ASSESSING THE CONCRETE COMPRESSIVE STRENGTH THROUGH PARTIAL REPLACEMENT OF CEMENT WITH COMPOSITE WASTE (A MIXTURE OF WASTE GLASS POWDER AND SAWDUST ASH)

Farhan Fahad*[1], Md. Imam Hossain[2], Md Nayemul Alam[2], Ashis Kumar Roy[3] and Fahad Bin Jaher[3]

[1] *Lecturer, Bangladesh Army International University of Science & Technology, Bangladesh, e-mail: farhanfahad136@gmail.com*

[2] *Assistant Professor, Bangladesh Army International University of Science & Technology, Bangladesh, e-mail: imam.ce@baiust.ac.bd*

[2] *Undergraduate student, Bangladesh Army International University of Science & Technology, Bangladesh, e-mail: mdnayemul61@gmail.com*

[3] *Undergraduate student, Bangladesh Army International University of Science & Technology, Bangladesh, e-mail: Akrroy1998@gmail.com*

[3]*Undergraduate student, Bangladesh Army International University of Science & Technology, Bangladesh, e-mail: fahadbinjaher50@gmail.com*

***Corresponding Author**

ABSTRACT

Preserving the environment and conserving natural resources are fundamental aspects of all progress and growth. The challenge stemming from ongoing technological and industrial advancements revolves around effectively managing waste disposal. Utilizing certain waste materials in the production of concrete not only reduces construction costs but also offers a secure means of waste material disposal. So for this purpose to utilize these waste materials in an efficient way a study is conducted to assess the concrete compressive strength using composite waste(waste glass powder and saw dust ash) by partial replacement with cement. The composite waste was formed with a combination of sawdust ash (SDA) and waste glass powder (WGP). The composite waste was partially replaced with cement by 10%, 20%, 30%, and 40% making an equal distribution for each ingredient of the composite waste. To observe the mechanical and material properties of concrete different types of tests were conducted which include compressive strength test, split tensile strength test, standard consistency, and initial and final setting time of cement. Cubes and concrete cylinders were cast and tested to determine the compressive strength and split tensile strength of concrete after a curing period of 7, 14, and 28 days, and variation of strength was observed by gradually increasing the proportion of waste glass powder (WGP) and sawdust ash (SDA), starting at a combination of 5% WGP and 5% SDA, in the concrete mix through partial replacement of cement..The research study shows that compressive and split tensile strength gradually decreases with the increasing percentage of the composite waste which is replaced with cement to observe their cementitious property. This research aims to investigate the effectiveness of composite waste on the strength development of concrete by considering the economic, and environmental benefits of using these supplementary waste materials which may help in reducing the dependency on cement.

Keywords: *Composite waste, compressive strength, split tensile strength, standard consistency and partial replacement.*

1. INTRODUCTION

Concrete is the most widely utilized material globally, with its creation vigorously subject to the accessibility and affordability of key components like cement, sand, and coarse aggregates. However, the costs of these materials have surged significantly in recent years. This surge in demand for concrete has led to adverse effects like the depletion of aggregate resources, environmental damage, and ecological imbalances. The escalating expenses in construction and to minimize environmental impacts extensive research have prompted the exploration of alternative materials, especially those found locally to replace the traditional ingredients in concrete production. Utilizing certain waste materials, like sawdust and finely powdered glass in concrete production not only helps reduce construction expenses but also ensures the safe disposal of waste materials (Umapathy et al., 2014). Over the past few decades, Portland cement has been extensively utilized in the construction industry. The manufacturing process of cement involves subjecting it to extremely high temperatures ranging from 1400 to 1500 degrees Celsius. This process entails the depletion of natural quarries to obtain the necessary raw materials and results in the release of polluting gases like CO_2 and NO. Climate change, primarily driven by global warming, has emerged as a significant environmental concern in the past decade. This global warming is primarily attributed to the discharge of greenhouse gases, including CO2, into the atmosphere as a result of human activities (Sivakumar et al., 2014). Concrete, a vital construction material, relies on cement as a vital component. So with rapid urbanization and civilization, the demand for concrete production has increased which ultimately triggers the production of cement.

