT DRINK CAN FIBER NON-LOAD BEARING CONCRETE HOLLOW BLOCKS

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ABSTRACT: The need to find solutions to recycle waste is becoming increasingly important as the amount of waste generated increases year after year. Thus, this study aims to enhance the durability and compressive strength of non-load-bearing concrete hollow blocks (CHB) with the inclusion of recycled soft-drink cans fibers as reinforcement. Response Surface Methodology (RSM) was used to model the relationship between the response and the factors considered. RSM was also used to determine the optimal mix proportion of the fiber content and fiber length in CHB to develop a model that could yield maximum compressive strength. As a result, the addition of soft drink can fiber content, and fiber length to CHB increased the compressive strength of the CHB. Furthermore, the results also indicated that an optimal combination of 3.0% soft drink can fiber content and 25mm fiber length would yield in compressive strength of 508.89 psi for CHB exceeding the Philippine National Standard’s (PNS's) minimum compressive strength criteria. From these findings, soft drink can fiber could be used in low-cost construction because they gradually increase the overall compressive strength of the CHB without requiring additional cement, resulting in cost savings and promotion of the utilization of this environmentally friendly product.

Keywords: Concrete Hollow Blocks, Fiber Reinforcement, Compressive Strength, Wasted Soft Drink Can Fiber, Response Surface Methodology

1. INTRODUCTION

The feasibility of using various waste materials as additional reinforcement for the primary concrete components is gaining attention nowadays. One such material in recent times is adding different fibers to the mixture of concrete to improve its compressive strength. Meanwhile, waste materials are continuously produced due to the modern industry; A substitute material made from recycled or waste materials is consequently required. Therefore, the objective of this research aims to increase the compressive strength of CHB with the inclusion of soft-drink cans as fiber reinforcement into the concrete mix.

Hollow blocks are precast masonry units made of fly ash and are intended to be used in most construction. These hollow blocks can be used as load-bearing or non-load-bearing walls. In the Philippines, the most economical and low-cost way to construct a building or home is through CHB. They are usually reinforced with steel bars to induce their strength, especially for load-bearing walls. Hollow blocks were also used in soundproofing a room.

Meanwhile, fiber-reinforced concrete (FRC) is a type of reinforced concrete that incorporates fibrous material to enhance structural integrity [1]. It comprises thousands of individual microscopic fibers randomly dispersed and oriented throughout the structure. Fibers include steel, glass, synthetic, and natural fibers. The characteristics of fiber reinforced concrete vary according to the concretes, fiber types, geometries, distribution, orientation, and densities used. Shotcrete is mostly reinforced with fibers. It may, however, be utilized in conventional concrete.

In recent years, significant research has been conducted to determine the feasibility of recycling waste in the development of concrete products. This is because concrete blocks appear to be the most popular alternative for recycling waste materials due to the materials' lower quality requirements. Moreover, environmental issues regarding the disposal of various waste products have reached alarming proportions. As a result, the demand for more sustainable development has increased the importance of green construction even more [2]. In addition, Behera [3] undertook an experimental study to evaluate the behavior of fiber-reinforced concrete. Bottle caps were used as a fiber addition for reinforcement. The results showed that incorporating 0.4 percent bottle caps fiber increased the compressive strength of fiber reinforced concrete samples by 16.204 percent.

Memon & Channa [4] also emphasized the importance of concrete hollow blocks in constructing houses or buildings. It is the oldest form and is essential in every building erected, notwithstanding the introduction of substitutes and the evolution of hydraulic cement in the 19th century, which changed the whole mode of construction to frame structures.

In research by Akhund [5], soft drink tins were used as fiber reinforcement in concrete to produce FRC. The cubes were cast using a proportion of fibers of 1%, 2%, and 3% by weight of cement using ½", 1" and 1 ½" long strips, respectively. And the results show that with the increase in the percentage and size of strips in concrete, the compressive strength is significantly increased in fiber-made mix concrete. For example, the compressive strength increases by 33% over control mix concrete when 1.5" long fiber strips with 3% fiber content are used.

