Malaysian Journal Of Civil Engineering

Full Paper

EXPERIMENTAL STUDY OF CONCRETE AS PARTIAL REPLACEMENT OF COARSE AGGREGATE BY SILICA SLAG

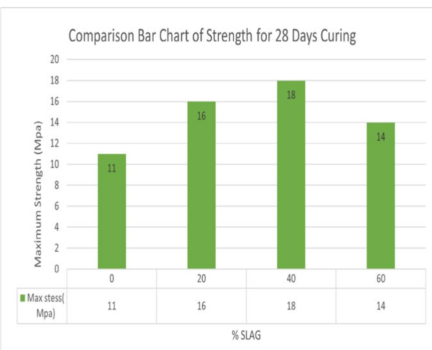
Labiba Mubashshira, Prium Reza, Abu Sayem Khan, Md. Mahmudur Rahman*

Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh

Article history
Received
14 June 2024
Received in revised form
24 August 2024
Accepted
29 August 2024
Published online
01 December 2024

*Corresponding author
mahmudurdr@aust.edu

Graphical abstract



Abstract

Aggregate is a key component of concrete, greatly impacting its volume and influencing its mechanical strength, durability, and serviceability. This study examines using silica slag, an industrial by-product waste, as a partial replacement for coarse aggregate (Recycled Brick Chips) in concrete. It assesses concrete properties with silica slag replacing recycled brick chips at 0%, 20%, 40%, and 60%. The findings show that adding silica slag with recycled brick chips enhances both compressive and tensile strengths. Concrete mixes, prepared with superplasticizer (ASTM C-494: Type A & F), achieved improved workability while maintaining the required water-cement ratio. Various mechanical properties of silica slag, such as impact resistance, specific gravity, unit weight, void ratio, and water absorption, were thoroughly tested. The study reveals that a 40% replacement of coarse aggregate with silica slag results in optimal compressive strength, around 18 MPa. This indicates that concrete incorporating recycled brick chips and silica slag can achieve moderate compressive strength and meet structural requirements effectively to achieve sustainable development.
.

Keywords: Silica Slag, Sustainable Development, Recycled Brick Chips, Superplasticizer, Moderate Strength

1.0 INTRODUCTION

Concrete is a mostly used material in architecture and construction. As the worldwide necessity for concrete continues to rise, finding substitutes to naturally occurring aggregates becomes imperative for sustainable development. Silica slag, a by-product predominantly from the steel industry, has been recognized as a potential replacements for coarse aggregates made from nature (Kalane and Shekokar 2023). Silica slag not only helps in managing the increasing demand but also promotes the reuse and recycling of industrial waste, which is often disposed of rather than utilized. This paper explores advantages of incorporating silica slag into concrete. It emphasizes silica slag's role as substitute of traditional construction materials, improving waste management, conserving natural resources, and enhancing the properties of building materials. This analysis highlights the possibilities of using silica slag for achieving sustainable development in the construction sector.

Studies have shown that the use of silica slag as both fine and coarse aggregate can significantly enhance the mechanical strength of concrete due to its high density and strength, surpassing traditional aggregates (Devi and Gnanavel 2014). Additionally, it has been found that stainless steel reduced slag can be used as a replacement of cement mortar and reveals that it increases workability but decreases the strength as the replacement percentage increases (Wang et al. 2021).

Different types of slag exhibit varied characteristics. For example, extensive substitution of natural aggregates in traditional concrete with Oxidizing Electric Arc Furnace (EAF) slag has been investigated. This research focused on the compressive and tensile strength, elastic modulus, and durability characteristics of concrete containing EAF slag, using Fuller's ideal grading curve (Wriggers and Moftah 2006). It was found that EAF slag provides an optimized gradation curve, enhancing the concrete's properties (Pellegrino and Gaddo 2009).

Moreover, studies have explored the impact of steel slag used as a binder material in place of cement. The pozzolanic activity increases as slag decreases. This study results that finer size of slag has greater strength by using as a binder material with cement (Jalil et al. 2019). Research involving the incorporation of slag in cement with polypropylene fibers has demonstrated that this combination yields concrete with higher strength compared to traditional concrete (Kumar and Kumar 2016).

In pavement engineering, slag has demonstrated significant benefits, including improvements in compressive strength, elasticity, and durability (Pasetto et al. 2023). Furthermore, studies on the partial replacement of fine aggregates with silica slag in concrete have reported increases in compressive, tensile, and flexural strength, despite a slight reduction in performance when coarse aggregates are substituted (Malathy and Kothai 2014).

Observing the previous studies, the research is conducted based on partial replacement of recycled brick chips by silica slag using superplasticizer as an admixture. This research serves the purpose of effective use of recycled and waste materials.