1.1 Sawdust Ash (SDA)

Sawdust is a by-product of the mechanical processing of wood of various shapes and sizes and is often used as a household fuel. The resulting residue, called sawdust ash (SDA), has pozzolanic properties. Dry concrete made with sawdust is significantly lighter, weighing only 30% of standard concrete, and it exhibits insulating characteristics similar to wood. The study is done by replacing the cement with sawdust by 10%, 20%, 30%, and 40% respectively (Marthong,2012). A concrete mix design incorporating coarse aggregate, sand, and cement, along with varying proportions of sawdust was developed to produce environmentally sustainable and thermally efficient normal and lightweight concretes (Ahmed et al.,2018). Various research has been conducted to investigate the suitability of SDA to be used commercially but not enough field application has been observed yet. When the correct cement-to-sawdust ratios are utilized, it isn't vulnerable to combustion. Sawdust concrete serves as a fundamental construction material with distinct advantages. Sawdust is readily available in regions like North Eastern India (Meghalaya) and various other parts of the world. Sawdust has been incorporated into concrete for a minimum of three decades, but its use has not been widespread. Despite being constrained by its relatively low compressive strength, sawdust concrete can be effectively utilized on a specific floor and in the application of wall construction (Marthong,2012). The use of sawdust ash, which is essentially calcined sawdust, may initially pose a negative effect on early-stage concrete behavior. However, as it undergoes a continued pozzolanic reaction overtime during the curing process, it contributes to enhancing the concrete's strength and long-term durability (Obilade, 2014; Folagbade & Aluko, 2019) To achieve favorable outcomes, it is recommended that the concrete should contain no more than 20% SDA (Folagbade & Aluko,2019).

Figure 1: Sample of SDA

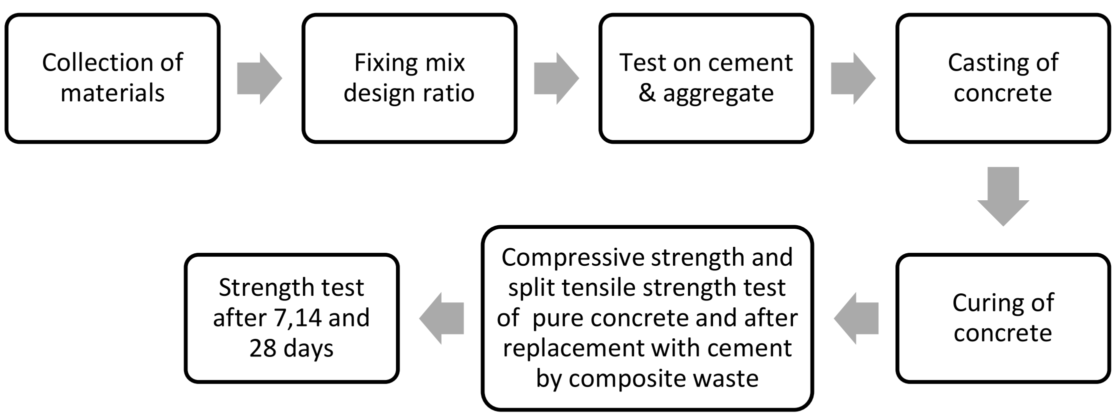
1.2 Waste glass powder (WGP)

Figure 2: Sample of WGP

Glass powder, which contains valuable silica, will engage in a pozzolanic reaction when incorporated into concrete. This reaction results in the creation of robust, long-lasting, cost-effective, and environmentally friendly concrete, provided it constitutes 20-30% of the material to partially substitute for Portland composite cement (Shayan & Xu, 2006; Maraghechi et al., 2014; Rashed, 2014; Sadiqul Islam et al., 2017). For optimal results, it is advised to utilize a 10% substitution rate of glass powder (Sadiqul et al., 2017). To mitigate concrete cracking caused by the reaction between alkali and silica, it is crucial to ensure that the size of the particle of waste glass powder is restricted to 300µm (Ke et al., 2018). The melding of waste glass powder and sawdust ash enables the inclusion of greater quantities of Supplementary Cementitious Material. This, in turn, results in blended cement concrete that is more cost-effective and environmentally friendly compared to traditional Portland cement concrete, while maintaining equivalent strength and durability levels. This can be ascribed to the lower embodied energy of SDA and WGP in comparison to the clinker of Portland cement, making the cement blended with three components a more cost-effective and more eco-friendly sustainable choice when compared to PC (Folagbade et al.2020).