In addition, a study was also conducted by Liew [6] on the utilization of recycled steel fiber in reinforced concrete, and the findings revealed that recycling tires to recover steel fibers is not only sustainable, environmental, and health-friendly but also provides an economical means of energy generation during cement production.

Internal microcrack propagation contributes to the concrete's low tensile strength, which results in the concrete being brittle. As a result, structural cracks in concrete can emerge even before the concrete is loaded due to drying shrinkage and other causes. In the presence of a load, these internal cracks expand and open up due to the applied stress, resulting in further cracks and the inelastic deformation of concrete. But, when the fibers are inserted into the concrete in a uniformly dispersed and randomly oriented pattern, they act as crack arrestors and improve their characteristics. Metal, synthetic, natural, and other fibers are available in multiple sizes and shapes [7].

When structural members are designed, it is believed that the concrete will resist compressive stresses rather than tensile pressures; hence, the compressive strength of the concrete is utilized to determine its quality. Other concrete stresses can be stated as a percentage of the compressive strength, which is quickly and precisely defined by experiments. Cylindrical, cubical, or prismatic specimens of compressive strength may be used. In preparation for testing, the samples are moist cured for 28 days before being subjected to a static load that is gradually applied until a rupture [8].

This study aims to determine the most effective fiber content of wasted soft drink can fiber by weight of cement method in concrete hollow blocks. The compressive strength of a loaded concrete hollow block was compared to the treated samples with fibers with a specific length of 15mm, 20mm, and 25mm and utilized hooked-end shape fiber with three different fiber content (2.0%, 2.5%, and 3.0%) as additives in Concrete Hollow block. The 4” x 8” x 16” specimens were used with a curing period of 28 days.

The significance level and interaction of each factor with the response were determined using statistical analysis such as analysis of variance (ANOVA). This gives a nonlinear analysis of results that captures curvature on the response plot with RSM. RSM also allows the researcher to find the optimal number of components to get the highest potential yield and create a prediction model for concrete's fresh and hardened properties depending on the proportion of parameters involved.

2. RESEARCH SIGNIFICANCE

This study aims to improve the compressive strength of CHB by incorporating steel fiber from waste soft-drink cans. As a result, the outcomes will benefit the general public considering CHB are the most widely utilized building material. Response Surface Methodology was employed to develop an optimization model to determine the maximum compressive strength given a mixture of fiber content and fiber length. The study's findings also indicated that CHB with steel fiber could be used in low-cost buildings. It gradually increases the overall compressive strength without requiring additional cement, resulting in cost savings and promotion of this environmentally friendly product.

3. METHODOLOGY

RSM and experiment design were used as the framework of the study since it utilized a non-load-bearing CHB sample and tested them using the universal testing machine (UTM). Shown in Fig. 1 is the flowchart of the study.

3.1 Gathering and Fabrication of Hooked-end Wasted Soft Drink Can Fiber

The fiber used in this study was collected and processed from the metallic waste of soft drink cans obtained from various sources such as junk shops, canteens, restaurants, etc., located in Metro Manila, Philippines.

The fibers also did not undergo any chemical solutions treatment since the study requires that the soft drink can fiber be purely natural. After taking the top and bottom covers off the soft drink cans, the rectangular sections of the body were adequately cleaned and dried. The body of the soft drink can then be cut into different sizes (15mm, 20mm, and 25mm), including the type of interlocking mechanism used, which was hooked-end.