2.0 METHODOLOGY

2.1 Materials

Silica slag, recycled brick chips, ASTM Type -II cement, and Superplasticizer (ASTM C-494: Type A & F) (Testing, Concrete, and Aggregates 2017) are used as the components of concrete. Silica slag is a byproduct of waste from the steel production industry. It is composed of silicates and oxides, with varying proportions of other compounds depending on the specific metallurgical operation and raw materials involved. Slag utilization offers several environmental and economic benefits, including reducing waste generation, conserving natural resources, and lowering greenhouse gas emissions associated with traditional construction materials. Recycled aggregate brick chips, commonly referred to as crushed bricks, represent a sustainable construction material derived from the demolition waste of brick buildings. The recycled brick chip has specific gravity of 2.17 and unit weight of 1145.86 kg/ m^3 which is derived from the experimental analysis. This material is gaining attention in the construction industry due to its environmental benefits, including reducing landfill waste and conserving natural resources by offering an alternative to traditional aggregates (Ashiquzzaman, Hossen, and Hossain 2013). Superplasticizers, also known as high-range water reducers, are a class of polymers used extensively in concrete technology to enhance the flowability and workability of concrete mixtures without compromising their mechanical properties (Yang et al. 2013). Their development and incorporation into concrete mix designs have revolutionized concrete practices, allowing for the production of highly workable, yet strong and durable concrete with lower water-to-cement ratios. Superplasticizer (ASTM C-494: Type A & F) are used which has specific gravity of 1.210 g/cc at 25°C. Bangladeshi Cement brand named as 7 rings cement (BDS EN 197-1:2003, CEM II/B-M(S-V-L) is used. From the cement brand specification, it is found that the cement has 65% – 79% clinker and 0% - 5% Gypsum. Moreover, the cement Specific Gravity is 3.15 g/cc. The sand that is used in this experimental study is called Sylhet Sand which has Fineness Modulus of 2.92. The particle size distribution of the sample sand is derived through the experimental analysis and a particle distribution curve is derived.

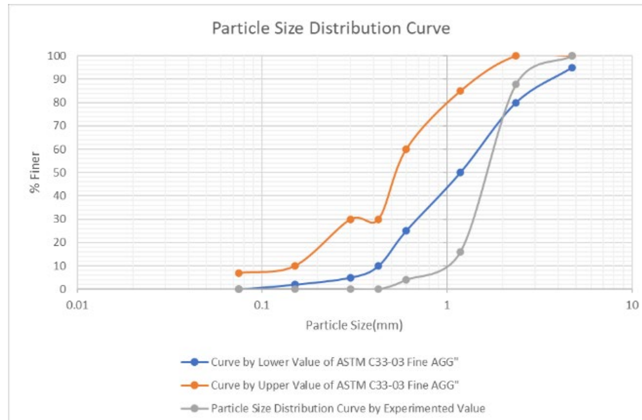


Figure 1 Particle Size Distribution Curve of Sylhet Sand

The Figure 1 compares the particle size distribution curve with the upper and lower value of ASTM C33-03 (ASTM 2003). The curve for the experimented values falls between the ASTM C33-03 specified lower and upper limits, indicating that the sand tested is within acceptable standards as per ASTM C33-03. Initially, the experimental values are closer to the upper specification limit, suggesting a higher proportion of smaller particles. As the particle size increases, the experimental values approach the lower specification limit, indicating a distribution with fewer larger particles.

This compliance with ASTM C33-03 standards suggests that the sand used in the experiment is suitable for construction purposes where these specifications are required. The particle size distribution curve also indicates a well-graded aggregate, which is beneficial for achieving good compaction and stability in concrete or other construction materials.

2.2 Characteristics of Silica Slag

Silica Slag refers to the waste residual after the pyrometallurgical production of metals, which are dominated by silicon dioxide. Figure 2 represents Silica slag has a blackish appearance containing many non-interconnected pores. This material forms when lime or dolomite flux reacts with the silicates, alumina, and other impurities present in the iron ore or scrap metal, facilitating their separation from the molten steel. Upon cooling, silica slag solidifies into a dense, granular material. Its physical and chemical properties, which include durability, high angularity, and considerable mechanical strength, make it a versatile material suitable for various applications. These applications range from its use as an aggregate in concrete and asphalt mixtures, road base and sub-base materials (Martauz, Václavík, and Cvopa 2017). The incorporation of silica slag in construction and industrial applications not only contributes to resource efficiency and waste reduction but also aligns with sustainable development goals by offering an environmentally friendly alternative to natural aggregates, thus minimizing the environmental footprint of construction projects and industrial activities.

Figure 2 Silica Slag

2.3 Silica Slag Aggregate Test

As silica slag is a waste material, its aggregate properties must be known to be effectively used in construction materials. Slag-specific gravity test, unit weight and void ratio test, impact test is conducted. Aggregates must possess adequate toughness to withstand disintegration from impact. Toughness is measured quantitatively by the aggregate impact value test .In adherence to S, the specific gravity test for aggregates is conducted at a controlled temperature of 23/23°C following ASTM C127(ASTM 2015). Additionally, the unit weight of silica slag is determined following ASTM C29 standard (ASTM 2009)that involves three methods: shoveling, tamping, and jiggling. These procedures are carried out in a specified sequence within a 3 cubic meter container to ensure precise measurement s showed in Figure 3.

(a) (b)

Figure 3 Silica Slag Aggregate test (a) Impact testing apparatus (b) Bucket for Unit weight and void ratio test

2.4 Concrete Mix Design

The concrete mix design is completed following the ACI Concrete Mix Design Method. Based on the concrete design criteria and the conditions of aggregates, cement and admixture, concrete mix design is conducted and final mix ratio is determined which is showed at Table 1.

