ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 9, Issue, 11(C), pp. 29660-29664, November, 2018

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Research Article

ECO-FRIENDLY GEOPOLYMER CONCRETE USING RECYCLED WASTE GLASS AS FINE AGGREGATE

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DOI: http://dx.doi.org/10.24327/ijrsr.2018.0911.2902

ARTICLE INFO

Article History:

Received 15th August, 2018
Received in revised form 7th September, 2018
Accepted 13th October, 2018
Published online 28th November, 2018

Key Words:

Recycled Waste Glass Fine Aggregate (RWGFA), Geopolymer, Compressive Strength, Splitting Tensile Strength, Flexural Strength, Acid resistance.

ABSTRACT

Eco-friendly environment concrete research feasibility of generating geopolymer concrete from fly ash with recycled waste glass as fine aggregate is studied. Waste glass is a non-biodegradable material and at present it is dumped on a land which becomes a highly unsustainable option. To find a better solution to reduce the environmental issues caused by disposable of waste glass, it can be used as aggregate in concrete. Recycled waste glass is potential to serve as precursor material in geopolymer production because of abundant amount of amorphous silica is in waste glass. However, only limited research has been conducted on waste glass as precursor material. An attempt is made to use waste glass as fine aggregate in concrete. In concrete, cement is being used as a binding material which produces equal amount CO_2 emission to the atmosphere. In geopolymer concrete, 100% cement is replaced by fly ash and GGBS with activator solution. This research work aims to study the feasibility of using waste glass aggregates as precursor to create alkali activated material (AAMs) along with Fly Ash. The performance this geopolymer concrete in terms of mechanical and durability properties is studied. M 20 grade mix is used for conventional concrete and the same proportion with NaOH of 8 Molar (8 M) is used for geopolymer concrete production with recycled waste glass as fine aggregate. Comparison is also made with conventional concrete using sand as fine aggregate.

INTRODUCTION

The recycled waste glass aggregate in concrete production possesses a major impact on environment A.Shyan (2004). The present situation the demand of natural fine aggregate is very high, due to the enormous use of concrete. For example if we run out of river sand as it is predicted to happen in some places, necessarily the alternative for fine aggregate is used for making concrete. It is possible for recycled waste glass as fine aggregate is to be viewed as a potentially suitable for concrete production B.Parthiban, S.Thirugnanasambandam (2018). The increasing significant interest development of concrete production with recycling waste glass as fine aggregate is effective for environmental conservation and economical advantage. The recycled waste glass fine aggregate is used as fine aggregate in concrete and no reaction is detected with fine particle size. Once the particle size is reduced, it contribute to the mortar act as micro-structural properties resulting in an evident improvement of its mechanical performance. The glass size is influenced the microstructure of the concrete and it leads to denser and less permeable concrete. Water absorption is decreased and the durability is increased with increase the waste glass content in concrete and thus making concrete is light weight in nature. In this study, the size of the recycled waste glass size of 3 mm and down 3 mm is used. An attempt is made to use recycled waste glass as fine aggregate in concrete. In concrete, cement is being used as a binding material which produces equal amount CO_2 emission to the atmosphere. In geopolymer concrete, cement is 100% replaced by fly ash and GGBS with activator solution J.Guru Jawahar (2016). Low calcium fly ash (ASTM Class F) is used as the binder, instead of ordinary Portland cement V.M. Malhotra (2005). The fly ash based geopolymer with ground granulated blast furnace slag paste binds the loose coarse aggregate, fine aggregate and other un-reacted materials together the form of geopolymer concrete, with or without the presence of admixtures. The silica and alumina in low calcium fly ash (ASTM Class F) are activated by a combination of sodium hydroxide and sodium silicate solution to form geopolymer paste that binds the aggregate and other un- reacted materials.

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Experimental Program

Fly Ash

Low-calcium class F type fly ash is used for this experimental work and it is obtained from Mettur Thermal Power Station, Tuticorin, Tamil Nadu, India. The source material of class F type fly ash is rich in silicon (Si) and aluminium (Al) and less than 10% of lime (CaO). Low-calcium fly ash has been used to manufacture the geopolymer concrete when the silicon and aluminium oxides constituted by 75% to 80% by mass. The carbon content of the fly ash is indicated by less than 2% of mass. Class F type fly ash is fine grained material of spherical and the particle size distribution tests revealed that 80% of the fly ash are smaller than 50 microns. The specific gravity of fly ash is 2.40 and the colour is gray. The lighter in colour indicates lower carbon content presents in the fly ash.

Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag is the industrial by-product obtained from steel industry. In this geopolymer concrete production, the cement is replaced by fly ash and GGBS of equal quantity. For ambient curing conditions necessarily GGBS is added. The advantage of using GGBS using in geopolymer concrete production is to resist chemical attack and maintain excellent thermal properties. The specific gravity of GGBS is 2.90 and the colour is white. GGBS is obtained from Toshaly cements private limited, Andhra Pradesh, India, conforming to IS: 12089 (1987). The advantage of GGBS in geopolymer concrete is saving the natural resources and energy in cement manufacturing process and to reduce the CO_2 emissions from environment impact.

Recycled Waste Glass as Fine Aggregate (RWGFA)

In concrete production white colour clear glass is used as fine aggregate. The glass is washed to remove the impurities then it is crushed and melted. After that it is screened into required size for immediate use. The size of the recycled waste glass size of 3 mm and down 3 mm is used. The sample of recycled waste glass fine aggregate is shown in Figure 1.

Figure 1 Recycled Waste Glass as Fine Aggregate

The properties of recycled waste glass fine aggregate are given in Table 1. The Scanning Electron Micrograph (SEM) images of recycled waste glass fine aggregates are shown in Figure 2. An X –Ray Fluorescence (XRF) is used to determine the chemical composition of the recycled waste glass. The chemical composition of recycled waste glass fine aggregate is given in Table 2.

Table 2 Physical properties of recycled waste glass as fine aggregate (RWGFA)

Physical Property	Test Result
Specific gravity	2.56
Size of the aggregate	3 mm and down

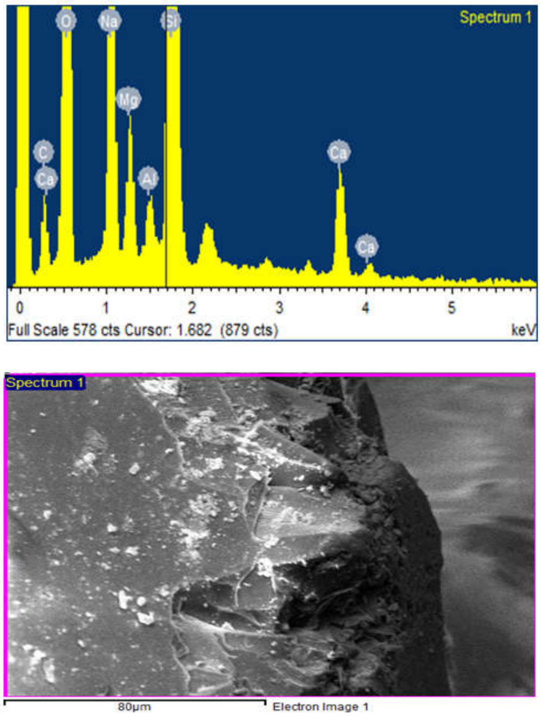

Figure 2 SEM Images of Recycled Waste Glass as Fine Aggregate (RWGFA)

Table 2 Chemical Constituents of Recycled Waste Glass as Fine Aggregate (RWGFA)

Constituent	In Percentage
SiO_2	78.01
$CaCO_3$	7.83
Na	8.60
MgO	1.81
Ca	3.02
Al_2O_3	0.61

The RWGFA posses a nearly same amount of silica and higher percentage (nearly 10%) of alumina as natural sand. The calcium and sodium content in river sand are minimum (less than 3%) as in RWGCA.

Alkaline Liquid

Sodium hydroxide pellets (NaOH) with 98% purity and sodium silicate solution ($NaSiO_3$) is used for geopolymer concrete manufacturing. The sodium silicate solution with sodium hydroxide ratio by mass is taken as 2.5. The sodium hydroxide pellets are dissolved in water to make a alkaline solution with required concentration. NaOH of 8 Molar (8 M) is used for this concrete manufacturing. If the molecular weight of NaOH is 40, in order to prepare 8 molar solution, 320 grams of sodium hydroxide pellets are dissolved in one litre of water. The alkaline solution is prepared prior to 24 hours before it use in mixing of concrete.