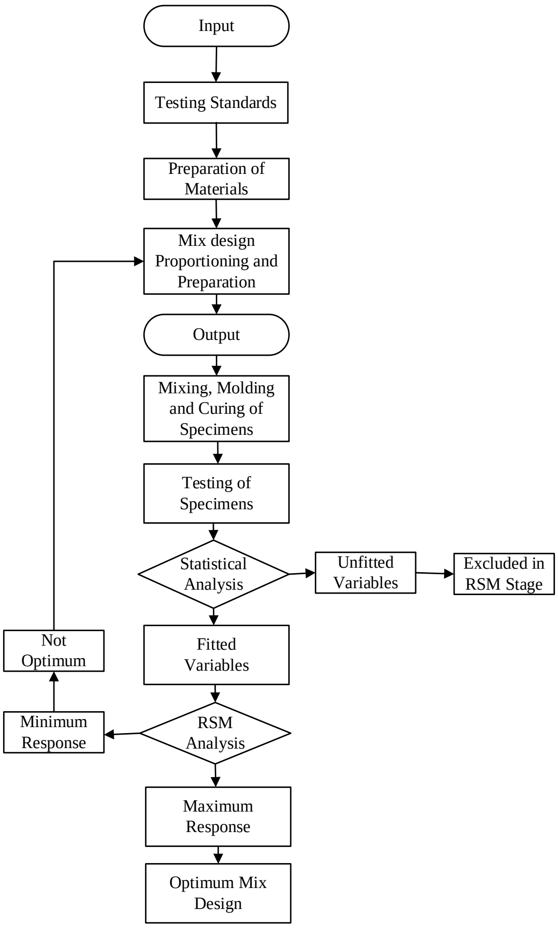

Fig. 1 Flowchart of the study

3.2 Design of Experiment

The proportions were established based on the recommended reinforcement of fiber content by the previous studies [9,10]. A total of 30 samples were made for the compressive strength test. The water-to-cement ratio was set at 0.50 and the cement-to-sand ratio was established at 1:5 for both concontrolsd treated CHB samples. While for the treated CHB samples additional reinforcement of 2.0%, 2.5%, and 3.0% fiber content with lelengthsth of 15mm, 20mm, and 25mm by weight of the cement method were added using hooked-end shape fiber.

3.3 Factors and Levels

Table 1 shows the numerical factors' low-level values, which are the lowest possible and permissible amounts for each factor. The maximum levels were tested for each concrete hollow block combination and proved to reach the desired quality. As a result, exceeding these values yield compressive strength that is undesirable.

Table 1 Values of each factor per level

	Factors	Low Level	Middle Level	High Level
Numerical Factors	Fiber Content (%)	2.0	2.5	3.0
	Fiber (mm)	15	20	25

3.4 Sampling Procedures and Runs

The performance of the individual factors was evaluated using the RSM, which was done independently using runs generated by Statistical Software, Minitab Version 18.1.

4. RESULTS AND DISCUSSION

The results of the 30 non-load-bearing concrete hollow block samples tested for compressive strength are shown in Table 2. These are then used to identify the coefficients and weights for the optimization model using Response Surface Methodology.

Table 2 Compressive strengths results

Mixture Design	Compressive Strength (psi)			
	1	2	3	Average
0-0	232	188	217	212.33
2-15	305	338	339	327.33
2.5-15	478	329	277	361.33
3-15	468	499	431	466.00
2-20	214	229	310	251.00
2.5-20	345	313	352	336.67
3-20	552	354	395	433.67
2-25	360	393	308	353.67
2.5-25	570	381	352	434.33
3-25	533	458	494	495.00

Note: Mixture design is coded as wa aste soft drink can fiber percentage – fiber length

In general, the results present an increasing compressive strength of hollow blocks as the fiber content of recycled wasted soft drink can fiber increases and the highest compressive strength appeared in mixture 10 (Hooked-25mm-3.0%), while the CHB without fiber content has the least.

4.1 Compressive Strength of Non-Load Bearing CHB

The graphical representation of data from Table 2 is shown in Fig. 2. This figure represents the average compressive strength of ten different mixtures on its 28th-day test. The result indicates that mixture 10 (Hooked-25mm-3.0%) obtained the highest compressive strength of 495 psi while mixture one or the control samples obtained the lowest compressive strength of 213.33 psi. The exact figure also shows a sudden increase in compressive strength between the control mixture and the treated one. Furthermore, these results revealed that as the fiber content of the mixture increases, it also increases the compressive strength with a maximum 133.13% increase for mixture 10 (3.0%-25mm).

