Waste Glass "An Alternative of Cement and Fine Aggregate in Concrete"

Muhammad Israr Pashtoon*, Shafiullah Miakhil**, Mohammad Mukhlis Behsoodi**

* Corresponding Author, Muhammad Israr Pashtoon, B.Sc Student, Civil Engineering Department, Alfalah University, Afghanistan. E-mail: israr10455@gmail.com

, * Lecturer, Civil Engineering Department, Alfalah University, Afghanistan. (E-mail: ** shafi_miakhil12@hotmail.com ; *** dean.engineering@alfalah.edu.af)

Received: 16.07.2022 Accepted: 28.04.2023

Abstract - The major aim of this study is to use Waste Glass Powder (WGP) which is obtained from grinding glass waste using an abrasion apparatus, as cement and a fine aggregate substitute in concrete. The physical and mechanical characteristics, workability, and compressive strength of concrete were studied by using WGP as cement and fine aggregate replacement simultaneously. In order to perform correctly, the glass has to be sieved to particle sizes of less than 150 μm sieve for cement replacement and 4.75 mm for fine aggregate replacement. WGP was used to replace the cement and fine aggregate in concrete, yielding products with respective cement contents of 10.0% and 15% and fine aggregate contents of 15.0% and 20%, and the properties of this concrete have been compared with reference specimens with zero replacement. Cube specimens were cast, cured, and tested for compressive strength and workability at 7, 14, 28, and 56 days of age, and the results were then compared to those of traditional concrete. The use of WGP as a cement and fine aggregate substitute resulted in a reduction in concrete's compressive strength and workability. However, the findings revealed that WGP could be used as a partial substitute for cement and fine aggregates, with 10 to 15% of cement and fine aggregate substitution by WGP being the optimum in terms of strength and economy. As a result, we can utilize it in structures that are moderately heavy.

Keywords: WGP, Compressive strength, Waste management, Workability, Concrete, Cement, Fine aggregate

1. Introduction

In the building sector, concrete is a common material. It is composed of cement, coarse aggregate, fine aggregate, and water, with an admixture occasionally applied to accomplish desired results. Aggregate makes up 70% – 75% of the total volume of concrete. Cement, being a binding material and a crucial element of concrete, makes up a 7–15% portion of it [1]. It is estimated that the global production rate of concrete is about one ton per person per year and that this rate is continuously rising [2]. Being an energy-intensive industry, the cement industry's contribution to CO_2 emissions is 5% globally [3]. Depending on the type of fuel used, one ton of cement is expected to produce 0.9 to 1 ton of CO_2. The largest environmental worry of today, according to scientists, is man-made climate change as a result of global warming, which is the outcome of continuous and constant rising concentrations of greenhouse gases, notably CO_2, in the earth's atmosphere over the past 100 years [4]. Even though fine natural aggregates currently outperform all other resources in the production of concrete, their supply is quickly declining due to deliberate overexploitation brought on by rising urbanization and the development of other utilities worldwide. River fine aggregate depletes natural resources, lowers the water table, causes bridge piers to sink, and causes river bed erosion when used as a fine aggregate. If a particular percentage of fine aggregate is substituted with waste glass in a predetermined size range, the fine aggregate content will be lowered, reducing the detrimental impacts of river dredging and improving the sustainability of the concrete production sector [5]. The cement and concrete industries are using more and more solid industrial byproducts, such as siliceous and aluminous materials, as well as some pozzolanic minerals to mitigate such environmentally depleting circumstances. Concrete production could be made greener by using supplementary cementitious materials (SCMs), recovered aggregates, and other industrial wastes [6]. Supplementary cementitious elements are frequently used in concrete mixes to lower cement content, enhance workability, increase strength, and extend the concrete's life [7]. Waste glass powder is pozzolanic and can be utilized as a cementitious material with proper processing. The adequate replacement level of WGP is 10% for cement in concrete [8]. In the same manner, the optimal replacement of fine aggregate by waste glass was found to be 10% [9]. In order to manufacture cement, four basic materials are required. Lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) are among them. The chemical combination of these basic ingredients in the kiln, as well as the interaction that happens, produces the four primary compounds found in cement (known as calcination). Glass is a useful member of the garbage family in many rural and urban areas, and it is made up of a variety of inorganic raw materials that are processed into a stable, inert, hard, homogenous, amorphous, and isotropic material [10]. Due to its non-decomposable nature, waste glass usually doesn't have a negative impact on the environment, but if disposed of inappropriately, it can harm both humans and animals. The tremendous amount of waste glass is a challenge for the world now, with millions of tons of glass trash produced every year in the world. Glass accounts for 0.7 percent of the total urban garbage created in India. [11]. Every year, the United Kingdom produces about three million tons of waste glass. [12]. Because it is non-biodegradable, it takes up a lot of space in landfills and poses serious environmental risks [13]. WGP is a fine, superfine, or powdered glass made from waste glass collected from landfills, dumpsites, and other waste disposal sites. Waste glass is washed, crushed, ground, and milled to produce a fine powder. The amount of silicon and calcium in glass is relatively high.