Coarse Aggregate

Coarse aggregate used are of machine crushed stone, angular in shape passing through 20 mm IS sieve and retained on 4.75 mm IS sieve and it conforms to IS 383-1970. The properties of coarse aggregates are given in Table 3.

Table 3 Physical Properties of Course Aggregate

Property	Result
Specific Gravity	2.76
Fineness Modulus	7.13

Chemical Admixtures

To maintain the slump and workability of the concrete, admixtures are used. Super plasicizer Conplast SP 430 is used in this concrete mix. The dosage of super plasticizer is 0.7% of the weight of the cement is used for his concrete production.

Water

Locally available portable water which is free from organic impurities is used for this concrete production.

Mixing, Casting and Curing

Geopolymer concrete is made with same mix proportion used in M 20 grade conventional cement concrete. The mix proportion of cement concrete is 1:2.75:3.36. In geopolymer concrete preparation, NaOH of 8M is used in the concrete mix. The geopolymer concrete constituents are fly ash, ground granulated blast furnace slag, recycled waste glass as fine aggregate, coarse aggregate, water and super plasticizer. Sodium silicate solution with sodium hydroxide pellets in the ratio by mass 2.5 has been used for concrete manufacturing. Figure 3 shows the materials used for preparation of concrete. River sand is used for control mix geopolymer concrete and the same mix is used for 100% replaced with recycled waste glass as fine aggregate. The constituents of geopolymer mix is given in Table 4.

Figure 3 Materials used for RWGFA Geopolymer Concrete

Table 4 Constituents of RWGFA Geopolymer Concrete

Description	Quantity in kg/m^3
Fly ash 50% + GGBS 50%	337.55
(Na_2SiO_3 + NaOH) / Fly Ash & GGBS	0.45
Na_2SiO_3 / NaOH	2.50
NaOH Pellets	13.89
Na_2SiO_3	108.50
Water	29.51
Recycled Waste Glass as Fine Aggregate (RWGFA)	928.26
Coarse Aggregate	1134.17
SP	2.24

For each mix, six cubes of size 100 × 100 × 100 mm are cast to find the compressive strength at 7 days and 28 days, three cubes of size 100 × 100 × 100 mm are cast to find acid resistance and three cubes of size 100 × 100 × 100 mm are cast to find sulphate resistance of concrete. Three cylinders of size 100 mm diameter and 200 mm long, three prisms of size 100 × 100 × 500 mm are cast to find the splitting tensile strength and flexural strength at 28 days respectively. The specimens are demoulded after 24 hours and cured in room temperature for ambient curing. After 7 and 28 days the specimens are tested. All the above tests are carried out for conventional concrete and recycled waste glass as fine aggregate concrete as per IS 516-1959.

Testing Procedure

Mechanical Properties

The mechanical properties such as compressive strength, splitting tensile strength and flexural strength are found for geopolymer control concrete and recycled waste glass as fine aggregate concrete. For compression test, 1000 KN capacity of compressive testing machine is used to apply the load. The load is gradually increases until the cube is failure. The maximum load taken by each specimen during the test is recorded. The average of three test results is the strength of the cube. For splitting tensile strength, cylinders are placed in compressive testing machine and the same procedure is followed as compressive strength test until the cylinder specimen failure. For flexure test, the specimens are tested under two point load application. The results of M 20 grade control concrete and recycled waste glass fine aggregate (RWGFA) concrete are tabulated in Table 5.

Table 5 Mechanical Properties of Concrete

Mix Designation	Compressive Strength (MPa)		Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
	7 days	28 days	28 days	28 days
Control Concrete	19.00	29.00	3.32	3.78
RWGFA Concrete	16.10	29.30	3.35	3.85

Durability Properties

Acid Resistance Test

The cube specimens of control concrete and RWGFA concrete cubes are weighed before immersing in acid made with 5% of HCl solution. The specimens are immersed in HCl solution as shown in Figure 4. After 90 days the specimens are taken out and the surface is wiped off using wire brush. Then the specimens are weighed and the specimens are tested for compressive strength. The percentage loss of weight of the specimen and the percentage loss of compressive strength are tabulated in Table 6.

