Journal of Research in Forestry, Wildlife & Environment Vol. 10(3) September, 2018
http://www.ajol.info/index.php/jrfwe
jfewr ©2018 - jfewr Publications
E-mail: jfewr@yahoo.com
ISBN: 2141 – 1778
Mokuolu and Adebanjo, 2018

ASSESSING THE SUITABILITY OF GREEN CONCRETE USING WASTE GLASS AS PARTIAL REPLACEMENT FOR CEMENT

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ABSTRACT
Green construction reduces the impact of the built environment on the natural environment and human health. The study of partial replacement of cement with waste glass powder and fire resistivity of concrete was investigated in two stages using quantitative approach, the first stage involved collection of waste glass samples, crushing and milling of the glass samples into powder less than 75µm, casting of concrete cubes at ratio 1:2:4 for concrete grade M15 (according to IS 456:2000) using 0%, 10%, 20%, 30%, 50% and 60% replacement of cement with waste glass powder. Compressive strength tests were carried out on the concrete cubes after curing ages (days) of 7, 14, 28, and 35.A total of 72 cubes were tested. The second stage involved testing for the strength of the concrete with 0% and 10% waste glass powder content obtained from the first stage as the optimum percentage replacement after heating to a temperature of 600℃ for 5 hours in a furnace. Result showed with 0% cement replacement with waste glass powder being the control, had the highest strength of all the samples, 10% had the second highest strength which exhibited a normal increased strength behaviour with increase in curing ages unlike all other percentage replacements making 10% replacement of cement with waste glass powder milled to a particle size of 75µmto be satisfactory. Fire resistivity at 5 hours gave 50% reduction in strength and the concrete was non-flammable. Use of waste glass could reduce cement content in concrete, suitable for green construction.

Keywords: Concrete, Compressive strength, fire resistivity, environment

INDRODUCTION
Green Buildings are defined to be "the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials, and reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal - the complete building life cycle" (Howard, J.L.,2002). Similarly, the environmental protection agency defined Green buildings as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort". Green building is also known as a sustainable or 'high performance' building (Cullen Howe, 2008).

The history of green building dates back much further than the 1970s. During the energy crisis of the 1970s, green building moved from research and development to reality. Builders and designers were looking for a way to reduce the reliance of buildings and homes on fossil fuels. Solar panels were used to make more environmentally friendly homes. Also, consumers started wondering if solar panels can make buildings more efficient, lower energy bills and reduce the negative impact on the environment. Eco-construction involves so much more than simply using solar panels (Bstone and Patsalides, 2011; Tafheem *et al*.,2011).

The main purpose of green construction is to reduce the impact of the built environment on natural environment and human health, there are quite a number of construction materials and processes that make a building green. The processes range from life cycle assessment of the building, siting and structure design efficiency, energy efficiency, water efficiency, materials efficiency, indoor environmental quality enhancement, operations and maintenance optimization and waste reduction. Incorporating waste materials in concrete has been demonstrated to be an effective way to increase the sustainability of structures and infrastructures (Jin *et al.*,2000). Green construction materials include renewable plant materials like bamboo, straw, dimension stone, recycled stone, recycled metal, recycled industrial good such as coal, combustion products, foundry sand and demolition debris, low emitting materials in form of interior paints, flooring and ceiling materials, high performance, or green concrete. There is, however, a gap in the validation of real performance in green buildings while reducing cement content in concrete.

General study on green concrete has shown that it can be produced using various environmentally friendly materials, some of which are fly ash, slag, power plant wastes, recycled concrete, mining and quarrying wastes, waste glass, incinerator residue, red mud, burnt clay, saw dust, combustor ash and foundry sand. Apart from material and energy conservation, reuse of some solid waste could result in better performances of concrete in several ways (Du and Tan, 2014; Idir *et al.*, 2015). Recycling rate for waste glass is low at 27.7% for United States, 45% for Australia and 20% for Singapore. Those unrecycled waste glasses are disposed of in landfills (Jingke *et al.*,2013). It was recently found that the finely ground glass powder can be used as cement alternative because of the pozzolanic reaction of fine glass powder with cement hydration products, in its original form, glass comes as a balanced combination from three main raw natural materials: sand, silica, and limestone (Kumar and Kurmar, 2006). The partial replacement of cement with glass powder would further reduce the cement content in concrete and consequently the CO_2 emission during the cement production (Abdullah *et al*.,2012; Gunalaan and Seri, 2013; Vijayakuman *et al.*, 2013; Du *et al*., 2014; Du and Tan, 2014).