2. METHODOLOGY

This experiment involved a systematic investigation aimed at examining the impact of partially substituted cement with varying proportions of composite waste. The study encompassed assessments on freshly mixed concrete, including normal consistency test and setting times of the cement paste which includes both initial and final setting time. For hardened concrete, destructive tests were conducted to determine the compressive strength using 6 x 6 x 6-inch concrete cubes and the split tensile strength using 6-inch diameter and 12-inch height concrete cylinders after curing of the concrete results were recorded after 7,14, and 28 days respectively.



2.1 Materials

- Cement-PCC grade 42.5
- Sand-Fine aggregate
- Crushed stone-Coarse aggregate
- The mixture of SDA and WGP replacement for cement

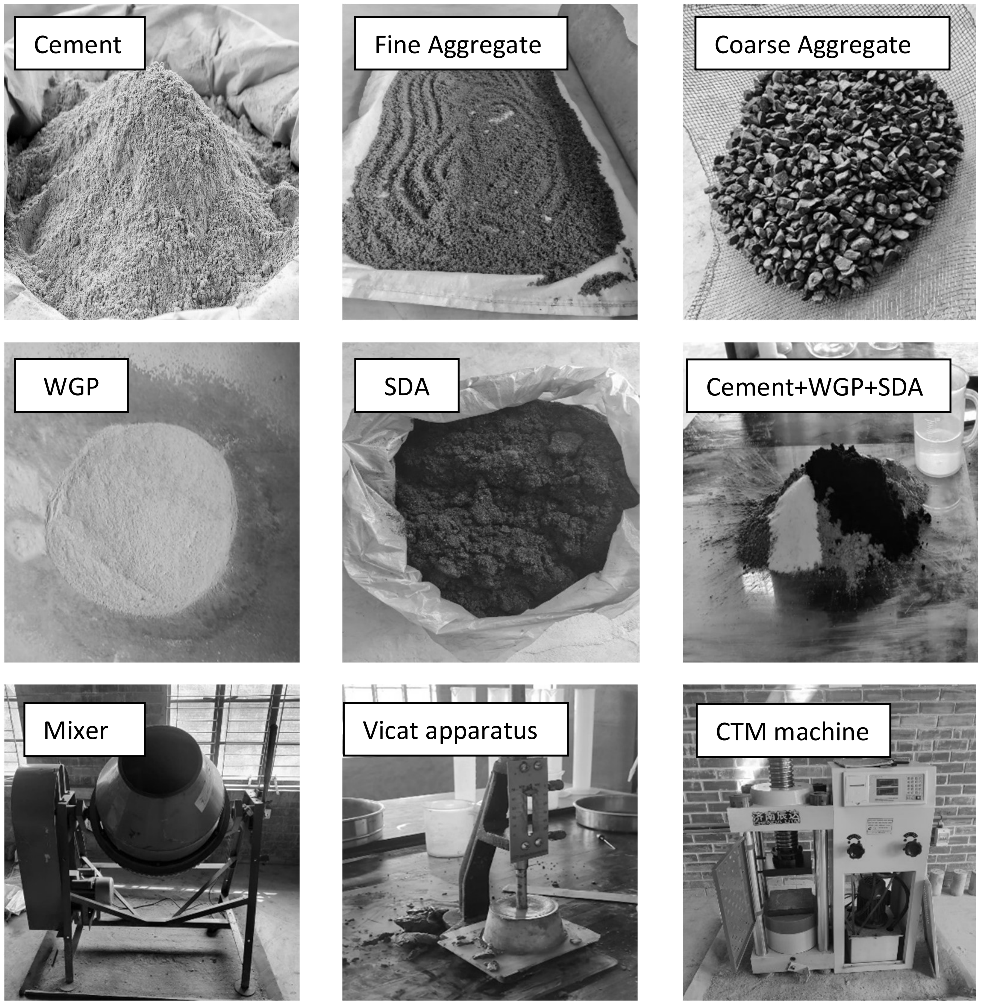


Figure 3:Material and Apparatus used for testing

2.1.1 Mix Proportion

- Grade of Concrete: M30

Water (litre)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)
75.26	150.52	218.11	496.386
0.5	1	1.45	3.30