In this study, cement and fine aggregate were partially substituted by waste glass at a rate of 10% & 15% and 15% & 20% by weight, respectively. For varying waste glass percentages, concrete specimens were evaluated for compressive strength and workability. When the results of the concrete mix containing 10% and 15% waste glass as cement and fine aggregate were compared to the results of a standard M-30 concrete mix, it was discovered that the compressive strength of the concrete mix containing 10% and 15% waste glass as cement and fine aggregate was comparable. Slump value declined as waste glass content increased, making concrete less workable. This study reviewed the behavior of concrete in which waste glass was utilized to replace cement and fine aggregate in proportions of 10%, & 15%, and 15% & 20% by weight, respectively, which may help to relieve waste disposal concerns while also improving the qualities of the concrete.

2. Research Significance

Due to its non-biodegradable nature, non-recyclable waste glass is a significant burden on landfills. Because of its non-decomposable nature and the scarcity of landfills in metropolitan areas, its disposal is considered a major concern. It is critical to determine the suitability of glass waste as an alternative cement and fine aggregate in concrete for these studies to persuade people that glass trash can be reused in the construction process. The test must be analyzed in order to determine whether the outcome meets the requirements or not. Because the test results will demonstrate whether glass waste can meet the minimal requirements for both physical and mechanical properties, this is the case. In this regard, the concrete and cement industries provide a better solution for glass waste, because of their identical physical properties and chemical composition to fine aggregate and cement. On one side, it will safeguard the environment, and on the other, it will conserve natural resources and save the economy. If waste glasses are utilized in the production of concrete goods, the cost of concrete production will be lowered [14]. Waste glass can be used to replace cement and fine aggregate to some extent in the manufacturing of concrete. Fine aggregate content will be reduced if waste glass is substituted in a particular proportion and in a specific size range, decreasing river dredging's harmful consequences and making the concrete manufacturing business more sustainable. Because of its pozzolanic tendency, it is a highly recommended alternative to cement in the making of concrete.

3. Materials and Methods

3.1. Materials Used

The laboratory experiments were carried out using the following materials:

3.1.1. Cement

Cement plays an important role in the production of concrete; as a binding agent, it holds together the aggregates in concrete. Ordinary Portland cement of 53R grade conforming to PS 232:2008 (R) was used throughout the work.

Table 1: *Chemical Analysis of Cement*

Test	Amount (%)
SiO_2	19.03
Al_2O_3	4.72
Fe_2O_3	3.556
CaO	61.08
MgO	2.67
K_2O	0.92
Na_2O	0.05
SO_3	2.89
Cl	0.001

The characteristics of concrete are greatly influenced by the amount of cement compound present. In general, there are five different types of cement. Their various qualities are a result of their compounds' various composition ratios, which have various hydration properties. For instance, a high belite percentage in cement types 2 and 4 results in low initial hydration heat and high long-term strength; a high aluminate ratio in type 3 results in a high initial strength.