The need to improve material, cost and energy efficiency in the construction business and the importance of improving human health and the state of the natural environment are the driving forces for this research. Glass being a recyclable and environmentally friendly material makes it a very good alternative for cement in the production of concrete.

This study concentrates on analyzing the environmental benefits of controlling the CO_2 emission of cement by partial replacement of cement with waste glass powder and determining the optimum percentage of waste glass powder that will produce maximum compressive strength compared to conventional concrete. Replacement assessed was at 0%, 10%, 20%, 30%, 50%, 60% and at 7, 14, 28 and 35 days. The fire resistance ability of the green concrete with the satisfactory compressive strength value was also determined at 600°Cfor 5 hours.

METHODS

Materials

Cement used for the research work was the Dangote brand of ordinary Portland cement manufactured by Dangote PLC, Obajana, conforms to BS 12 (1996) ASTMC 150 and grade 32.5 (Anum *et al*., 2014) as the partial binder for the glasscrete but as the full binder for the conventional concrete which was the control.***Waste glass powder*** used for the research work was majorly from broken Louvre windows milled to a particle size that passed through sieve No. 200 (75μm). According to Jitandra and Saoji, 2014, waste glass powder samples at particle sizes ranging from 75μm to 90μmhave increased pozzolanic properties hence, the glass samples were crushed to a fine particle size of 75μm.

Well graded coarse and fine aggregate was used. The coarse aggregate used comprised of granite chippings of particle sizes 20mm sieve and was free from dust, silt and clay. The fine aggregate comprised of clean river sand particles of sizes that passed through 0.25mm sieve size. It was ensured that the fine aggregate sample used was completely dried to remove the moisture content to prevent an alteration of the water content of the concrete mix.

Water used for the concrete mixes was up to the specification of the water type desirable for mixing concrete. Specifications include that the water is suitable for drinking, free of inorganic solids and other deleterious impurities.

Procedures

The waste glass particles gathered in a sack and taken to the laboratory for crushing. The samples were crushed in the hammer mill into particles sizes of about 5mm before transferring to the ball mill. The ball mill further crushed the glass particles to powder form of desired particle distribution. The resulting waste glass powder was then sieved through 75μm.

Steel cube moulds:

The mould size selected for the purpose of this research was the 100mm by 100mm by 100mm mould size with volume capacity 0.001m^3. Scrapers and wire brushes were used to remove dirt and foreign materials from the steel moulds before casting the cubes. The workable concrete mix was poured into the steel cube moulds in properly compacted layers to form concrete cubes. The compacting rod was used to expel air bubbles from the concrete mix and make the concrete denser to improve its performance. The rod has a circular cross-section of approximately 16mm diameter and length 600mm. The top surface of each concrete cube was levelled with a levelling rod and thereafter labelled.

Concrete Batching:

The batching type used for the project was by mass. The quantity by mass of each ingredient required to produce 2600g of concrete mix 1:2:4 (for one 100mm by 100mm by 100mm concrete cube mould) was calculated using the proposed mix ratio.

Concrete mixing:

The mixing of concrete involved rotation or stirring to achieve the basic objective of coating the surface of the aggregate particles with cement paste, and to blind all the ingredients of the concrete into a uniform mass.

Concrete cubes:

The concrete cubes with different cement replacement percentages of 0%, 10%, 20%, 30%, 50% and 60% were cast using moulds of equal sizes and then cured for 7, 14, 28 and 35 days. The concrete cubes were tested at the end of every curing period to determine their respective strengths and the eventual optimum percentage replacement suitable for construction works which will eventually be tested for fire resistivity. A total of 72 cubes were tested

Concrete tests:

Two tests were carried out on the concrete cubes. These include compressive strength test and the fire resistance of concrete cubes with optimum percentage cement replacement.