Table 1: Concrete Mix Design

Cement type	ASTM Type -II cement
C:FA: CA	1:2.17:2.81
W/C	0.55
Slump value	3 inches
Type of coarse aggregate	Brick chips and Silica slag
Silica slag size	12.5 mm
`	Sylhet Sand
Admixture	Superplasticizer (ASTM C-494: Type A & F)

The constant 0.55 W/C ratio is used for each sample of concrete cylinder casting even when a water reducing superplasticizer is used. A W/C ratio of 0.55 ensures sufficient initial workability of the concrete mix. Even though superplasticizer can significantly reduce the water content required for achieving desired workability, maintaining a W/C ratio like 0.55 helps ensure that the mix remains workable without becoming too stiff or difficult to handle, while casting the concrete. Furthermore, a 0.55 W/C ratio provides a balance between compressive strength and durability, essential for the overall performance of the concrete. In essence, a 0.55 W/C ratio, despite the inclusion of a high-range water-reducing admixture (superplasticizer), reflects a strategic approach to balancing workability, strength, durability, and consistency in the concrete mix.

2.5 Concrete Casting

Concrete Casting is completed varying the percentage of silica slag from 0% to 60% replacement. Superplasticizer is used as an admixture to enhance the concrete strength. Sand is used as fine aggregate and ASTM Type -II cement is used as binder. Concrete was mixed by a manual concrete mixture machine. Concrete casting is a process of creating solid shapes or forms out of concrete by pouring a mixture of cement, water, and aggregates into a mold. Once the concrete sets and cures, the mold is removed, leaving behind the desired structure. For our casting, we used cement, sand, recycled brick chips, Silica slag, and water.

Table 2 shows that a total of 24 samples of concrete cylinders are cast, varying the replacement of recycled brick chips by slag from 0% to 60%.

Table 2: Sample Details of Experimented Concrete Cylinder

Sample Details						
W/C ratio	Slag Percentage in Concrete	Recycled Brick Chips percentage in concrete	No. of Samples for 28day Crushing Cylinder strength test	No. of Sample for 14day Crushing Cylinder Strength Test	No of Sample for Split Cylinder Tensile Test	Final Total No of Sample
0.55	0	100	2	2	2	24
	20	80	2	2	2	
	40	60	2	2	2	
	60	40	2	2	2	

The experiment conducted using cylinder molds. The cylinder used for concrete casting has height of 203.2 mm, diameter of 101.6 mm. Hence the area of the cylinder is 8107.3386 mm². After mixing the concrete, the freshly mixed concrete is casted on this cylinder mold. Finally, curing preserves the right moisture conditions, temperature, and time during which concrete is allowed to gain maximum strength, and durability. Adequate curing enhances the quality and prolongs the life of the concrete structure. After 24 hours, the mold was removed and the specimens were kept in fresh water at the submerged condition for curing to ensure adequate moisture as required by the specification by ASTM C192/C192M-02 (ASTM 2007). The whole casting process is showed in Figure 4.

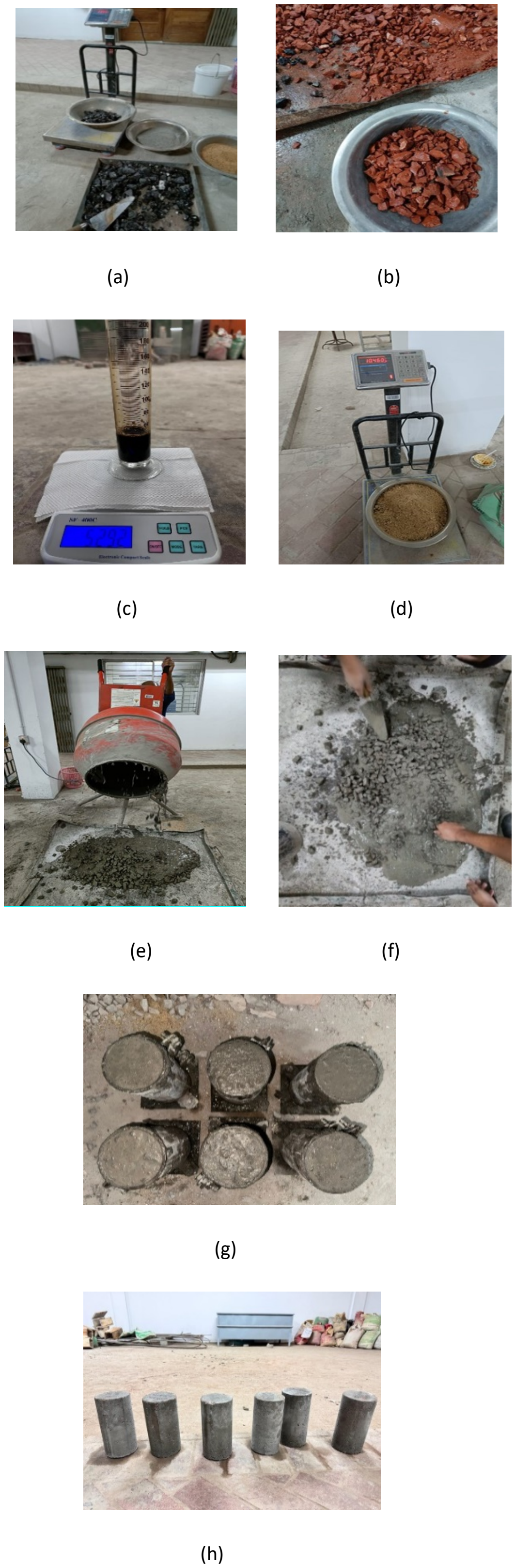


Figure 4 Concrete Casting (a) Slag Weighing (b) Recycled Brick Chips Weighing (c) Superplasticizer (ASTM C-494: Type A & F) measuring as per requirement (d) Sylhet Sand Weighing (e) Concrete Mixing Machine (f) Mixing the fresh concrete after coming out from the mixing machine for homogenous concrete mix (g) Freshly Casted Concrete Cylinder (h) Concrete after 28days curing.

