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A Comprehensive Study On The Utilization Of Waste Glass As A Partial Replacement For Fine Aggregate In Concrete

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Abstract:
This study explores the viability and ramifications of using waste glass in place of fine aggregate in concrete mixtures in order to solve environmental concerns related to conventional concrete production and encourage sustainable building practices. After 7 and 28 days of curing, the concrete specimens' compressive and splitting tensile strengths were assessed. Specimens were made with a water-to-cement ratio of 0.45 and a concrete mix ratio of 1:1.5:3 by volume. Waste glass was used to partially replace fine aggregate in different proportions (10%, 20%, 30%, and 40% by weight of sand). At both 7 and 28 days, the results showed that the splitting tensile strength decreased as the waste glass content increased. However, compressive strength rose with each replacement level, peaking at 30% waste glass content. The compressive strength was similar to the control concrete at 40% waste glass content. This study sheds light on the possibility of partially substituting waste glass for fine aggregates in concrete, emphasizing the advantages of doing so for increased compressive strength and environmentally friendly building methods.
Key Word: *Concrete, fine aggregate, compressive strength, splitting strength, waste glass*

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I. Introduction

The most common material used in building nowadays is concrete, which is made up of cement, fine aggregates (sand), and coarse aggregates that have been combined with water and allowed to set over time (Chong et al. 2020, Naqi and Jang 2019). Aggregates make up between 70 and 75 percent of the volume of concrete, indicating the significant reliance on natural resources like sand, which is becoming less sustainable as building demands rise (Olutoge, 2016). Furthermore, industrial operations produce a lot of garbage, which contributes to environmental imbalances and landfill shortages (Ab Zail and Adnan, 2021).

Considering glass has a short lifespan in its original forms and is not biodegradable, it presents environmental problems when disposed of in landfills. Glass can be made in a variety of forms, including flat, container, and tube glass (Shayan and Xu, 2004). Only around 21% of the more than 130 million tonnes of glass produced annually worldwide is recycled, highlighting the necessity of efficient reuse techniques (Glass recycling, 2018). Although glass does not release pollutants, improper handling can harm both humans and wildlife, necessitating innovative recycling methods.

One promising solution is the use of waste glass in concrete as a partial replacement for fine aggregates. Previous studies have indicated that incorporating waste glass in concrete can mitigate issues like the Alkali-Silica Reaction (ASR), which causes expansion and cracking due to the formation of silica gel when alkalis in cement react with silica in aggregates (Ali and Al-Tersawy 2012, Corinaldesi et al. 2005). Research has shown that using waste glass particles up to 100 μm in size in concrete prevents ASR, suggesting its potential viability as a fine aggregate substitute (Topçu et al., 2008).

This study aims to explore the feasibility and effects of using waste glass as a partial replacement for fine aggregates in concrete. By examining the impact on the strength properties of concrete, this research seeks to contribute to sustainable construction practices and address the depletion of primary resources.

Scope of the study

This study investigates the use of waste glass as a partial replacement for fine aggregate in concrete, where stone chips (FM 7.05) and Sylhet sand (FM 3.165) were used as coarse and fine aggregates respectively, and waste glass (FM 3.8) was incorporated with sand at replacement levels of 10%, 20%, 30%, and 40% by volume. Portland Composite Cement (Shah Cement) was utilized, with a mix ratio of 1:1.5:3 by volume and a water-cement ratio of 0.45 by weight. The compressive and splitting tensile strengths of concrete cylinder specimens were evaluated at curing periods of 7 and 28 days.