2.1.2 Physical properties of material

Some physical tests were conducted for the materials used in this study and the results are mentioned below:

Table 1: Physical Properties

Property	Saw dust ash	Waste glass powder	Cement	Fine aggregate	Coarse aggregate
Specific gravity	2.43	2.58	3.12	2.42	2.67
FM	-	-	-	3.1	7.64
Bulk Density	210 Kg/m3	850 Kg/m3	-	1680 Kg/m3	1520 Kg/m3

2.1.3 Chemical composition of material

A detailed breakdown of the chemical compounds that are available in cement, WGP and SDA is mentioned below:

Table 2:Chemical Composition (%)

Element	Cement	Waste glass powder	Saw dust Ash
SiO_2	20.36	70.03	68.71
Al_2O_3	5.67	2.16	4.54
Fe_2O_3	2.92	0.71	2.05
CaO	63.17	11.51	9.48
MgO	1.88	2.76	4.13
SO_3	2.86	0.12	1.07
K_2O	0.78	0.66	2.45
Na_2O	0.24	11.42	0.06
P_2O_5	-	0.05	-
TiO_2	-	0.09	-
$CaCO_3$	-	-	4.8
Cr_2O_3	-	0.11	-
LOI (Loss on Ignition)	2.12	0.38	2.71

2.2 Experimental work

To conduct the experimental work 45 cubes were cast for the compressive strength test and 45 cylinders were cast for the split tensile strength test. So, 90 specimens had been prepared for performing the experimental work. The average strengths of three cubes for each period of curing had been taken as the value of compressive and split tensile strength. A list of the specimens with detailed proportions is mentioned below:

Table 3:Proportion of cement and composite waste

Specimen	Cement (%)	SDA (%)	WGP (%)
SDA 0+ WGP 0	100	0	0
SDA 5+ WGP 5	90	5	5
SDA 10+ WGP 10	80	10	10
SDA 15+ WGP 15	70	15	15
SDA 20+ WGP 20	60	20	20

2.2.1 Compressive strength

Lab test has been accomplished to calculate the compressive strength of cubic specimens as shown in **figure 4**, measuring 150mm x 150mm x 150mm. All the specimens are tested in a saturated surface dry state, with moisture removed. For each percentage variation, as well as for the standard condition, three identical specimens are tested with the application of a consistent rate of loading. Compressive strength has been determined at the time intervals of seven, fourteen, and twenty-eight days.

Figure 4:Application of load to the cube specimen to determine the compressive strength

2.2.2 Split tensile strength

This experiment is led on concrete to evaluate their tensile strength properties. In this experiment, a cylindrical sample of the material is placed horizontally and exposed to a gradually increasing tensile load as shown in **Figure 5**. The force is applied at the vertical axis of the specimen, causing it to split or crack as shown in **Figure 6**. This examination gauges the material's resistance to forces attempting to pull it apart, offering valuable insights into its durability and ability to withstand tensile stresses. The test is commonly employed to evaluate concrete's tensile strength, as concrete exhibits considerably lower strength in tension compared to compression. Cylinders with sizes of 150 mm in diameter and 300 mm in height were prepared and then subjected to testing.

Figure 5: Application of load to the cylindrical specimen to determine the split tensile strength

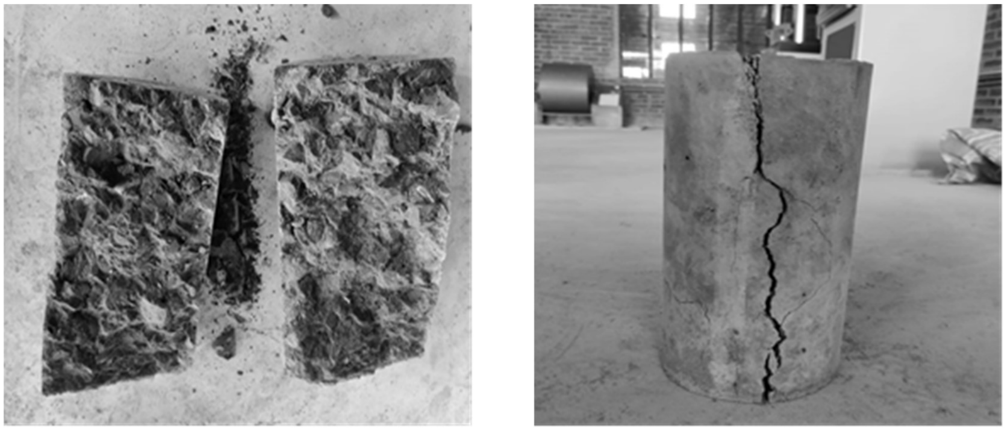


Figure 6: Failure pattern (Split Tensile Strength Test)