Compressive strength test on concrete:

The resulting strength of the concrete after curing was obtained using the ultimate testing machine. The concrete cube sample is placed in the machine which is operated in a highly conducive environment. The machine was then lowered to come in contact with the cube and force is applied until the cube was crushed. Immediately the cube crushes, the computer connected to the machine plots the resulting stress-strain graphs and gives the compressive strength value of the cube.

Fire resistivity:

Upon completion of all compressive strength tests on the cubes, the optimum percentage replacement of cement with waste glass powder that gave the maximum concrete strength was placed in a furnace and heated to a temperature of 600℃ for 5 hours. Visual observation was made to view the effect of the temperature on the concrete and then the strengths of the cubes were tested with the ultimate testing machine.

RESULTS AND DISCUSSION

Compressive strength test

The results obtained from carrying out compressive strength test of the concrete cubes are presented in the tables below, each percentage replacement for all the four curing ages (7, 14, 28 and 35 days) had three cubes tested and their mean was derived for all the values obtained. The targeted strength for the mix ratio 1:2:4 for this test is 15 N/mm^2, hence concrete grade M15 according to IS 456:2000. Also shown is SD (standard deviation) and C of V (Coefficient of Variance).

Table 1: Compressive strength test for 0% waste glass powder (control)

Age of curing (days)	**Measurement**	**Density (kg/m^3)**	**Force at peak (N)**	**Strain at peak (%)**	**Stress at peak (N/mm^2)**	**Young's modulus (N/mm^2)**
7	Minimum	2582.00	62180.00	3.45	6.22	266.08
	Maximum	2618.00	144529.99	8.57	14.45	830.39
	Mean	2599.33	117023.33	6.20	**11.70**	641.40
	SD	18.04	47495.79	2.58	4.75	325.04
	C of V	0.69	40.59	41.69	40.59	50.676
14	Minimum	2489.00	88809.99	5.31	8.88	284.68
	Maximum	2625.00	211220.00	14.431	21.12	792.87
	Mean	2568.33	144936.67	8.86	**14.49**	523.44
	SD	70.77	61833.81	4.88	6.18	255.48
	C of V	2.756	42.66	55.09	42.66	48.81
28	Minimum	2359.00	143949.99	4.11	14.39	830.46
	Maximum	2564.00	251119.99	7.31	25.11	1730.50
	Mean	2467.67	197499.99	6.07	**19.75**	1210.65
	SD	103.06	53585.03	1.71	5.36	465.99
	C of V	4.18	27.13	28.24	27.13	38.49
35	Minimum	2507.00	195009.99	5.36	19.50	571.096
	Maximum	2601.00	256470.00	6.65	25.65	1050.414
	Mean	2548.67	234223.33	5.99	**23.42**	815.589
	SD	47.89	34062.21	0.65	3.41	239.805
	C of V	1.88	14.54	10.76	14.54	29.403

Table 1 provides the compressive strength test results for 0% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. Three samples were tested for each curing age and the maximum, minimum and mean values were obtained and represented in the table. At 7 days, the early strength was obtained to be 11.70N/mm^2, and then the strengths after 14, 28 and 35 days were obtained to be 14.49N/mm^2, 19.75N/mm^2 and 23.42N/mm^2 respectively. The targeted strength of 15N/mm^2 was obtained at 28 days and beyond as should be. The values obtained from this test will serve as the control with which all other test results at different percentage replacement will be compared. The table also provides the force, strain and young modulus value for all tests carried out to show the behaviour of the concrete.