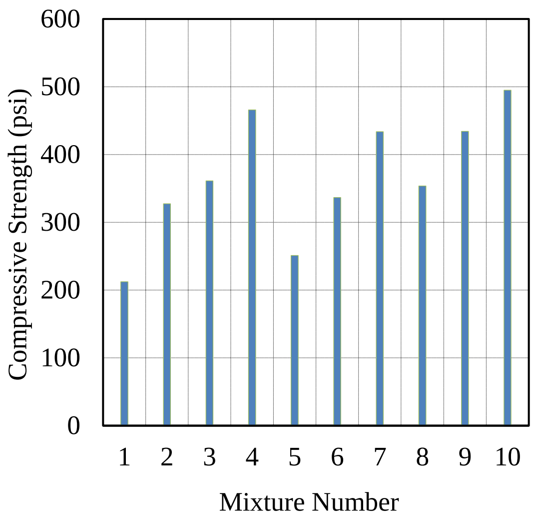

Fig. 2 Comparison of average compressive strengths

The graph shown in Fig. 3 describes the behavior of the compressive strength of the CHB sample concerning the different hooked-end fiber content added. Results were analyzed using a fiber lengths of 15mm, 20mm, and 25mm. It was observed that CHB produced with 3.0% soft drink can fiber obtained the highest average compressive strength of 495 psi for 25mm, 433.67 psi for 20m,m, and 466 psi for 15mm.

While Fig. 4 illustrates the percentage increase of compressive strength of concrete hollow blocks to the control specimen's results. The results revealed that using the maximum fiber content of 3.0% of soft drink can fiber will result in the maximum increase in the compressive strength of 119.47%, 104.24%, and 133.13% relative to the results, which do not comply with the governing strength. This follows by 2.5% fiber content with a rise of 70.17%, 58.56%, and 104.56% in its compressive strength. Furthermore, this study's least fiber content also resulted in the slightest increase in its compressive strength of 54.16%, 18.21%, and 66.57%, respectively, to its fiber length of 15mm, 20mm, and 25mm. As a result, compressive strength improved correspondingly as the percentage of soft drink can fiber increased.

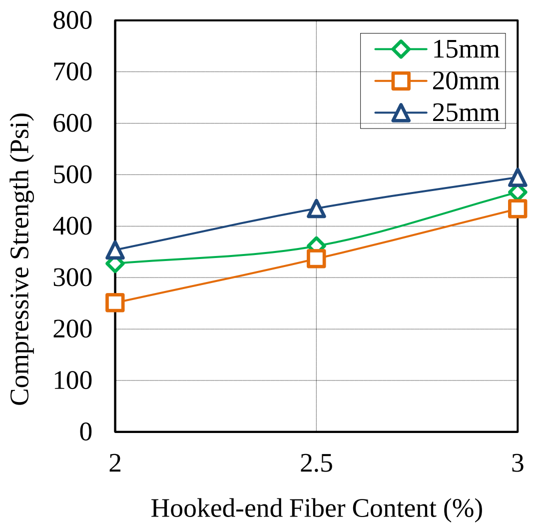

Fig. 3 Average compressive strength (compressive strength vs. fiber content vs. fiber length)

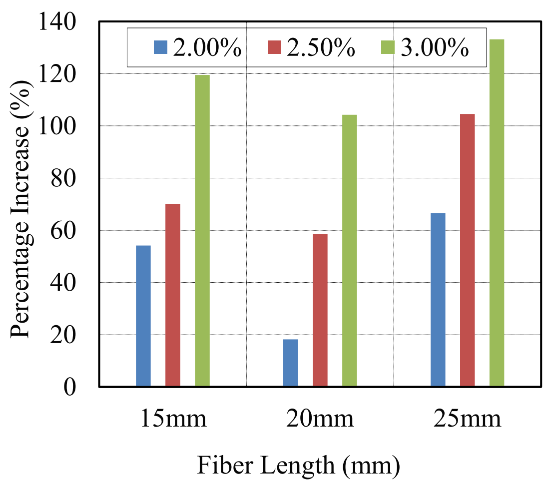

Fig. 4 Percentage Increase for Fiber Content

4.2 Mixing Procedure Error

The percent error between the measured and theoretical weights of CHB integrated with fiber is shown in Table 3. Although fibers inclusion is expected to result in a slight increase in CHB weight, the results of this study revealed that the final weight of the CHB specimens was almost unchanged when weighted. It can be observed that the percentage weight error is between 0.08% minimum to 1.58% maximum.