II. Material And Methods

In this chapter, the mechanical properties of materials used in the study are presented. The primary objective is to evaluate the compressive and splitting tensile strength of concrete incorporating varying percentages of grinded waste glass as a partial replacement for fine aggregate. Laboratory tests were conducted to gather essential data for concrete design. These included assessments of fineness modulus, bulk specific gravity, absorption capacity, unit weight, and void percentage of both fine and coarse aggregates. Stone chips (FM 7.05) and Sylhet sand (FM 3.165) were used, while waste glass (FM 3.8) replaced sand at 10%, 20%, 30%, and 40% by volume. A mix ratio of 1:1.5:3 (cement, sand & aggregate) and a water-cement ratio of 0.45 were maintained. Cylindrical specimens were cast, cured, and tested at 7 and 28 days to determine strength properties.

Materials Used

Cement

In this study, Portland Composite Cement (PCC) was utilized. The cement mortar specimens were tested to determine the compressive strength, normal consistency, and initial and final setting times of the cement. The physical and chemical properties of the cement are detailed in **Tables 1 & 2.**

Table 1: Cement's physical properties

Types of cement	Normal consistency (%)	Setting time (min.)		Compressive strength (MPa)		
		Initial	Final	3 days	7 days	28 days
Portland composite cement (PCC)	29	97.5	195	12.48	17.46	27.06

Table 2: Chemical compounds of Portland Composite Cement (PCC)

Chemical compounds	(%)	Reference
MgO	0.99	Caronge et al., 2017
SO_3	1.81	
Fe_2O_3	3.14	
Al_2O_3	5.15	
SiO_2	18.39	
CaO	61.79	
LOI	4.61	

Fine Aggregate

Sylhet sand was used as the fine aggregate in this study. According to ASTM C136-06, (2006) specifications, materials passing through a 4.75 mm sieve and retained on a 0.075 mm sieve consist primarily of coarse materials. The physical properties of the fine aggregate used (Sylhet sand) are detailed in **Table 3.**

Table 3: Fine aggregate's physical characteristics

Properties	Condition	Value
Bulk Sp. Gravity	SSD	2.5
Bulk Sp. Gravity	OD	2.27
Apparent Sp. Gravity	-	2.63
Absorption Capacity (%)	-	6
Unit Weight (Kg/m^3)	OD	1491
Unit Weight (Kg/m^3)	SSD	1580
Fineness Modulus (FM)	-	3.16

Coarse Aggregate

In this study, coarse aggregates were sourced locally. The coarse aggregates used were crushed stone with a maximum size of 20 mm. They were cleaned and dried in air to remove impurities and moisture before being used in the concrete mix. The physical properties of the coarse aggregates are detailed in **Table 4.**

Table 4: Coarse aggregate's physical characteristics

Properties	Condition	Value
Bulk Sp. Gravity	SSD	2.73
Bulk Sp. Gravity	OD	2.72

Apparent Sp. Gravity	-	2.75
Absorption Capacity (%)	-	0.5
Unit Weight (Kg/m3)	OD	1450
Unit Weight (Kg/m3)	SSD	1455
Fineness Modulus (FM)	-	7.05

Waste Glass

In this study, waste window glass was sourced from New Gausiya Glass and Thai Aluminium Eyakub Ali Market located on Pubail Road in Tongi, Gazipur. The waste glass was first crushed (**Figure 1**) using the Los Angeles abrasion apparatus and then sieved through a No. 4 sieve (4.75 mm) and retained on a No. 100 sieve (0.15 mm). The physical and chemical properties of the waste glass are provided in **Tables 5 & 6.** A gradation curve is used for assessing the aggregate's size distribution. **Figure 2** shows the aggregate gradation curves of fine aggregate, coarse aggregate and waste glass.