Table 2: compressive strength test for 10% waste glass powder

Age of curing (days)	Measurement	Density (kg/m^3)	Force at peak (N)	Strain at peak (%)	Stress at peak (N/mm^2)	Youngs modulus (N/mm^2)
	Minimum	2400.00	51450.00	4.51	5.15	143.98
	Maximum	2689.00	174300.00	10.28	17.43	837.32
7	Mean	2529.33	94326.67	6.46	**9.43**	409.99
	S. D	146.87	69319.21	3.30	6.93	373.76
	C. of. V	5.81	73.49	51.12	73.48	91.16
	Minimum	2464.00	130589.99	5.26	13.06	246.58
	Maximum	2597.00	138300.00	11.67	13.83	661.18
14	Mean	2523.00	133186.67	8.02	**13.32**	419.78
	SD	67.76	4428.46	3.29	0.44	215.55
	C of V	2.69	3.33	41.07	3.33	51.35
	Minimum	2428.00	119599.99	4.13	11.96	502.20
	Maximum	2511.00	223570.01	5.52	22.36	1520.00
28	Mean	2457.33	178280.00	5.01	**17.83**	1033.61
	SD	46.54	53262.65	0.76	5.33	510.39
	C of V	1.89	29.88	15.27	29.88	49.38
	Minimum	2470.00	152800.00	4.49	15.28	515.81
	Maximum	2530.00	256929.99	5.97	25.69	1065.11
35	Mean	2492.00	213423.33	5.35	**21.34**	834.78
	SD	33.05	54134.08	0.76	5.41	285.18
	C of V	1.33	25.37	14.26	25.37	34.16

Table 2 provides the compressive strength test results for 10% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. The average strength of the cubes at 7, 14, 28 and 35 days were obtained to be 9.43N/mm^2, 13.32N/mm^2, 17.83N/mm^2 and 21.34N/mm^2 respectively. Comparing these results to that obtained using 0% waste glass powder, it was observed that there was 19.4%, 0.04%, 9.7% and 8.9% decrease in strength at 7, 14, 28 and 35 days curing ages respectively. However, the targeted strength for the concrete mix (15 N/mm^2) was obtained after 28 and 35 days of curing. This shows that there is a continuous increase in strength of concrete at 10% cement replacement with increased curing age as was observed with the control and would obtain the targeted strength at 28 days, 35 days and beyond. This shows the suitability of glasscrete at 10% cement replacement with waste glass powder similar to findings of Jangid and Saoji, 2014; Kishan *et al*., 2016; Meyer,2016. Apart from material and energy conservation, use of waste glass as fine aggregate provides concrete with higher resistance to chloride penetration. (Du and Tan, 2014).

Table 3: Compressive strength test for 20% waste glass powder

Age of curing (days)	Measurement	Density (kg/m^3)	Force at peak (N)	Strain at peak (%)	Stress at peak (N/mm^2)	Young's modulus (N/mm^2)
	Minimum	2359.00	63349.99	6.75	6.34	266.94
	Maximum	2419.00	77980.00	9.39	7.79	358.57
7	Mean	2390.67	68410.00	7.74	**6.84**	300.14
	SD	30.14	8292.43	1.45	0.83	50.76
	Cof V	1.26	12.12	18.72	12.12	16.91
	Minimum	2484.00	114949.99	6.034	11.49	293.46
	Maximum	2556.00	159229.99	9.82	15.92	548.69
14	Mean	2518.33	130633.33	7.81	**13.06**	424.51
	SD	36.12	24804.14	1.91	2.48	127.75
	C of V	1.43	18.99	24.42	18.99	30.09
	Minimum	2520.00	107339.99	3.74	10.73	545.91
	Maximum	2629.00	175639.99	5.65	17.56	1313.49
28	Mean	2564.00	148246.66	4.93	**14.83**	992.41
	SD	57.45	36099.59	1.04	3.61	398.86
	C of V	2.24	24.35	21.07	24.35	40.19
	Minimum	2276.00	69440.00	4.52	6.94	312.69
	Maximum	2607.00	131100.01	7.75	13.11	717.59
35	Mean	2482.67	102103.34	6.19	**10.21**	488.32
	SD	180.21	30993.10	1.62	3.09	207.72
	Cof V	7.26	30.36	26.14	30.36	42.54