Slump test is a test technique for evaluating the consistency of hydraulic cement concretes that have not been set. It plays an important role in observing hydraulic cement slump, which is a crucial measure of the material's plasticity, and strength.

2.6 Compressive and Tensile Test

A total of 24 cylinders had been tested for compressive strength test. Two rubber pads were introduced at both ends of the cylinder for better grip while conducting the test. Compressive strength was tested using UTM (Universal Testing Mechanism) as per the test method of ASTM C39/C39M (Concrete and Aggregates 2014). The maximum load of the specimen was noted. The maximum applied force at the failure was divided by the area of the specimen to give the strengths of the concrete. The compressive strength of the sample was calculated as below;

$C = P/A$; where $A = \pi D^2/4$ ……………… (1)

Where, C = Compressive strength, MPa [psi], P = Maximum applied load, N [lb.], D = Diameter of the specimen, mm [in]

The split tensile strength of concrete is usually measured using a standard testing procedure that can be considered as ASTM C496 in the United States. This is a test in which a concrete cylinder is laid horizontally around both load surfaces of a compression testing equipment, and a load is applied at a constant rate until the cylinder fails. The force applied perpendicularly to the cylinder's axis induces tensile strength along the vertical diameter, eventually causing the cylinder to split along that diameter. The split tensile strength becomes

Split Tensile Strength = $2P/\pi DL$; …………………… (2)

Where, P = Maximum load applied in N or lb., D = cylinder diameter in meters (or inches), L = cylinder length in meters (or inches)

3.0 RESULTS AND DISCUSSION

3.1 Slag Test

The conducted tests on silica slag, following ASTM standards (Specific Gravity - ASTM C127, Unit Weight - ASTM C29, Impact Test - ASTM-D58-74), demonstrate that it possesses desirable characteristics for use as a construction material. The key findings from the tests include:

3.1.1 Silica Slag Impact Value:

The silica slag impact test yielded a slag impact value of 30.43%. According to British Standard BS 812: Part 112 (British Standard 1990), AIV between 20% and 30% reflects moderate toughness, where the aggregates can perform adequately under lighter to medium dynamic loads, such as in residential roads or structures with moderate traffic. This indicates that the silica slag has sufficient toughness and resistance to impact, making it suitable for use in concrete and other construction applications where impact resistance is critical.

3.1.2 Specific Gravity and Absorption Capacity

The specific gravity of the silica slag was tested in both oven dry and saturated conditions as shown in Table 3

Table 3: Silica Slag Specific Gravity

Bulk Specific Gravity (OD)	2.54
Bulk Specific Gravity (SSD)	2.58
Absorption (%)	1.43%

This value indicates that the slag can absorb a significant amount of water, which is a crucial factor in concrete mix design.

The specific gravity values for the silica slag fall within the recommended range of 2.5 to 3.0 for coarse aggregates. This ensures that the slag has adequate density and strength, contributing positively to the overall structural integrity of the concrete.

3.1.3 Unit Weight:

The unit weight of the silica slag was determined to be 1654.124 kg/m³ which is within the ASTM C29 standard ranges for unit weight.

These test results collectively indicate that silica slag possesses the necessary properties for effective use in concrete applications, providing sufficient resistance, density, strength, and absorption capacity.

3.2 Slump test

A slump test was performed following the casting of the concrete mix, revealing that a decreasing slump value is attributed to the increased percentage of silica slag while maintaining a constant water-cement (W/C) ratio. This reduction is due to an increase in voids in slag and heterogeneous concrete mix. As the percentage of slag increases, it absorbs more water due to higher pores in slag, resulting in the drying out of the concrete mix. Experimental results indicate that a 40% slag substitution provides a good slump value which provides medium workability and making it effective percentage for the concrete mix design. At this replacement level, the slump value is satisfactory, ensuring the desired workability and performance of the concrete mix. Thus, a 40% slag substitution is recommended for achieving appropriate slump values and effective concrete mix design.

The test result has shown in Table 4 that the value of slump is 0% and 20% of slag constant on partial replacement of recycled brick chips. At 40% slag, the slump value of concrete comes out to be 76.2 mm.

Table 4: Slump Test

Slump Test	
%Silica Slag Substitution	Slump Value (mm)
0	88.9
20	88.9
40	76.2
60	50.8

At a 60% substitution level of slag, the slump value decreases to 50.8 mm. This reduction occurs because the silica slag absorbs more water at a constant water-to-cement ratio, leading to a decrease in workability. Achieving a homogenous concrete mixture becomes challenging with reduced workability, potentially impacting the overall performance of the concrete. Therefore, as the percentage of slag substitution increases, the slump value correspondingly decreases. From the slump test analysis, it is determined that a 40% partial replacement of recycled brick chips with silica slag represents the optimal balance, ensuring sufficient workability for concrete applications.