Table 5: Waste glass's physical characteristics

Properties	Condition	Value
Bulk Sp. Gravity	SSD	2.33
Bulk Sp. Gravity	OD	2.17
Apparent Sp. Gravity	-	2.56
Absorption Capacity (%)	-	7
Unit Weight (Kg/m3)	OD	1634
Unit Weight (Kg/m3)	SSD	1748
Fineness Modulus (FM)	-	3.8

Table 6: Chemical compounds of waste glass

Chemical Composition	(%)	Reference
SiO_2	67.72	Ali and Al-Tersawy, 2012
$Al_2O_3 + Fe_2O_3$	3.40	
CaO	6.90	
SO_3	0.17	
$Na_2O + K_2O$	10.75	
MgO	6	

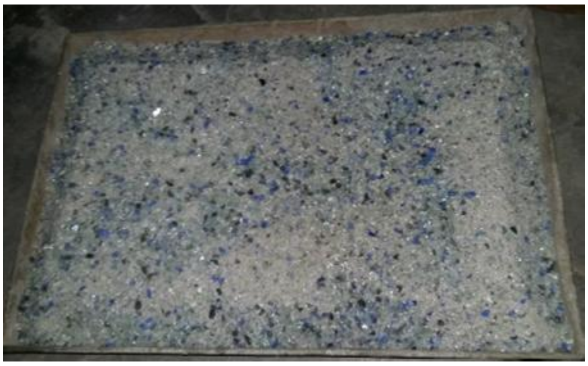


Figure 1: Crushed waste glass

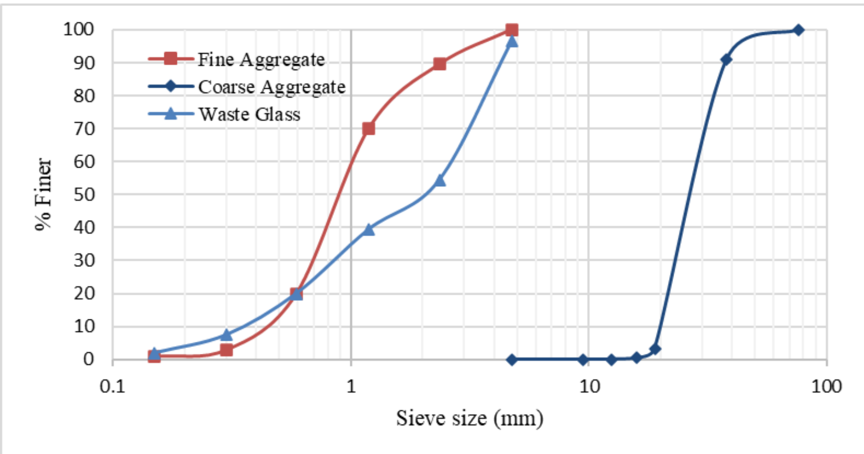


Figure 2: Aggregate gradation curves of fine aggregate (FA), coarse aggregate (CA) and waste glass (WG)

Preparation of Specimens

A cubic mold measuring 100 mm × 100 mm × 100 mm was utilized to gauge the volumes of waste glass, cement, fine aggregate, and coarse aggregate. The concrete mix ratio adhered to a 1:1.5:3 formula, and a water-cement ratio of 0.45 was consistently maintained. The fine aggregate was partially replaced with waste glass in varying proportions of 10%, 20%, 30%, and 40% by weight of sand. Manual hand mixing was employed using a shovel, with water being incrementally added during the process to achieve a balanced mix that was smooth and plastic but not overly wet.

The workability of the fresh concrete mix was evaluated using slump tests, which yielded values between 90-100 mm. Cylindrical molds of 100 mm diameter and 200 mm height were used for casting, with a plain tamping bar (16 mm in diameter) applied for compaction and to eliminate voids. After 24 hours, the concrete specimens were demolded and then submerged in a water tank for curing periods of either 7 or 28 days.