Table 3 provides the compressive strength test results for 20% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. The average strength of the cubes at 7, 14, 28 and 35 days of curing were obtained to be 6.84N/mm^2, 13.06N/mm^2, 14.83N/mm^2 and 10.21N/mm^2 respectively. Comparing these results to the strength obtained for the control cubes, it was observed that the cubes with 20% cement replacement obtained an approximate value of the targeted strength at 28 days but dropped after 35 days of curing. There was a gradual increase in the strengths recorded from 7 days to 28 days of curing but dropped by 31.2% at 35 days curing age. It can, however, be safe to say that 20% replacement of cement with waste glass powder is safe at 28 days of curing age.

Table 4: compressive strength test for 30% waste glass powder

Age of curing (days)	Measurement	Density (kg/m^3)	Force at peak (N)	Strain at peak (%)	Stress at peak (N/mm^2)	Young's modulus (N/mm^2)
	Minimum	2375.00	62099.99	5.03	6.21	187.28
	Maximum	2445.00	105790.00	9.01	10.58	766.30
7	Mean	2420.00	81713.33	6.58	**8.17**	416.93
	SD	39.05	22184.34	2.13	2.22	307.52
	C of V	1.61	27.15	32.39	27.15	73.76
	Minimum	2290.00	38730.00	6.17	3.87	223.97
	Maximum	2412.00	72089.99	11.27	7.21	270.08
14	Mean	2362.33	53819.99	8.04	**5.38**	241.85
	SD	64.08	16905.82	2.81	1.69	24.74
	C of V	2.71	31.41	35.01	31.41	10.23
	Minimum	2285.00	33980.00	5.31	3.39	186.69
	Maximum	2431.00	115699.99	6.22	11.57	554.00
28	Mean	2368.67	81383.33	5.78	**8.14**	414.63
	SD	75.30	42402.66	0.45	4.24	199.03
	Cof V	3.18	52.10	7.84	52.10	48.00
	Minimum	2344.00	36200.00	5.68	3.62	74.14
	Maximum	2615.00	114860.00	12.13	11.49	791.85
35	Mean	2450.00	67103.33	8.16	**6.71**	346.09
	SD	144.81	41950.87	3.48	4.19	389.15
	C of V	5.91	62.52	42.59	62.52	112.44

Table 4 provides the compressive strength test results for 30% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. The mean strengths obtained for 7 days, 14 days, 28 days and 35 days of curing include 8.17N/mm^2, 5.38N/mm^2, 8.14N/mm^2 and 6.71N/mm^2 respectively. Comparing these values to that obtained with the control cubes, it was observed that none of the cubes tested for 30% cement replacement with waste glass powder obtained a strength that is almost equivalent to the early strength of the control mix from 7 to 35 days of curing. Furthermore, an increase and decrease pattern was observed between the curing ages, there was 34.14% decrease between the strength at 7 days and the strength at 14 days curing ages, then a 51.3% increase in strength from 14 days to 28 days and a 17.6% decrease in strength from 28 days to 35 days curing ages. This explains how unsuitable a 30% glasscrete is in any type of construction.

Table 5: Compressive strength test for 50% waste glass powder

Age of curing (days)	Measurement	Density (kg/m³)	Force at peak (N)	Strain at peak (%)	Stress at peak (N/mm²)	Young's modulus (N/mm²)
	Minimum	2416.00	42020.00	5.13	4.20	96.57
	Maximum	2659.00	85239.99	12.18	8.52	781.19
7	Mean	2528.00	65193.33	7.89	**6.52**	389.63
	SD	122.61	21778.98	3.77	2.18	352.78
	C of V	4.85	33.41	47.71	33.41	90.54
	Minimum	2524.00	32320.00	4.79	3.23	93.09
	Maximum	2533.00	79129.99	10.66	7.91	313.47
14	Mean	2527.33	55369.99	7.61	**5.54**	204.88
	SD	4.93	23413.07	2.94	2.34	110.22
	Cof V	0.19	42.29	38.68	42.29	53.797
	Minimum	2454.00	67070.00	4.77	6.71	289.79
	Maximum	2747.00	109169.99	8.91	10.92	539.78
28	Mean	2602.67	86979.99	6.26	**8.69**	378.67
	SD	146.55	21142.40	2.29	2.11	139.77
	C of V	5.63	24.31	36.70	24.31	36.91
	Minimum	2410.00	71610.00	3.32	7.16	286.99
	Maximum	2592.00	94349.99	5.81	9.44	608.24
35	Mean	2477.33	86330.00	4.71	**8.63**	412.02
	SD	99.81	12764.97	1.27	1.28	172.05
	C of V	4.03	14.79	26.92	14.79	41.76