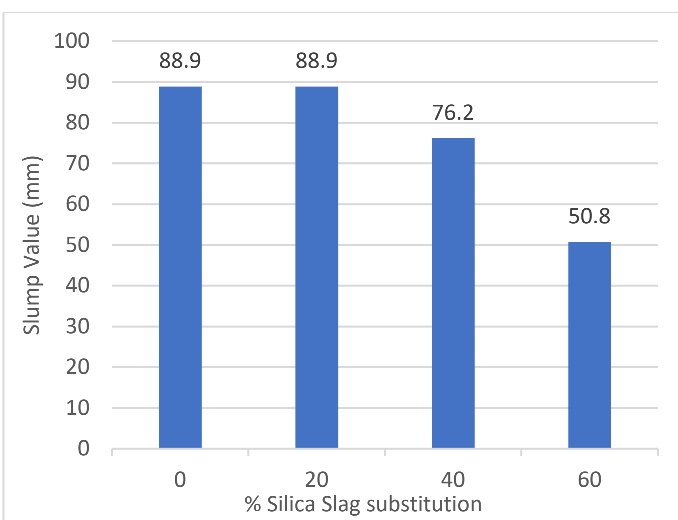


Figure 5 Bar Chart of Slump Value of Concrete varying % Silica Slag Substitution

Figure 5 illustrates the relationship between the percentage of silica slag substitution and the slump value (in millimeters) of concrete mixes. The slump value of the concrete without silica slag substitution (0%) is recorded at 88.9 mm. When 20% of the recycled brick chips is replaced by silica slag, the slump value remains unchanged at 88.9 mm, indicating that a 20% substitution does not significantly affect the workability of the concrete mix in terms of its slump value. At 40% substitution, the slump value decreases to 76.2 mm yet maintaining medium workability. With 60% silica slag substitution, the slump value further decreases to 50.8 mm, indicating a significant reduction in workability compared to the control mix. The lower slump value suggests a stiffer mix that may be more difficult to work with during the concrete placement process. This finding highlights the importance of optimizing the silica slag content in concrete to balance workability and performance.

3.3 Compressive test

Compressive strength was conducted after curing of 14 days and 28 days respectively. Hence the concrete strength and the failure pattern are within the acceptable limit.

Table 5 Compressive Strength of concrete

Compressive test of Concrete									
Sand (Kg)	Cement (kg)	% Silica Slag	% CA (Recycled Brick Chips)	Weight of CA (Recycled Brick Chips) (kg)	Weight of Silica Slag (kg)	W/C Ratio	Compressive Strength at 14 Days (MPa)	Compressive Strength at 28 Days (MPa)	Failure pattern
10.4	4.8	0	100	13.4	0	0.55	9	11	Combine (Mortar and Aggregate)
		20	80	10.728	2.682		15	16	Combine (Mortar and Aggregate)
		40	60	8.046	5.364		16	18	Combine (Mortar and Aggregate)
		60	40	5.364	8.046		11	14	Combine (Mortar and Aggregate)

The Table 5 expresses the compressive strength of concrete at 14 days and 28 days respectively. Moreover, the weight of required sand, cement, recycled brick chips, silica slag is provided for each casting and the failure pattern of concrete is defined as well.

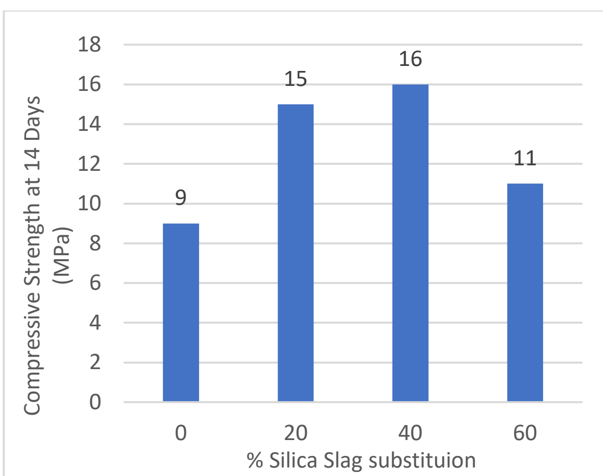


Figure 6 Bar chart of Maximum Compressive Strength of concrete with partial replacement of recycled brick chips by silica slag (14 Days)

Figure 6 illustrates the effect of different percentages of silica slag substitution on the compressive strength of concrete at 14 days of curing. The percentages of silica slag substitution considered are 0%, 20%, 40%, and 60%, with their corresponding compressive strengths shown in megapascal (MPa). The results demonstrate a clear trend where the compressive strength initially increases with the inclusion of silica slag up to an optimal substitution percentage of 40%. Beyond this point, however, further increases in silica slag content led to a decline in compressive strength.

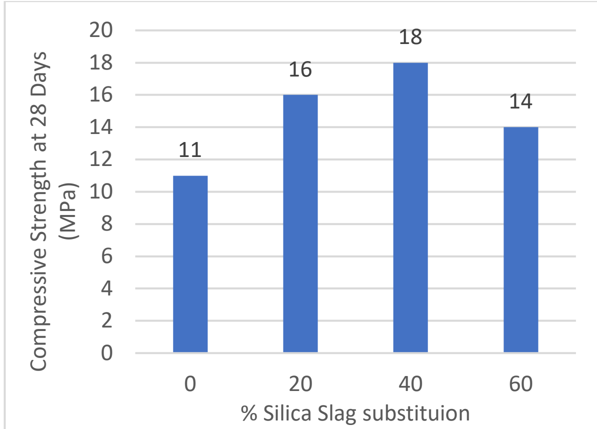


Figure 7 Bar chart of Maximum Compressive Strength of concrete with partial replacement of recycled brick chips by silica slag (28 Days)

From the data in Figure 7, it is observed that the maximum strength of the concrete increases as the percentage of Silica Slag substitution rises from 0% to 40%. At 40% substitution, the concrete reaches its highest strength of 18 MPa. Beyond 40% substitution, a decrease in strength is observed, with the strength dropping to 14 MPa at 60% substitution. This suggests that while the substitution of Silica Slag generally strengthens the concrete up to a certain point (40% substitution), further increases in substitution beyond this level begin to reduce the strength of the concrete.