Table 2: *Physical Tests Result of Cement*

Name of Test	Unit	Result Obtained
Fineness	m^2/kg	312
Consistency	%	27.54
Le-chetlier Expansion	mm	1.21
Auto Clave Expansion	%	0.07
Initial Setting Time	minutes	173
Final Setting Time	minutes	224

Table 3: *Compressive Strength Test Result of Cement*

Period	Result Obtained (MPa)
3 Days	36.56
7 Days	46.13
28 Days	55.25

3.1.2. Coarse Aggregate

Inert granular aggregates that make up 60 to 75 percent of overall concrete production are referred to as gravel. Gravel is made up of particles that are larger than 4.74 mm but usually fall between 9.5 and 37.5 mm. Locally available crushed coarse aggregate having a maximum size of 20 mm is used. The following laboratory tests were conducted on coarse aggregate.

Table 4: *Lab Test Result Conducted on Gravel*

Name of Test	Unit	Result Obtained	Standard
Aggregate Impact Value Test	%	16.57	BS812: part 112: 1990
Aggregate Crushing Value Test	%	15.6	BS812: part 110: 1990
Los Angeles Abrasion Value Test	%	33.32	ASTM C131 – 89
Rodded Bulk Density	gr/cm^3	1.57	BS812: part 2: 1975 OR ASTM C29 – 91a
Loose Bulk Density	gr/cm^3	1.40	BS812: part 2: 1975 OR ASTM C29 – 91a
SSD Specific Gravity	–	2.691	ASTM C127 – 93
OD Specific Gravity	–	2.668	ASTM C127 – 93
Water Absorption	%	0.8	-

3.1.3. Fine Aggregate

In the entire project, fine river aggregate conforming to grading zone 1 and passing through a 4.75 mm sieve and containing 75 microns was employed. The following tests were performed using ASTM standards.

Table 5: *Lab Test Result of Fine Aggregate*

Test	Unit	Result	Standard
SSD Specific Gravity	-	2.41	ASTM C128 – 93
OD Specific Gravity	-	2.365	ASTM C128 – 93
Fineness Modulus	-	3	ASTM C136 – 92
Grading Zone	-	1	-
Water Absorption	%	2.3%	-

3.1.4. Water

During concrete casting and curing, potable water is used. It was found behind the Laboratory Building of Alfalah University's Civil Engineering Department in Nangarhar, Afghanistan.

3.1.5. Glass Powder

The waste glass came from the dumpsites of glass selling shops. In order to obtain WGP, waste glass was cleaned with water to remove soil and other pollutants. The glass was then left to dry naturally. It was then pulverized in a Los Angeles abrasion apparatus until the particles were small enough to pass through a No. 100 sieve, achieving cement grading, and added to concrete to increase its strength. Waste glass was found to have a specific gravity of 2.42. The different percentages of cement replaced by glass powder were 10, and 15% respectively. It was also pulverized to obtain particle sizes ranging from 4.75 mm to 0.075 mm for grading fine aggregate. In the trials, the different percentages of fine aggregate replaced with glass powder were 15% and 20%. The chemical makeup of glass is shown in the table below.

Table 6: *Chemical Composition of Glass*

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Percentage	71.2	1.6	0.8	9.8	2.9	13.4	0.3

Glass can be produced using thousands of distinct chemical combinations. The mechanical, electrical, chemical, optical, and thermal properties of the manufactured glasses are influenced by various formulations. Glasses don't all have the same chemical make-up. Here, we have utilized a common, contemporary soda-lime silica glass (used to make bottles and windows).

Figure 1: *Obtained broken waste glass*

Figure 2: *Sieved glass powder for cement and sand*

3.2. Methods

A mix ratio of 1:1.98:2.29 (Cementitious material: Fine aggregate: Coarse aggregate) was used in casting concrete cubes to achieve the desired concrete for the control mix.