Test on Concrete

Test to measure compressive strength

The concrete's strength was evaluated on the specimens after 7 and 28 days of curing. The experiment involved testing concrete prepared with a mix design ratio of 1:1.5:3, combined with a water-cement (w/c) ratio of 0.45. It was then necessary to taken out the concrete specimens from the water tank after curing for 24 hours and prepare them for testing. Each concrete cylinder specimen was subjected to a gradually increasing load until the point of structural failure was reached. It is recommended that the load be applied at an appropriate rate of movement based on the guidelines in (ASTM C39, 1997). Each cylinder's compressive strength was determined based on equation (1),

$$P = F/A \qquad (1)$$

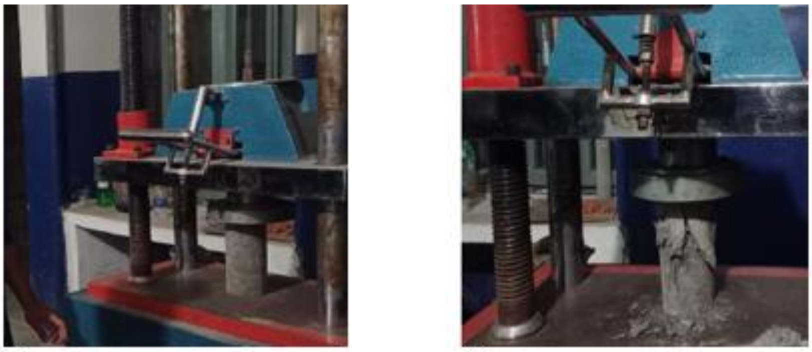
Where,

P = Compressive strength, (MPa)

F = Crushing load, (N)

A = Cross-sectional area, (mm^2)

In this study, a total of 30 concrete cylinders were selected from the overall pool of specimens to conduct a thorough examination of compressive strength assessment following the designated curing period. The procedure for assessing compressive strength is illustrated in **Figure 3.**



(a) (b)

Figure 3: (a) Before crushing & (b) After crushing of cylinder specimen

Test to measure splitting tensile strength

The test was conducted using the Standard Test Method for concrete specimens with cylindrical shapes to determine their tensile strength (ASTM C496/C496M-17, 2017). The test specimens were placed horizontally on a universal testing apparatus, and the specimens were subjected to a steady force application until visible cracking appeared within them. In this study, a subset of 30 cylinders was selected from the total pool of specimens to conduct the assessment. The procedure for assessing splitting tensile strength is illustrated in **Figure 4**. The splitting tensile of cylinders was determined by the equation (2),

$$\delta = 2P/\pi DL \qquad (2)$$

Where,

δ = Splitting tensile strength, (MPa)

P = Crushing load, (N)

D = Diameter of concrete cylinder, (mm)
L = Length of concrete cylinder, (mm)

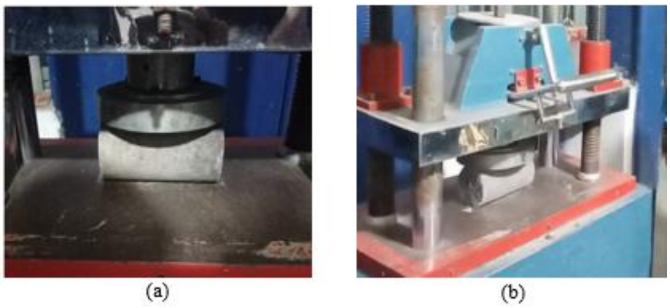


Figure 4: (a) Before crushing & (b) After crushing of cylinder specimens

III. Result

Compressive Strength

Concrete specimens were evaluated at 7 and 28 days for their compressive strength characteristics. The compressive strength of various concrete mixtures was assessed, including a control concrete and concrete cylinders that incorporated waste glass as a substitute for fine aggregate in different proportions. Specifically, the waste glass was used to replace fine aggregate at levels of 10%, 20%, 30%, and 40%. Gautam et al. (2012) observed that the compressive strength of concrete slightly increased when waste glass was used as a fine aggregate replacement. This enhancement in strength was particularly noticeable at 28 days, but only up to a replacement level of 20%. During the 7-day period, an increase in strength was observed across all replacement levels. Moreover, there was a notable enhancement in strength, reaching up to 10% for the 7-day period and 25% for the 28-day period. The compressive strength showed a gradual improvement at specific replacement percentages of waste glass for fine aggregate, in comparison to the control concrete. At a 15% waste glass content, the highest compressive strength was noted to be approximately 25% higher than that of the control concrete after 28 days (Ibrahim, 2017). The compressive strength of concrete incorporating different percentages of waste glass as a replacement for fine aggregate is presented in **Table 7** for a 7 days and in **Table 8** for a 28 days of curing period.