Table 5 provides the compressive strength test results for 50% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. The average strengths obtained for cubes tested after 7 days, 14 days, 28 days and 35 days of curing were obtained to be 6.52N/mm^2, 5.54N/mm^2, 8.69N/mm^2 and 8.63N/mm^2 respectively. As was observed with the cubes tested for 30% cement replacement with waste glass powder, none of the resulting strength obtained for all the curing ages gave a value that is almost equivalent to the early strength obtained with the control mix, indicating how poor the strength of such concrete is. It also showed the increase and decrease in strength pattern that was observed with 30% cement replacement with waste glass powder, a behaviour that further disqualifies it from being suitable for any form of construction work.

Table 6: Compressive strength test for 60% waste glass powder

Age of curing (days)	Measurement	Density (kg/m^3)	Force at peak (N)	Strain at peak (%)	Stress at peak (N/mm^2)	Young's modulus (N/mm^2)
	Minimum	2285.00	15772.00	4.23	1.58	31.22
	Maximum	2336.00	17339.00	8.22	1.73	126.12
7	Mean	2313.00	16544.33	5.79	**1.65**	66.14
	SD	26.08	783.74	2.13	0.08	52.18
	C of V	1.13	4.74	36.79	4.85	78.89
	Minimum	2484.00	46980.00	5.27	4.69	178.21
	Maximum	2688.00	59389.99	8.04	5.94	530.65
14	Mean	2583.33	54980.00	6.22	**5.49**	322.99
	SD	102.11	6940.32	1.58	0.69	184.44
	C of V	3.95	12.62	25.36	12.62	57.10
	Minimum	2461.00	45490.00	3.11	4.55	84.51
	Maximum	2620.00	77570.00	8.30	7.76	491.79
28	Mean	2526.00	63246.67	5.19	**6.33**	298.62
	SD	83.37	16313.26	2.74	1.63	204.45
	C of V	3.30	25.79	52.81	25.79	68.47
	Minimum	2465.00	60119.99	4.26	6.01	175.76
	Maximum	2515.00	68790.00	6.22	6.88	397.27
35	Mean	2495.33	65820.00	5.54	**6.58**	292.03
	SD	26.65	4937.81	1.12	0.49	111.17
	C of V	1.07	7.50	20.13	7.50	38.07

Table 6 provides the compressive strength test results for 60% cement replacement with waste glass powder at 7, 14, 28 and 35 curing days. The average strengths obtained for cubes tested after 7 days, 14 days, 28 days and 35 days of curing were obtained to be 1.65N/mm^2, 5.49N/mm^2, 6.33N/mm^2 and 6.58N/mm^2 respectively. As was observed with the cubes tested for 30% and 50% cement replacement with waste glass powder, none of the resulting strength obtained for all the curing ages gave a value that is almost equivalent to the early strength obtained with the control mix, indicating how poor such concrete is. Unlike the results obtained for 30% and 50% cement replacement with waste glass powder, there was a gradual increase in the strength through the curing ages, but the highest strength obtained after 35 days is highly unsuitable for construction works.

Fire resistance test

The results obtained from the compressive strength test carried out on the cubes after being heated to a temperature of 600°C are presented in the tables 7 and 8. Three cubes each for 0% and 10% percentage replacement were tested and the mean, standard deviation and coefficient of variation of all three values were obtained. Prior to crushing the cubes with the ultimate testing machine to test, the following visual observations were made on the concrete cubes after heating for 5 hours:

i) Change in colour of concrete cubes from grey to light orange.
ii) The process produced no flames; hence indicating concrete is highly nonflammable.
iii) No crack was noticed on the concrete cubes.
iv) Few portions of the cubes turned coal black.