Table 7: *Mix Proportion for Control Sample*

Cement	Fine aggregate	Coarse aggregate	Water/Cement Ratio
1	1.98	2.29	0.45

Natural fine and coarse aggregate were procured after the ingredients for manufacturing the design concrete mix of M-30 grade were obtained. The proportions established in the design mix were used to cast concrete cubes in sufficient numbers. A 0.45 water-to-cement ratio was chosen. The resulting waste glass was used to replace 10% and 15% by weight of cement content and 15% and 20% by weight of fine aggregate, respectively. In order to explore the impact of GP on concrete consistency, slump tests were utilized to assess the workability of various replacement-level concrete mixes. The concrete cubes were cured for 7, 14, 28, and 56 days. For each replacement level, twelve cubes were formed for 7, 14, 28, and 56 days to assess the compressive strength. Iron cube molds with dimensions of $150 \times 150 \times 150$ mm were used for concrete cubes.

Table 8: *Mix Proportion for Prepared Samples*

Mix type	Water/Cement	Cementitious materials (kg/m^3)		Water (kg/m^3)	Fine Aggregate (kg/m^3)		Coarse Aggregate (kg/m^3)
		OPC	WGP		Fine aggregate	WG	
Control	0.45	411.11	0	185	816.89	0	942
Trial 1	0.45	369.99	41.11	185	694.35	122.54	942
Trial 2	0.45	349.44	61.66	185	653.51	253.38	942

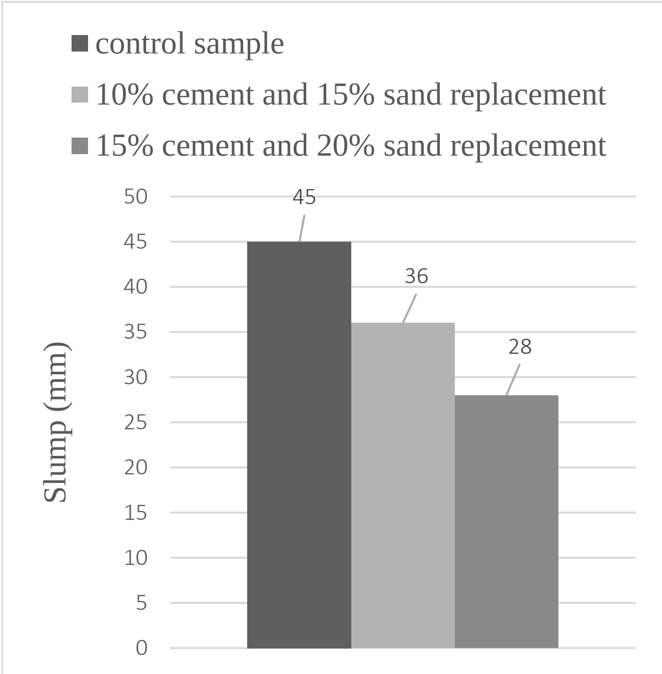

Figure 3: *Comparison of slump values of control, trial 1 and trial 2.*

4. Results and Discussions

4.1. Workability

The slump test was carried out in accordance with ASTM C143. The value is presented in the figure below.