2.2.3 Standard Consistency

The standard consistency of cement paste is precisely defined as the degree of consistency that allows the Vicat plunger, with a length of 50mm and a diameter of 10mm, to penetrate a Vicat mould to a depth of approximately 10 mm from the top of the mould. The standard consistency test is done with pure cement paste and by replacing the cement with composite waste as shown in **Figure 7**.

Figure 7: Determination of standard consistency of cement paste with the help of Vicat's Apparatus

2.2.4 Initial and Final Setting Time

The term "setting" is used to describe the strength of cement paste. Cement hardening means that the cement paste changes from semi-solid to solid condition. It is distinct from the cement toughening process, where the strength of the set cement paste increases. Even though the cement paste develops a certain resistance upon setting, the setting process itself should not be confused with the subsequent hardening process.

2.2.5 Slump test

The slump test is employed to assess workability and measures how easily concrete can flow under its own weight by gauging its resistance to deformation. The test procedure complies with the specifications outlined in the ASTM standard c143/c143m. The value of the slump for different specimens is tabulated in **Table 4**.

3. RESULTS AND DISCUSSION

3.1 Result of Standard Consistency

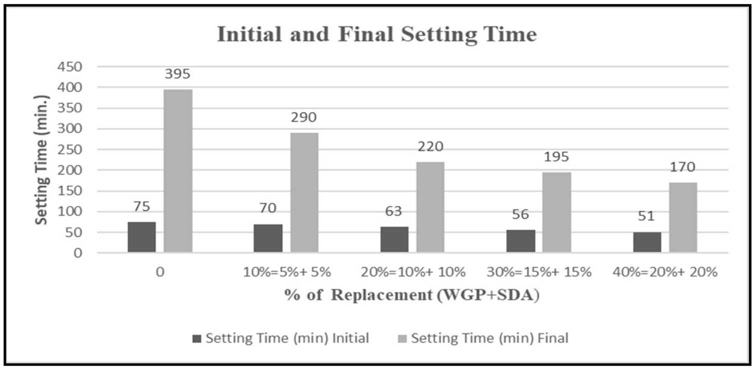


Figure 8:Graphical representation of Standard Consistency Test

The graph of **Figure 8** indicates that the standard consistency is highest, approximately 29.5%, for a pure blend of cement and water. However, as the cement is progressively substituted with composite waste, the value gradually decreases. It reaches 25.3% when 40% of the cement is replaced with a combination of sawdust ash and waste glass powder.

3.2 Result of Initial and Final Setting Time

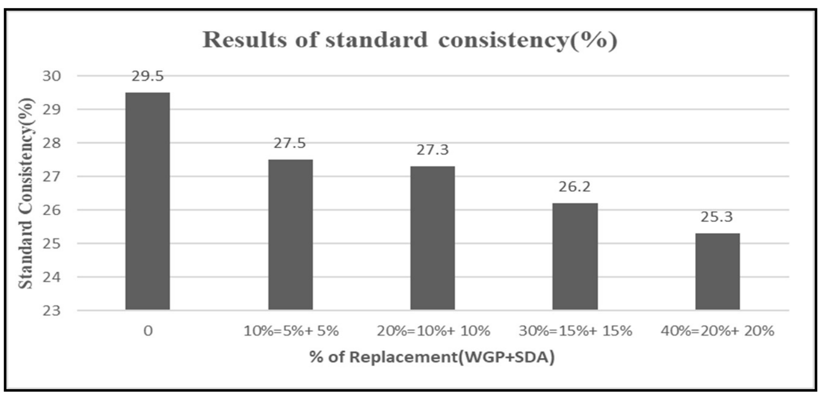


Figure 9: Graphical representation of Setting Time of cement paste

The graph of **Figure 9** illustrates that the initial and final setting times are roughly 75 minutes and 395 minutes, respectively, for a pure mixture of cement and water. However, as the cement is progressively substituted with composite waste, these values decrease. Specifically, for a 40% replacement of cement with a combination of waste glass powder and sawdust, the initial and final setting times were reduced to 51 minutes and 170 minutes, respectively.