Table 3 Percent error of CHB integrated with fiber

Specimens	Measured Weight (kg)	Theoretical Weight (kg)	Percent Error (%)
15mm-2.0%-1	9.987	10.056	0.70%
15mm-2.0%-2	9.988	10.056	0.68%
15mm-2.0%-3	9.945	10.056	1.11%
15mm-2.5%-1	10.021	10.070	0.49%
15mm-2.5%-2	9.990	10.070	0.80%
15mm-2.5%-3	9.981	10.070	0.88%
15mm-3.0%-1	9.995	10.083	0.87%
15mm-3.0%-2	10.020	10.083	0.63%
15mm-3.0%-3	9.986	10.083	0.96%
20mm-2.0%-1	9.957	10.056	0.99%
20mm-2.0%-2	9.975	10.056	0.81%
20mm-2.0%-3	9.946	10.056	1.10%
20mm-2.5%-1	9.966	10.070	1.04%
20mm-2.5%-2	9.941	10.070	1.28%
20mm-2.5%-3	9.969	10.070	1.00%
20mm-3.0%-1	10.091	10.083	0.08%
20mm-3.0%-2	9.989	10.083	0.93%
20mm-3.0%-3	10.000	10.083	0.83%
25mm-2.0%-1	9.988	10.057	0.68%
25mm-2.0%-2	10.090	10.057	0.34%
25mm-2.0%-3	9.982	10.057	0.74%
25mm-2.5%-1	10.000	10.070	0.70%
25mm-2.5%-2	9.988	10.070	0.81%
25mm-2.5%-3	9.982	10.070	0.87%
25mm-3.0%-1	9.930	10.083	1.52%
25mm-3.0%-2	9.945	10.083	1.37%
25mm-3.0%-3	9.924	10.083	1.58%

4.3 Post Cracking Behavior

The result of testing for crack behavior of CHB samples was determined on its 28th day of curing. Several failure modes were observed during the compression tests of CHB. This includes face shell separation, diagonal cracks along the larger face of the samples, and shearing failure. For example, Fig. 5 shows concrete hollow samples with a face shell separation failure after being tested on UTM, while Fig. 6 shows a failure of CHB with inclined crack and spalling of face shells. The addition of soft drinks can fiber also improves the resistance to cracking.

Fig. 5 Face shell separation failure

Fig. 6 Failure with crack and spalling of face shells

4.4 Response Surface Model

The statistical significance is checked using analysis of variance (ANOVA), and the t-test results are shown in Table 4. The p-value for the overall model is 0.015, which is less than the 0.05 level of significance. This implies that we reject the null hypothesis that no significant difference in compressive strength exists between control and treated concrete hollow block specimens on their 28th day of curing and accept the alternative hypothesis. Therefore, the whole quadratic model of waste fiber length and content (independent variables) considerably affects the compressive strength of concrete hollow blocks (dependent variable).

The p-value for the linear terms of the fiber content factor is 0.003 or 3%, which is also lower than the level of statistical significance of 5%. This indicates that the fiber content significantly influences the compressive strength. On the other hand, while the fiber length factor is observed to be 0.087 or 8.7%, which is higher than the level of significance of 5%, it can be concluded to be insignificant concerning compressive strength.

Table 4 Analysis of variance

Source	Adj MS	F-Val	P-Val
Model	9461.0	21.61	0.015
Linear	19211.2	43.87	0.006
Fiber Length (mm)	2745.2	6.27	0.087
Fiber Content (%)	35677.3	81.48	0.003
Square	4440.4	10.14	0.046
Fiber Length (mm)*Fiber Length (mm)	8667.2	19.79	0.021
Fiber Content (%) *Fiber Content (%)	213.6	0.49	0.535
2-Way Interaction	1.8	0.00	0.953
Fiber Length (mm)*Fiber Content (%)	1.8	0.00	0.953
Error	437.9		

The p-values for the quadratic terms for both factors and the significance level are below the significance threshold. As a result, the quadratic terms for the fiber content and fiber length significantly impact the compressive strength. However, the interaction between the fiber content and the fiber length is insignificant for compressive strength.