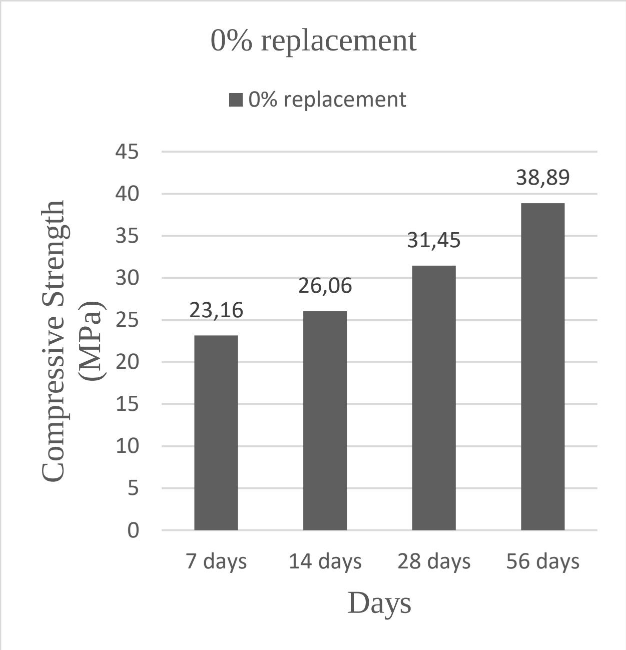

Figure 4: *Compressive strength of control sample*

The results demonstrate the slump value reduces as the amount of glass powder utilized increases. The fact that slump decreases as WGP content in concrete increases suggests that WGP-containing concrete is less workable than plain concrete. The angular form of glass powder particles is associated with slump minimization. Furthermore, glass powder in concrete has a higher density than cement and fine aggregate. Because glass powder is not cementitious in and of itself, using too much of it decreases the binding characteristics of fresh concrete, making it difficult to work with and compact.

4.2. Compressive strength

The concrete's compressive strength when WGP is used in place of cement and fine aggregate is shown in the figures below.