Figure 4 Specimens Immersed in HCl Solution

Table 6 Percentage of Loss in Weight and Percentage of Loss in Strength

Sl. No.	Mix Designation	Initial Weight in Kg.	Final Weight in Kg.	% of Weight Loss	Initial Compressive Strength in MPa	Final Compressive Strength in MPa	% of Strength Loss
1.	Control Concrete	2.517	2.510	0.278%	29.00	28.46	1.86
2.	RWGFA Concrete	2.348	2.339	0.383%	29.30	28.73	1.95

Sulphate Resistance Test

The cube specimens of control concrete and RWGFA concrete cubes are weighed before immersing in acid made with 5% of $MgSo_4$ added with 5% of Na_2So_4 solution. The concentrated magnesium sulphate and sodium sulphate are dissolved in required water. The specimens are immersed in solution as shown in Figure 5. After 90 days the specimens are taken out and the surface is wiped off using wire brush. Then the specimens are weighed and the specimens are tested for compressive strength. The percentage loss of weight of the specimen and the percentage loss of compressive strength are tabulated in Table 7.

Figure 5 Specimens Immersed in $MgSo_4$ with Na_2So_4 Solution

Table 7 Percentage of Loss in Weight and Percentage of Loss in Strength

Sl. No.	Mix Designation	Initial Weight in Kg.	Final Weight in Kg.	% of Weight Loss	Initial Compressive Strength in MPa	Final Compressive Strength in MPa	% of Strength Loss
1.	Control Concrete	2.460	2.455	0.203	29.00	28.48	1.79
2.	RWGFA Concrete	2.365	2.358	0.295	29.30	28.73	1.95

RESULTS AND DISCUSSIONS

Mechanical Properties

The mean value of compressive strength at 7 and 28 days, splitting tensile strength and flexural strength at 28 days for control mix concrete and recycled waste glass as fine aggregate concrete are found and the typical failure mode of the recycled waste glass fine aggregate concrete are shown in Figure 6 a,b,c respectively. The properties of the recycled waste glass fine aggregate are not significantly varying from the river sand. Due to the lower water absorption and smooth surface texture of the recycled waste glass fine aggregate, workability is enhanced and more cohesive then control mix concrete. The absorption of water can affect the strength parameters. The higher water absorption leads to lower strength. Recycled waste glass fine aggregate absorbs minimum quantity of water and hence the results of mechanical properties are higher than the control mix concrete

Figure 6 (a) Crack Patterns of Cubes after Testing

Figure 6 b Crack Patterns of Cylinder after Testing

Figure 6 (c) Crack Patterns of Prism after testing

Durability Properties

In acid resistance test, the percentage of weight loss in control is found as 0.278% and the same in RWGFA concrete is 0.383%. The percentage of strength loss of control concrete and RWGFA concrete is found after 90 days immersion in acid are 1.86% and 1.95% respectively. The percentage of weight loss and the percentage of strength loss of RWGFA are marginally higher than the control concrete and it is not affected in durability parameters. In sulphate resistance test, the percentage of weight loss in control is found as 0.203% and the same in RWGFA concrete is 0.295%. The percentage of strength loss of control concrete and RWGFA concrete is found after 90 days immersed in acid are 1.79% and 1.95% respectively. The percentage of weight loss and the percentage of strength loss of RWGFA concrete are marginally higher than the control concrete and it is not affected in durability parameters.

CONCLUSIONS

The paper presents the utilization of recycled waste glass as fine aggregate in geopolymer concrete. The strength properties of recycled waste glass as aggregate in concrete is compared with control mix concrete. The result of mechanical properties of recycled waste glass as fine aggregate in concrete is higher than control mix concrete using river sand as fine aggregate. The durability properties of RWGFA concrete results are slightly lower than the control concrete but within the permitted values. The performance of test results using of RWGFA in concrete is satisfactory. The recycling of waste glass into aggregate will preserve the natural resources and the glass is found to be an alternative material for making concrete.

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How to cite this article:

Parthiban B and Thirugnanasambandam S., 2018, Eco-Friendly Geopolymer Concrete Using Recycled Waste Glass as Fine Aggregate. *Int J Recent Sci Res.* 9(11), pp. 29660-29664. DOI: http://dx.doi.org/10.24327/ijrsr.2018.0911.2902

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