Determining significant factors and interaction, results were plotted to generate a response surface representing the compressive strength behavior concerning the wasted can fiber content and fiber length.

4.5 The Practical Significance

The practical significance test is carried out using the summary output from the model shown in Table 5. With an adjusted R-square value of 92.79 percent, the adjusted coefficient of determination indicates that the model parameters are reliable and can explain variation in the dependent variable and the compressive strength response exceptionally well. As a result, the model has significant practical implications.

Table 5 Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
20.9257	97.30%	92.79%	67.27%

4.6 Optimization

One of the main objectives of this study was to generate an optimization model that would be useful in predicting the maximum compressive strength, given the mixed proportion of fiber length and fiber content of wasted soft drink cans, as well as finding the optimum mix proportions for a given response criterion.

The optimization model in Eq. (1) was used in predicting the optimum mix design for compressive strength of CHB with a wasted soft drink can fiber content and fiber length combination.

$$CS = 1187 - 101.7A - 58B + 2.633A^2 + 41.3B^2 + 0.27AB \quad (1)$$

where:

CS = Predicted compressive strength of CHB, psi
A = Soft drink can fiber length, mm
B = Soft drink can fiber content, %

Based on the 3D response surface plots for compressive strength on different fiber content and fiber length in Fig. 7, it was observed that there is a nonlinear behavior of compressive strength with the variation of fiber content from 2.0% to 3.0%.

The maximum compressive strength value was located near the maximum fiber content considered at 3.0%.

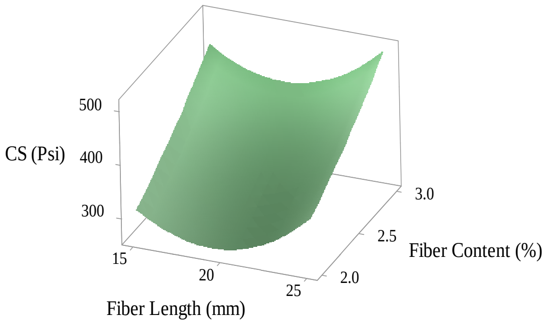

Fig. 7 Response surface model of the study

The optimum mix design was determined using the numerical optimization tool of Minitab Software, as shown in Table 6. These results indicated that a combination of soft drink fiber content and length into CHB could yield a maximum compressive strength of 508.89 psi using the optimum combination generated.

Table 6 Optimum Mix Design

Factors/Response	Optimum Value	Unit
Fiber Length	25	mm
Fiber Content	3	%
Compressive Strength	508.89	psi

5. CONCLUSION

This study showed that the parameters considered soft drink can fiber percentage and fiber length had a significant effect on the resulting properties of CHB. Based on the results, mixture 10 (3.0%-25 mm) obtained the highest compressive strength of 495 psi. In comparison, mixture one or the control specimen obtained the lowest of 213.33 psi, which means that the compressive strength was improved by as much as 133.13% on its 28th day of curing, based on the average strength of the three specimens. Moreover, when a maximum fiber content of 3% is employed, the compressive strength of the 15 mm, 20 mm, and 25 mm samples is 466 psi, 433.56 psi, and 495 psi, respectively. This signifies that all compressive strength results exceed the PNS's minimum criteria for compressive strength. Therefore, we may conclude that increasing the fiber content in the mixture tends to increase the compressive strength of the specimens. Results also suggest that the optimization model developed in this study could help predict the maximum compressive strength, given the mixed proportion of fiber length and fiber content of soft drink cans, and find the optimum mix proportions for a given response criterion. The final output showed that a combination of soft drink fiber content and length into CHB could yield a maximum compressive strength of 508.89 psi. However, several failure modes were also observed during the compression tests of CHB. This includes face shell separation, diagonal cracks along the larger face of the samples, and shearing failure. In addition, the incorporation of soft drinks can fiber increases crack resistance and, most importantly, promotes environmentally friendly materials.

6. ACKNOWLEDGMENTS

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