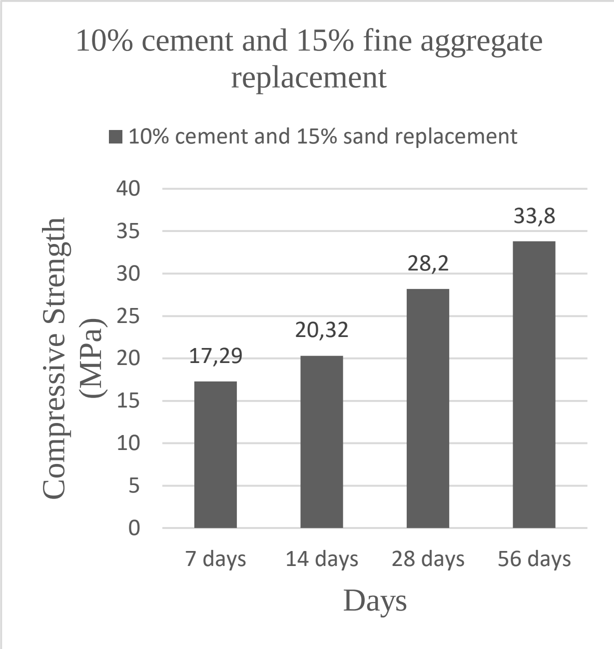

Figure 5*: Compressive strength of trial 1*

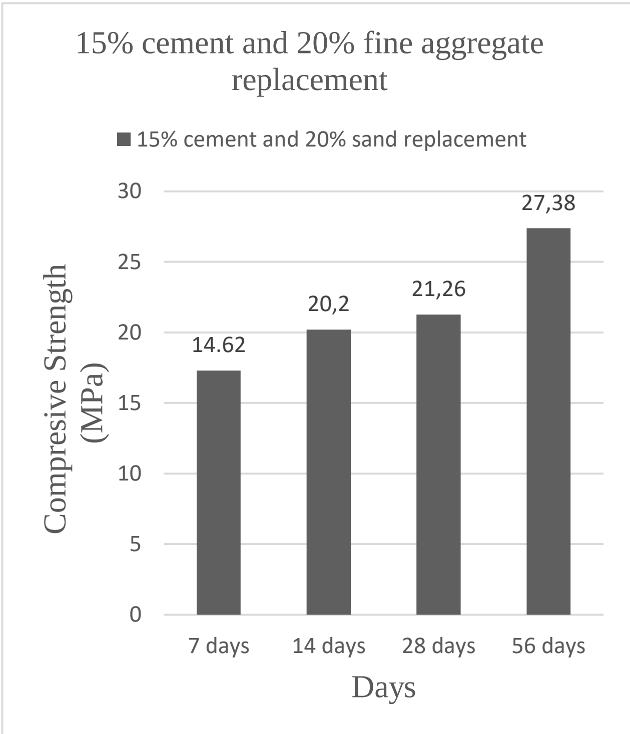

Figure 6*: Compressive strength of trial 2*

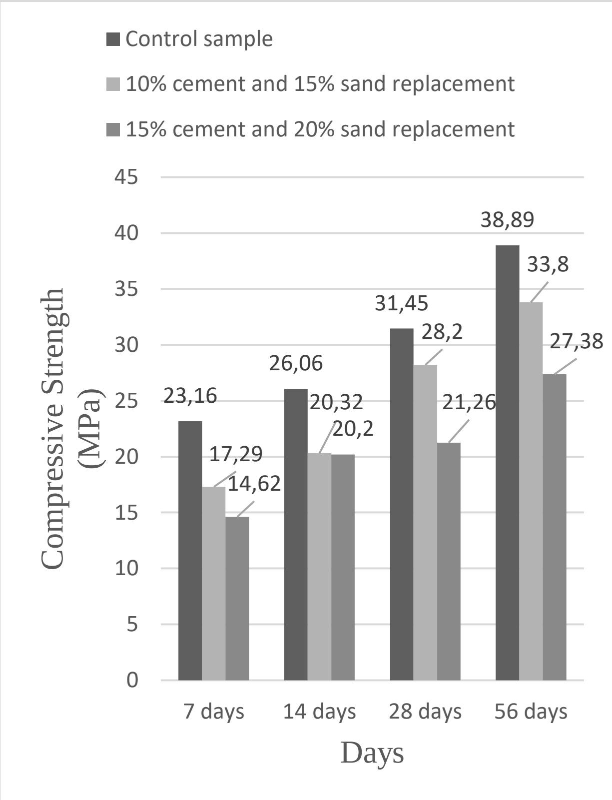

***Figure 7**: Compressive strength of comparison*

The control mix's strength was 31.45 MPa after 28 days, greatly exceeding the minimum cube crushing strength of 30 MPa. Trial 1 indicated an exceptional strength value of 28.2 MPa, which was practically the target strength, despite the fact that mixes containing WGP did not meet the needed 28-day strength. Because pozzolanic effects would not be noticeable in such short durations, the drop in 28-day strength is likely to be a short-term effect, as evidenced in the 56-day result, where Trial 1 exceeded the goal of 28-day strength and Trial 2 almost achieved the target strength.

The concrete samples for the control as well as each replacement level gained strength as the curing time rose, as expected, despite the influence of glass powder content on the mixes. The compressive strength at 14 and 28 days in Trial 2 shows just a modest rate of strength development when compared to the rate of strength gain in Trial 1. The maximum percentages of WGP that can be used to replace both cement and fine aggregate at once are 10% and 15%, respectively.

5. Conclusions

The following conclusions can be drawn based on the results obtained:

1. WGP has the potential to be pozzolanic and can be used as a cementitious material with proper preparation.
2. As the percentage of replacement increases, the workability of concrete reduces.
3. There is a marginal decrease in slump for the first trial compared to the control sample.
4. The strength of concrete can be improved with a long curing time.
5. Compared to the control sample, there is a deficiency of only 10.33% at 28 days and 13.1% at 56 days for trial 1 in compressive strength, thus making it an optimal replacement level. This indicates that concrete with appropriate characteristics was produced when cement was replaced with WGP and fine aggregate with glass sand. In light of the strength requirements, WGP can replace cement up to 10% and glass sand can replace fine aggregate up to 15%.

Future Scope

This research is focused on the properties and strength behavior of concrete if WGP is used as cement and fine aggregate in concrete simultaneously. However, further studies are required on the following issues:

- The effect of WGP in concrete by keeping the replacement level constant and changing the size parameter.
- The effects of using WGP as a cement substitute and demolished brick waste as a fine aggregate substitute in concrete production at the same time.
- At the same time, the impact of using WGP as fine aggregate and demolished brick waste as replacement for coarse aggregate in the manufacture of concrete.