Table 7: Compressive strength test for 0% waste glass powder at 600℃ (28 days)

Measurement	**Density (kg/m^3)**	**Force at peak (N)**	**Strain at peak (%)**	**Stress at peak (N/mm^2)**	**Young's modulus (N/mm^2)**
Minimum	2348.00	55849.99	5.87	5.59	93.42
Maximum	2392.00	142369.99	7.77	14.24	584.74
Mean	2369.67	98263.33	6.86	**9.83**	358.26
SD	22.01	43284.85	0.95	4.33	247.89
C of V	0.93	44.05	13.85	44.05	69.19

Table 7 provides the results of compressive strength test carried out on cubes containing 0% waste glass powder after being heated to a temperature of 600℃ after 28 days of curing. The average strength obtained was 9.83N/mm^2, compared to the targeted strength 15N/mm^2. The effect of heat on the concrete reduced its strength by about 50% relative to the concrete strength without heating.

Table 8: Compressive strength test for 10% waste glass powder at 600℃ (28 days)

Measurement	**Density (kg/m^3)**	**Force at peak (N)**	**Strain at peak (%)**	**Stress at peak (N/mm^2)**	**Young's modulus (N/mm^2)**
Minimum	2322.00	79389.99	5.86	7.94	234.136
Maximum	2384.00	96760.00	7.33	9.68	441.79
Mean	2351.67	90543.34	6.67	**9.05**	342.47
SD	31.09	9680.25	0.75	0.97	104.12
C of V	1.32	10.69	11.24	10.72	30.40

Table 8 shows the compressive strength test result on concrete cubes containing 10% waste glass powder of cement replacement after subjecting it to 600℃ temperature for five hours. The average strength of the concrete was 9.05N/mm^2. This value is only 0.78N/mm^2 smaller than the strength of the control, (0% waste glass powder), but experienced a 50% decrease in strength relative to its strength without heating.

CONCLUSION

The strength of concrete cubes with varying percentage replacement of cement with waste glass powder of 0%, 10%, 20%, 30%, 50% and 60% were tested. Three cubes each were cast at these percentages and cured for 7, 14, 28 and 35 days, making a total of 72 cubes. The values obtained were presented in tables.

The concrete cubes with 0% cement replacement with waste glass powder being the control had the highest strength of all the samples, 10% had the second highest strength which exhibited a normal increased strength behaviour with an increase in curing ages, unlike all other percentage replacements. Although at 28 days, 20% cement replacement produced cubes with strength that is approximately equal to the targeted strength of 15N/mm^2 but decreased after 35 days to a strength lower than the targeted strength, hence, confirms it unsuitable for use in construction works. All other cubes at 30%, 50% and 60% waste glass powder produced strengths that are not even close the early strength at 7 days of the control. This makes them unsuitable for use. In conclusion, cement content in concrete can be replaced by waste glass powder partially at 10% of its total quantity and still provide the required strength.

0% and 10% waste glass content cubes were tested for fire resistivity being the control and optimum percentage cement replacements respectively.

Visual observation was made on the concrete cubes, a change in the colour of concrete cubes was observed from grey to very light orange, the heating process did not produce fumes indicating that concrete is nonflammable.

The compressive strength of the cubes was tested after heating to a temperature of 600℃ for 5 hours each after curing for 28 days. The average strength obtained for 0% was 9.83N/mm^2 and that for 10% was 9.05N/mm^2. The effect of heat on the concrete cubes was 50% reduction in strength.

RECOMMENDATIONS

1. The quantity of cement produced and used for construction could be reduced by 10% and replaced with waste glass to reduce CO_2 emission.
2. Waste glass could be used as a pozzolan. Thereby, promoting waste to wealth.
3. From this study, fire resistivity of concrete is satisfactory though strength was reduced by 50%

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