Table 7: Concrete's compressive strength after 7 days with varying proportions of waste glass

Waste glass replacement, (%)	Compressive strength, (MPa)	Strength variation, (%)	Increase/Decrease
0	10	-	-
10	6.67	33.3	Decreased
20	9.33	6.7	Decreased
30	11	10	Increased
40	10	0	Not changed

Table 8: Concrete's compressive strength after 28 days with varying proportions of waste glass

Waste glass replacement, (%)	Compressive strength, (MPa)	Strength variation, (%)	Increase/Decrease
0	12	-	-
10	9	25	Decreased
20	13.33	11.08	Increased
30	15	25	Increased
40	12.67	5.58	Increased

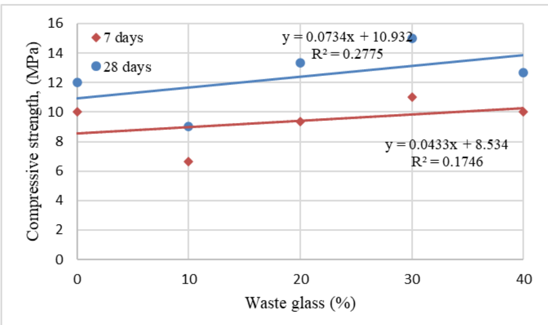


Figure 5: With varying amounts (%) of waste glass, compressive strength at 7 days and 28 days

Figure 5 illustrates the comparison of compressive strength between control concrete and concrete incorporating varying percentages of waste glass (WG) as a replacement for fine aggregate. At the 7-day mark, the compressive strength exhibited a slight increase of approximately 10% with 30% waste glass content as fine aggregate compared to the control concrete, yielding a value of 11 MPa. However, with a 40% waste glass content, the strength remained unchanged relative to the control concrete after 7 days of curing. By the 28th day, the maximum strength of 15 MPa was observed at a 30% waste glass content, representing an approximate 25% enhancement compared to the control concrete. Notably, the maximum strength was attained at 30% WG content, while the strength closely resembled that of the control concrete at both 7 and 28 days of curing when 40% WG content was utilized.

Splitting Tensile Strength

The experiment employed cylindrical concrete specimens with dimensions of 100 mm in diameter and 200 mm in height. These specimens were fabricated incorporating varying proportions of waste glass, specifically 0%, 10%, 20%, 30%, and 40%, as substitutes for a portion of the fine aggregate. Kavyateja et al., (2016) observed that the splitting tensile strength of concrete steadily decreased as replacement percentages increased. The experimentation encompassed replacement levels of 0%, 10%, 20%, 30%, and 40% of waste glass, with testing conducted following a 28-day curing period. Keryou and Ibrahim, (2016) studied the utilization of waste glass as a partial substitute for fine aggregate in concrete, with replacement percentages of 0%, 20%, 25%, and 30%. An elevation in splitting tensile strength was exclusively observed at the 20% waste glass replacement level, registering an increase of 8.4% following 7 days of curing and a more substantial rise of 12.7% after 28 days of curing. **Table 9** & **Table 10** show the splitting tensile strength evaluated with different proportions of waste glass substituting fine aggregate at both 7 and 28 days.