Acknowledgments

The authors are thankful to Rahmani Mohammad Malyar, Senior Teaching Assistant, Department of Veterinary Science, Nangarhar University, Jalalabad City, Afghanistan. The authors gratefully acknowledge the support provided by the Civil Engineering Department and the close collaborations of the Research and Development Department, Alfalah University, Jalalabad City, Afghanistan.

References

[1] F. A. Olutoge and C. Strength, “Effect of Waste Glass Powder (WGP) on the Mechanical Properties of Concrete,” *Am. J. Eng. Res.*, vol. 38, no. 511, pp. 2320–847, 2016, [Online]. Available: www.ajer.org.

[2] J. Cassar and J. Camilleri, “Utilisation of imploded glass in structural concrete,” *Constr. Build. Mater.*, vol. 29, pp.

299–307, 2012, doi: 10.1016/j.conbuildmat.2011.10.005.

[3] A. M. Matos and J. Sousa-Coutinho, “Durability of mortar using waste glass powder as cement replacement,” *Constr. Build. Mater.*, vol. 36, pp. 205–215, 2012, doi: 10.1016/j.conbuildmat.2012.04.027.

[4] P. K. Mehta, “Greening of the Concrete Industry for Sustainable Development,” *Concr. Int.*, vol. 24, no. 7, pp. 23–28, 2002.

[5] T. Darshita and P. Anoop, “Study of Strength and Workability of Different Grades of Concrete by Partial Replacement of Fine Aggregate by Crushed Brick and Recycled Glass Powder,” vol. 3, no. 6, pp. 141–145, 2014.

[6] M. D. Lepech, V. C. Li, R. E. Robertson, and G. A. Keoleian, “40 Design of Green Ecc for Improved Sustainability,” no. 105, 2009.

[7] A. D. Neuwald, “Supplementary cementitious materials-part 1: pozzolanic SCMs,” *MC Magezine*, pp. 8–17, 2004.

[8] F. A. Olutoge, “Effect of Waste Glass Powder (WGP) on the Mechanical Properties of Concrete,” *Am. J. Eng. Res.*, vol. 38, no. 511, pp. 2320–847, 2016, [Online]. Available: www.ajer.org.

[9] S. P. Gautam, V. Srivastava, and V. C. Agarwal, “Use of glass wastes as fine aggregate in Concrete,” *J. Acad. Indus. Res*, vol. 1, no. 6, p. 320, 2012.

[10] L. M. Federico and S. E. Chidiac, “Waste glass as a supplementary cementitious material in concrete - Critical review of treatment methods,” *Cem. Concr. Compos.*, vol. 31, no. 8, pp. 606–610, 2009, doi: 10.1016/j.cemconcomp.2009.02.001.

[11] A. Pappu, M. Saxena, and S. R. Asolekar, “Solid wastes generation in India and their recycling potential in building materials,” *Build. Environ.*, vol. 42, no. 6, pp. 2311–2320, 2007, doi: 10.1016/j.buildenv.2006.04.015.

[12] P. Turgut and E. S. Yahlizade, “Research into Concrete Blocks with Waste Glass,” *Int. J. Civ. Environ. Eng.*, vol. 1, no. 4, pp. 203–209, 2009.

[13] Y. Jani and W. Hogland, “Waste glass in the production of cement and concrete - A review,” *J. Environ. Chem. Eng.*, vol. 2, no. 3, pp. 1767–1775, 2014, doi: 10.1016/j.jece.2014.03.016.

[14] I. B. Topçu and M. Canbaz, “Properties of concrete containing waste glass,” *Cem. Concr. Res.*, vol. 34, no. 2, pp. 267–274, 2004, doi: 10.1016/j.cemconres.2003.07.003.