3.3 Result of Slump test

Table 4:Slump value of the specimen

Specimen	Slump value (mm)
SD 0+ WG 0	86
SD 5+ WG 5	70

SD 10+ WG 10	64
SD 15+ WG 15	59
SD 20+ WG 20	53

The value of slump in **Table 4** clearly indicates the downward trend of slump value when cement is replaced with composite waste and the variation increases with an increase in the percentage of composite waste.

3.4 Result of Compressive Strength Test

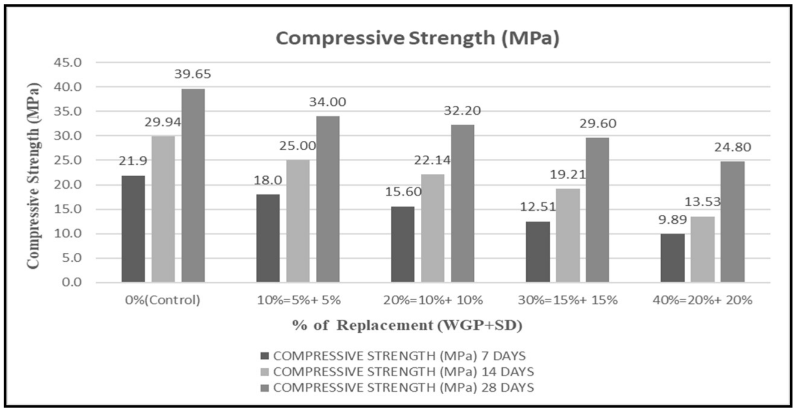


Figure 10: Graphical representation of Compressive Strength test of concrete cube

The mixture of waste glass powder and saw dust ash (composite waste) concrete is shown in the graph of Figure 10 along with its compressive strength results. The result shows the gradual decline of compressive strength with the increase of the combined proportion of WGP and SDA and comparatively more strength is noticed to be decreased for 40% replacement of WGP and SDA with cement paste.

3.5 Result of Split Tensile Strength Test

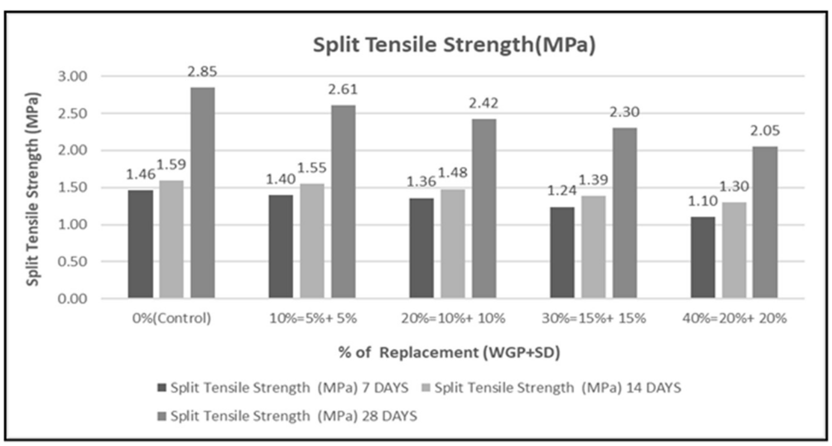
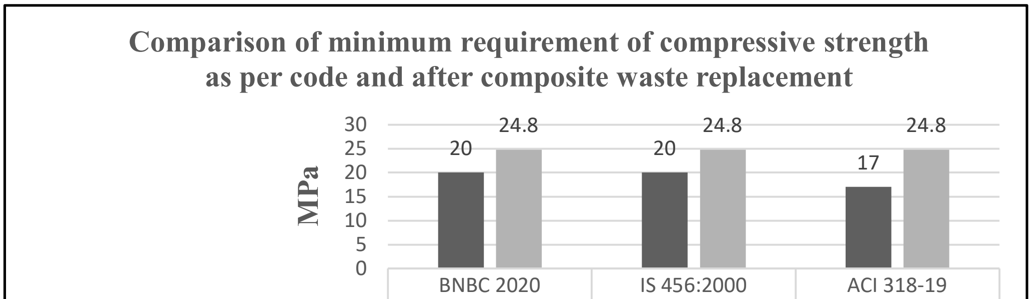