Table 9: Concrete's Splitting tensile strength after 7 days with varying proportions of waste glass

Waste glass replacement, (%)	**Splitting tensile strength, (MPa)**	**Strength variation, (%)**	**Increase/Decrease**
0	1.55	-	-
10	1.32	14.83	Decreased
20	1.48	4.52	Decreased
30	1.14	26.45	Decreased
40	1.24	20	Decreased

Table 10: Concrete's Splitting tensile strength after 28 days with varying proportions of waste glass

Waste glass replacement, (%)	**Splitting tensile strength, (MPa)**	**Strength variation, (%)**	**Increase/Decrease**
0	2.03	-	-
10	1.31	35.47	Decreased
20	1.93	4.93	Decreased
30	1.48	27.09	Decreased
40	1.65	18.72	Decreased

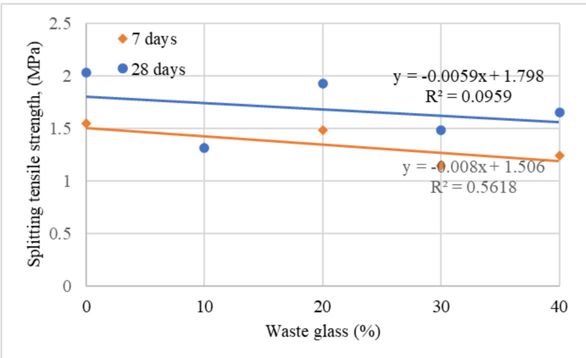


Figure 6: With varying amounts (%) of waste glass, splitting tensile strength at 7 days and 28 days

Figure 6 illustrates slight variations in strength observed in concrete cylinders tested at 7 and 28 days, with different percentages of waste glass utilized as a partial replacement for sand. In this investigation, it was observed that for waste glass content (10%, 20%, 30%, and 40%), there was a reduction in strength compared to the control concrete, with decreases of 14.83%, 4.52%, 26.45%, and 20%, respectively, at 7 days of curing. Furthermore, at 28 days, there was a notable decrease in splitting tensile strength of up to 35.47%. The findings indicate that higher proportions of waste glass in concrete correlate with diminished splitting tensile strength when compared to control concrete.

Splitting tensile strength correlation with compressive strength

The correlation between splitting tensile strength and compressive strength was derived for 28 days of WG replacement, which is shown in **Figure 7.** The relationship was carried out for the values of splitting tensile strength varying from 1.31 to 2.03 MPa and the values for compressive strength varying from 9 to 15 MPa. The investigations observed that the relationship was $f_{ct} = 0.48\sqrt{f'_c}$ and the correlation coefficient was, r = 0.3423. According to (ACI 318-08, 2008) for normal concrete relationship between splitting tensile strength and compressive strength as $f_{ct} = 0.56\sqrt{f'_c}$. Therefore, in present study's outcome almost met the recommended guideline. A similar relationship also observed based on (Kavyateja et al., 2016) and (Arivalagan and Sethuraman, 2021). The relationship was examined as $f_{ct} = 0.384\sqrt{f'_c}$, r = 0.0663 and $f_{ct} = 0.67\sqrt{f'_c}$, r = 0.6555 according to (Kavyateja et al., 2016) and (Arivalagan and Sethuraman, 2021) respectively.