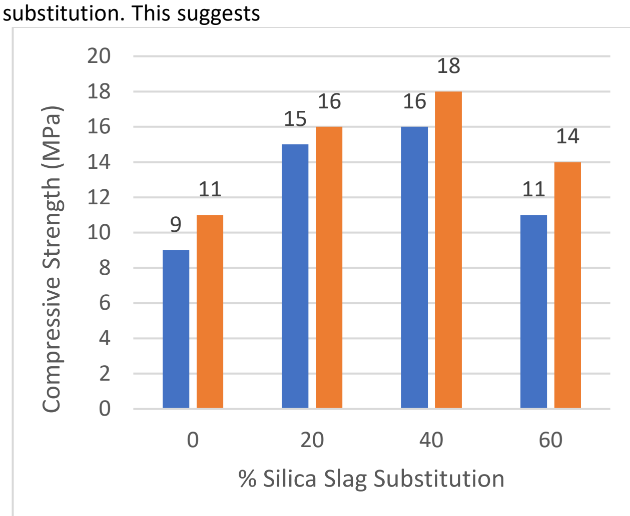


Figure 8 Bar chart of Comparison of Concrete Compressive Strength at 14 days and 28 days respectively

Figure 8 illustrates the effect of different percentages of silica slag substitution on the compressive strength of concrete at 14 and 28 days of curing. The blue bars represent compressive strength at 14 days, while the orange bars represent strength at 28 days. The concrete without any silica slag substitution exhibited compressive strengths of 9 MPa at 14 days and 11 MPa at 28 days. As the percentage of silica slag substitution increased to 20%, the compressive strength improved to 15 MPa and 16 MPa at 14 and 28 days, respectively. Further substitution at 40% led to a maximum compressive strength of 16 MPa at 14 days and 18 MPa at 28 days. However, with 60% silica slag substitution, the compressive strength declined to 11 MPa at 14 days and 14 MPa at 28 days. This indicates that while moderate silica slag substitution enhances concrete strength, higher substitution levels may result in diminishing returns.

Comparing the concrete compressive strength at 14 days of curing and 28 days of curing, it is observed that the compressive strength increase at 28 days of curing for 0% silica slag substitution is comparatively lower than 14 days of curing strength. This variation might be due to concrete casting errors like inadequate curing condition, errors in concrete compaction and mixing.

The observed trend in compressive strength, where it increases up to 40% silica slag substitution and then decreases beyond that, can be attributed to several factors. Pozzolanic Reaction Enhancement (Up to 40% Substitution) can be a reason for increasing strength up to 40% silica slag substitution. When silica slag is introduced into the concrete mixture, it acts as a pozzolan, which contributes to secondary hydration reactions. The finely ground silica slag reacts with the calcium hydroxide ($Ca\ (OH)_2$) produced during cement hydration to form additional calcium silicate hydrate (C-S-H), which is the primary strength-giving compound in concrete. Up to 40% substitution, the balance between the silica slag and the calcium hydroxide is optimal, leading to an increased generation of C-S-H and thus enhancing the compressive strength. The microstructural improvement might also be a reason. Silica slag, being a finer material, helps in filling the voids in the concrete matrix, leading to a denser microstructure. This densification reduces porosity, resulting in a stronger and more durable concrete. Moreover, high levels of silica slag can also negatively affect the workability of the concrete mix. Poor workability may lead to improper compaction and increased porosity in the concrete, which further reduces compressive strength. Hence any factors might affect the compressive strength of concrete. On the basis of this experimental analysis, it can be said that 40% silica slag substitution with recycled brick chips provide adequate compressive strength.

3.4 Split Tensile Strength

The test was conducted after curing, and splitting load is the ultimate load to be considered for determining maximum splitting tensile strength of concrete.

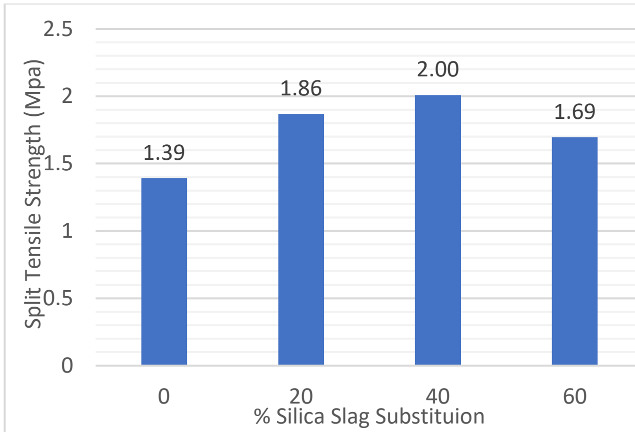


Figure 9 Comparison of Split Tensile Strength as variation of percentage of slag substitution

From the data following Figure 9, it is observed that a control mixture with 40% slag exhibits the maximum tensile strength at 2.008 MPa. As percentage of slag substitution reaches to 20%, there is a noticeable decline in strength to 1.868 MPa. However, further augmentation to 60% slag significantly reduces the strength to 1.695 MPa.