Figure 11: Graphical representation of Split Tensile Strength test of cylinder

The graph of **Figure-11** illustrates the split tensile strength of the composite concrete containing waste glass powder and sawdust ash after 7, 14, and 28 days of curing. There is minimal deviation in split tensile strength compared to the controlled sample (0% replacement). However, the decline in strength becomes more pronounced as the proportion of waste glass powder and sawdust ash increases.

3.6 Strength comparison as per different codes and after replacement with composite waste



	BNBC 2020	IS 456:2000	ACI 318-19
Strength requirement as per code (MPa)	20	20	17
Concrete strength nearer the code requirement after 40% composite waste replacement (MPa)	24.8	24.8	24.8

Figure 12: Comparison of the minimum requirement of compressive strength as per code and after replacement of composite waste

In the graph of **Figure-12**, the minimum requirement of compressive strength for any structure has been plotted against the concrete strength after 40% composite waste replacement and the value of concrete for composite waste replacement is chosen in such a way that is nearer to the strength requirement of different codes i.e. 40% (20% SDA+20% WGP).

4. CONCLUSION

The compressive strength and durability of conventional cement may not be achieved by SDA and WGP. If these components are employed in excess, the performance of the concrete may be impacted. The utilization of WGP and SDA plays a significant role in mitigating environmental pollution during the disposal of surplus waste glass powder and saw dust ash. Since cement is an expensive material, incorporating the WGP and SDA as partial replacements helps lower the overall cost of concrete. In summary, the inferences derived from the findings mentioned above are as follows:

1. The value of compressive and split tensile strength shows a downward drift as the percentage of WGP and SDA increases. The maximum value of compressive and split tensile strength is found at the replacement level of 10% (WGP 5% & SDA 5%). This is because in **Table 2** it is observed that cement contains 63.17% Calcium oxide (CaO) whereas WGP and SDA contain 11.51% and 9.48% CaO respectively. CaO, commonly called lime, plays a vital role in cement. When exposed to water, CaO undergoes a hydration reaction, forming calcium hydroxide, a critical reaction in the cement-setting process. This chemical transformation is essential for the strength and resilience of the cured cement. Additionally, CaO contributes to the binding and solidification of the cement mixture through its hydration reaction, creating a gel-like substance that ultimately imparts the characteristic structural integrity and strength found in hardened concrete.
   Furthermore, in the clinker formation phase, CaO reacts with alumina (Al_2O_3) and silica (SiO_2), resulting in the formation of tricalcium aluminate (C3A) and dicalcium silicate (C2S). These compounds play a significant role in determining the overall properties of the cement, influencing factors such as setting time and strength development.
   So as the percentage of composite waste is increased the proportion of CaO is increased but not as much as compared to the proportion available in cement which might affect the strength property of

the concrete and a decent value of slump is obtained for 10% replacement which indicates better workability of the mix along with the strength compared with the slump value of other mixes.

2. In the graph of **figure-12** it is observed that both BNBC 2020 and IS 456:2000 have recommended M20 grade concrete as a minimum requirement for any structure but in our study, we have utilized M30 grade concrete and the cost will increase for preparing M30 grade concrete so for preparing a cost-effective mix design, the composite waste can be replaced with cement and cement replacement up to 40% gives a value of 24.8 MPa which is nearer to the code requirement 20 MPa. So, by reducing the cost of the material by supplementing it with composite waste, the concrete grade can be upgraded to get better strength.
3. The water-cement ratio percentage depends on the quantity of ash incorporated into the concrete, as ash is characterized by its high porosity. Concrete with high porosity indicates the presence of a substantial quantity of voids or pores within the concrete and water is absorbed through the pores during mixing and the water content becomes insufficient to handle the concrete mix resulting in the decrease of slump value and for this reason, it is observed in **table 4** that with the gradual increase of composite waste the value of slump decreases.

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