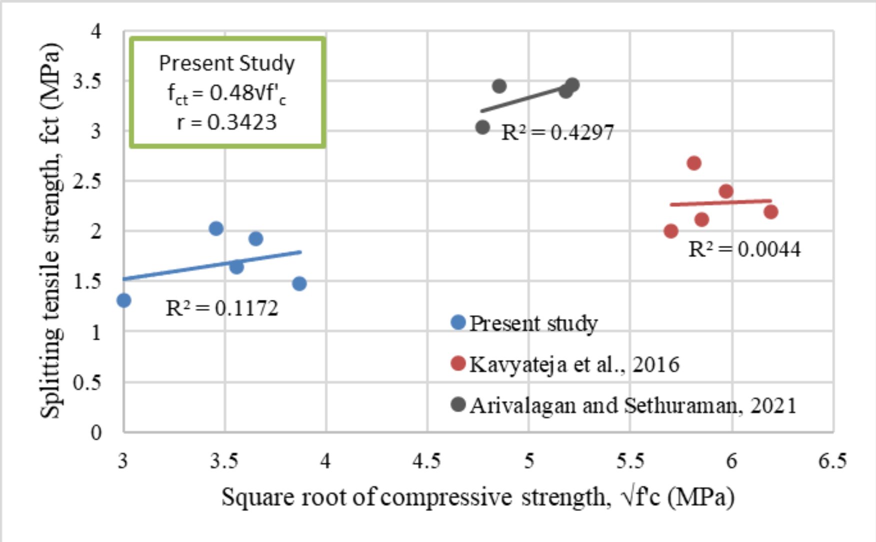


Figure 7: Correlation between splitting tensile strength and square root of compressive strength

IV. Discussion

The results of this study's experiments demonstrate that the mechanical characteristics of concrete, particularly its compressive and cracking tensile strengths, are greatly impacted when waste glass is used in place of some of the fine aggregate. When waste glass was incorporated to concrete up to a 30% replacement level, the concrete's compressive strength showed a rising trend before plateauing. In particular, after 28 days, the 30% replacement produced the maximum compressive strength (15 MPa), which was a 25% improvement over the control mix. The angular shape and tiny particle size of the crushed waste glass are responsible for this improvement, which could lead to better interlocking and packing density in the cementitious matrix.

On the other hand, through both 7 and 28 days, the splitting tensile strength showed a steady decline as the waste glass content increased. This decrease is probably caused by the glass particles' smooth surface texture and brittle character, which restrict their ability to form an effective connection with the surrounding cement paste and hinder the transfer of tensile stress throughout the matrix. At 28 days, the splitting tensile strength of the 10% waste glass mix decreased significantly (35.47%) compared to the control. The empirical expression for the relationship between compressive strength and splitting tensile strength $f_{ct} = 0.48\sqrt{f'_{c'}}$ howed a moderate correlation coefficient but an acceptable match with the observed data (r = 0.3423). This outcome, while lower than the ACI 318-08 standard correlation of $f_{ct} = 0.48\sqrt{f'_{c'}}$ aligns with results from prior research (e.g., Kavyateja et al., 2016; Arivalagan and Sethuraman, 2021), suggesting that, in comparison to compressive behavior, the tensile reaction is generally weakened by the insertion of waste glass.

Overall, waste glass has a negative impact on tensile capacity even though it can effectively increase compressive strength up to an ideal dosage. These results imply that waste glass application in structural concrete needs to be carefully optimized, particularly in situations where tensile performance is crucial. However, using up to 30% waste glass as fine aggregate offers a practical option to produce concrete in a sustainable manner, balancing environmental benefits with mechanical performance by reducing waste.

V. Conclusion

This research elucidates the effects of integrating waste glass as a partial substitute for fine aggregate on the compressive strength and splitting tensile strength of concrete. The examination of test outcomes and subsequent data analysis enables the formulation of the following conclusions.

1. The incorporation of 30% waste glass (WG) led to an enhancement in compressive strength within the concrete. Notably, the highest compressive strength recorded was 15 MPa after 28 days, utilizing stone chips at a mix ratio of 1:1.5:3. Moreover, an increase in compressive strength was observed for both 7 days and 28 days curing period.
2. The introduction of waste glass at varying percentages (10%, 20%, 30%, and 40%) consistently resulted in a reduction in splitting tensile strength when compared to the control concrete. Thus, both 7-day and 28-day curing durations, alongside the differing percentages of waste glass incorporated into the concrete, exhibited no significant influence on splitting tensile strength.
3. The splitting tensile strength and compressive strength were well correlated when using waste glass (WG) as a partial substitute for fine aggregate in concrete.

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