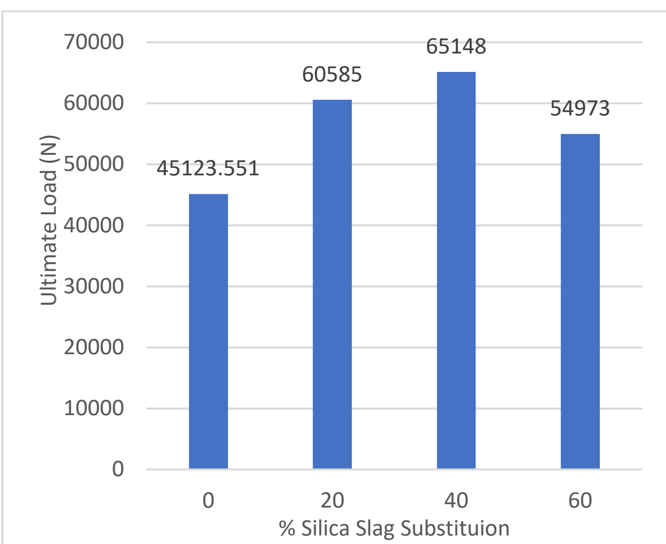


Figure 10: Cracking Load for concrete with partial replacement of coarse aggregate by slag

Figure 10 demonstrates that at a silica slag substitution level of 0%, serving as the conventional sample, the cracking load is approximately 45,124 N. When percentage of silica slag substitution is elevated to 20%, there is a notable rise in the cracking load, reaching around 60,585 N. This upward trend continues until a 40% replacement is achieved, at which point the maximum cracking load observed in the data set is about 65,148 N. This suggests a significant enhancement in the crack resistance of the concrete.

3.6 Regression Analysis

Figure 11 shows that it is a polynomial 3rd Degree curve for compressive strength at 28 days of curing and it fits all the points properly. The regression equation is Y= -6E-05x^3+0.275x+11 and the value of R^2 is 1 which indicates that it fits all the points well. Hence the predicted values might be accurate enough.

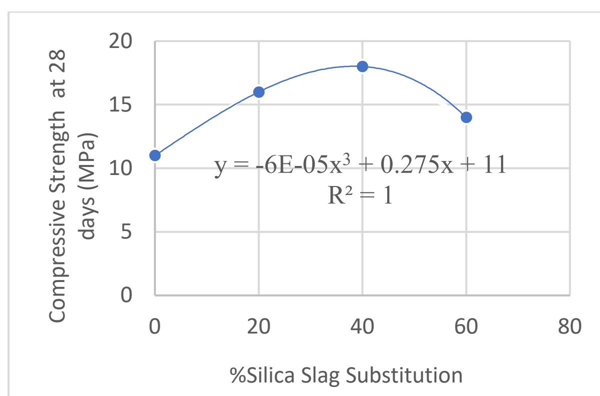


Figure 11 Regression Analysis for concrete compressive strength at 28 days

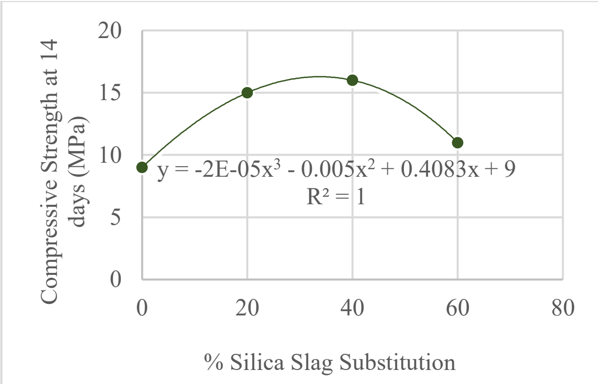


Figure 12: Regression Analysis for concrete compressive strength at 14 days

Figure 12 shows that it is a polynomial 3rd Degree curve for compressive strength at 14 days of curing and it fits all the points properly. The regression equation is Y= -2E-05x³+0.005x²+0.4083X +9 and the value of R^2 is 1.

Regression analysis is conducted for concrete compressive strength at both 28 days and 14 days. Both graphs exhibit peak compressive strength at a silica slag substitution of around 40%. However, the peak strength at 28 days is slightly higher 18 MPa than that observed at 14 days 16 MPa. The rate of strength gain is more pronounced in the 28-day graph, as seen by the steeper slope of the curve before reaching the peak. This suggests that silica slag substitution may contribute more significantly to strength development as curing time increases. The R^2 value of 1 in both graphs indicates a perfect fit for the cubic polynomial model used to describe the relationship between silica slag substitution and compressive strength. This high degree of correlation suggests that the cubic model accurately captures the underlying behavior of the system across the two-time frames. However, this comparative analysis emphasizes the importance of identifying an optimal level of silica slag substitution to maximize concrete's compressive strength.

4.0 CONCLUSION

Based on our present experimental study, we can make the following conclusion

1. The research demonstrates that achieving compressive strengths between 11 MPa and 18 MPa is feasible through the use of silica slag substitution and recycled brick aggregates. It is noted that the Standard compressive strength of M15 grade of concrete has specified compressive strength about 15 MPa and M20 grade of concrete has specified compressive strength about 20 MPa.
2. Compressive Strength varies with the percentage of slag substitution. The proper percentage is 40% which provides a maximum strength of 18 MPa. Besides further increasing the percentage to 60% significantly reduces the strength to 14 MPa.
3. As outlined by the International Code Council (ICC) the tensile strength of concrete is generally estimated to be approximately 10% of its compressive strength, typically ranging between 2 MPa and 5 MPa. In line with these established standards, the tensile strength obtained in this experimental study was also found to be within a reasonable range, varying from 1.39 MPa to 2 MPa.
4. The slump value decreases from 88.9 mm to 50.8 mm by increasing the replacement of recycled brick chips by silica slag. According to IS 456-2000 the concrete with a slump value ranges from 50 mm to 100 mm provides medium workability. However, superplasticizer influences to maintain adequate workability with a constant W/C ratio. Hence the casted concrete might provide adequate workability for concrete casting.
5. The failure patterns of the concrete cylinders are Combined (Mortar and Aggregate).
6. The concrete has a compressive strength of 18MPa. It can be used in small construction work such as structural blocks, partition walls, retaining wall, embankments and fill materials etc where 18 MPa strength of concrete will suffice.
7. Concrete composed of recycled brick chips, silica slag, sand, and superplasticizer as admixture can be used for utilization of waste products.

The study demonstrates that partially replacing recycled brick chips with 40% silica slag in concrete significantly impact the concrete compressive strength, offering a promising solution for improving the overall performance and utilization of waste products.

Acknowledgements

The authors would like to express their heartfelt appreciation to the Department of Civil Engineering at Ahsanullah University of Science and Technology for their unwavering support and for facilitating this research by providing access to the laboratories and equipment facilities. Their commitment to fostering a conducive research environment was integral to the progress and completion of this study. Furthermore, the authors wish to extend their sincere thanks to the management of SSRM Steel Industry for their generous contribution of silica slag, sourced from their steel manufacturing process, which played a pivotal role in the experimental phase of this research. Their collaboration and willingness to support academic inquiry are deeply valued and greatly appreciated.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Ashiquzzaman, M, SK B Hossen, and FMZ Hossain. 2013. 'Prospect of using recycled concrete as coarse aggregate in Bangladesh', *Mist International Journal Of Science And Technology*, 2: 7-15

[2] ASTM, ASTM. 2015. 'Standard test method for relative density (specific gravity) and absorption of coarse aggregate', *ASTM West Conshohocken, PA*.

[3] ASTM, C29. 2009. 'Standard test method for bulk density (“unit weight”) and voids in aggregate', *American Society for Testing and Materials, Annual Book: West Conshohocken, PA, USA*.

[4] ASTM, C33. 2003. 'Standard specification for concrete aggregates', *Philadelphia, PA: American Society for Testing and Materials*.

[5] ASTM, C. 2007. 'Standard practice for making and curing concrete test specimens in the laboratory', *C192/C192M*.

[6] British Standard, BS. 1990. 'Testing aggregates. Method for determination of aggregate impact value (AIV)',. *BS*: 812-112.

[7] Concrete, ASTM International Committee C09 on, and Concrete Aggregates. 2014. *Standard test method for compressive strength of cylindrical concrete specimens* (ASTM international).

[8] Devi, V Subathra, and BK Gnanavel. 2014. 'Properties of concrete manufactured using steel slag', *Procedia Engineering*, 97: 95-104.

[9] Jalil, Affan, Anwar Khitab, Hamza Ishtiaq, Syed Hassan Bukhari, Muhammad Tausif Arshad, and Waqas Anwar. 2019. 'Evaluation of steel industrial slag as partial replacement of cement in concrete', *Civil Engineering Journal*, 5: 181-90.

[10] Kalane, Saurabh Pramod, and Shubhangi R Shekokar. 2023. 'Steel Slag as a Construction Material for Sustainable Deveploment: A State of Art'. Research Square, 1: 1-34.

[11] Kumar, P Vignesh, and R Kumar. 2016. 'An experimental study on partial replacement of coarse aggregate by iron slag with polypropylyne fiber', *International Journal of Science and Research (IJSR)*, 5: 212-16.

[12] Malathy, PS Kothai1 Dr R, and R Kothai. 2014. 'Utilization of steel slag in concrete as a partial replacement material for fine aggregates', *International Journal Of Innovative Research In Science, Engineering And Technology*, 3: 11585-11592

[13] Martauz, Pavel, Vojtěch Václavík, and Branislav Cvopa. 2017. 'The use of steel slag in concrete', *IOP Conference Series: Earth and Environmental Science*, 92: 012041.

[14] Pasetto, Marco, Andrea Baliello, Giovanni Giacomello, and Emiliano Pasquini. 2023. 'The use of steel slags in asphalt pavements: A state-of-the-art review', *Sustainability*, 15: 8817.

[15] Pellegrino, Carlo, and Vittorio Gaddo. 2009. 'Mechanical and durability characteristics of concrete containing EAF slag as aggregate', *Cement and Concrete Composites*, 31: 663-71.

[16] Testing, American Society for, Materials. Committee C-09 on Concrete, and Concrete Aggregates. 2017. *Standard specification for chemical admixtures for concrete* (ASTM International).

[17] Wang, Her-Yung, Wei-Chien Wang, Jen Chun Wang, and Yu-Wen Chen. 2021. 'Evaluation of the engineering properties and durability of mortar produced using ground granulated blast-furnace slag and stainless steel reduced slag', *Construction and Building Materials*, 280: 122498.

[18] Wriggers, Peter, and SO Moftah. 2006. 'Mesoscale models for concrete: Homogenisation and damage behaviour', *Finite elements in analysis and design*, 42: 623-36.

[19] Yang, Jian Wei, Qiang Wang, Pei Yu Yan, and Bo Zhang. 2013. 'Influence of steel slag on the workability of concrete', *Key Engineering Materials*, 539: 235-38