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PROPERTY CHARACTERISATION OF CONCRETE WITH GROUND GLASS AS PARTIAL REPLACEMENT FOR CEMENT

By

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ABSTRACT

Suitability of ground glass culet as partial replacement for Portland cement in concrete was investigated. Three grain size ranges of ground glass were considered as partial replacement for cement in concrete. The sizes $\leq$0.300mm, $\leq$0.150mm, and $\leq$0.075mm were used at 0%, 5%, 10%, 15%, 20%, 25 and 30% replacement levels. The effects of these on the properties of fresh and hardened concrete were investigated. The results showed that at fixed water-cement ratio and for every 5% increase in the replacement of ground glass for cement, there was an increase in the initial and final setting times as well as in workability (slump) of the concrete. The compressive strength was found to be inversely proportional to both the particle size of the ground glass and the quantity of ground glass replacement for cement. However, the three grain size ranges of ground glass were found to be adequate as partial replacement for cement in concrete production. The concrete with ground glass of $\leq$0.075mm grain size gave the best results that compared favourably well with that of normal concrete at all levels of replacement. Its compressive strengths at 28-day with 5%, 10%, 15%, 20%, 25% and 30% replacement for cement were 25.89, 22.11, 21.51, 19.84, 18.73 and 16.80 N/mm^2, while at 56-day the strengths were 30.00, 29.73, 29.22, 28.60, 26.16 and 24.73 N/mm^2 respectively. The coefficients of regression show that the quantity and sizes of ground glass have no serious adverse effects on the compressive strengths. The pozzolanic activity index (PAI) was reducing as the quantity of ground glass replacement for cement was increased but the rate of reduction was lowest at 56-day curing.

Key words: Concrete, ground glass, grain sizes, setting time, workability, compressive strength, coefficient of regression, pozzolanic activity index.

1 INTRODUCTION

There are many environmental, economical and social issues in the management of solid wastes which need to be addressed in order to be able to derive wealth from wastes. Broken glasses form substantial part of solid wastes in typical developed and developing countries and most of these waste glasses are not recycled or re-used, they usually end up in landfill or dumping sites. This has made effective management of this type of solid wastes an unsolved problem in many urban cities of the world because they are non-degradable. In a research commissioned by WRAP (Waste and Resources Action Programme) in 2006, up to 500,000 tonnes of flat glass wastes are generated from buildings in the UK alone every year. The report added that the domestic replacement window sector is one of the United Kingdom's main sources of wastes and replacing around 6.7million units each year generates some 190,000 tonnes of waste including 90,000 tonnes of glass. However, very little of this waste is currently recycled, but the potential is considerable and growing. Therefore, finding alternative use for waste glass would divert large percentage of this non-degradable solid waste from landfill and would reduce its environmental nuisance. One of such alternative ways is in the production of concrete.

Concrete is formed through a process of chemical reaction between cement and water with the aggregates. This hydration reaction that takes place has been explained by various authors (Neville and Brooks, 1993 and Murdock et al, 1991) as a process of producing a very strong binding medium for the aggregate particles in the concrete. The hydration reaction is usually accompanied by the liberation of heat. Minimizing such heat of hydration reduces the risk of formation of thermal cracks in the concrete.

Use of pozzolans in concrete has been identified by Mehta (1986) as a way of improving the quality of concrete and in reducing heat of hydration in concrete. Finely ground glass has been reported to possess pozzolanic properties. According to Khana (1996), glass in ground form comprises amorphous siliceous or siliceous and aluminous materials which react with calcium hydroxide, $Ca(OH)_2$, and water to form cementing material known as calcium silicate hydrates (C-S-H). This hydrate is said to be similar in size to Portland cement particles. Glasser (1996) simply gave the pozzolanic reaction as:

$$SiO_2 + Ca(OH)_2 + H_2O \longrightarrow CaOSiO_2.2H_2O$$

However, some authors have reported that one of the major problems in the use of glass as aggregates in concrete is the 'alkali-silica reaction' (ASR). According to Marsh (2003), ASR produces gel on the surface of aggregates, which swells and can cause concrete to crack; this has made concrete industry to avoid the use of glass as aggregate in concrete despite its strength and ability for lower water-cement ratio. This shows that it is not the formation of the gel that is deleterious but the deterioration of concrete structures is due to the water absorption by the gel and its expansion. However, he stated further that recent works have demonstrated that ASR can be avoided either by using finely ground glass of size $\leq$0.300mm or by suppressing the ASR with admixtures or by using alkali cement. This was also reported by The Concrete Society (1999). Also, Dyer and Dhir (2001) reported that the presence of ground glass cullet has little effect on the reactions of Portland cement and that blends containing the large quantity of calcium silicate hydrate (C-S-H) gel also display the highest strength. According to them the fine cullet particles have high surface area and hence, favour the rapid pozzolanic rate of reaction over the slower alkali-silica reaction.

This study aims at providing effective recycling method for waste glass and to investigate the appropriate sizes of ground glass that can be used as partial replacement for cement in concrete without compromising strength and durability requirements.

2 MATERIALS AND METHODS

2.1 Preparation and Treatment of Materials

The waste glass cullet used in the research was sourced from Beta Glass Company in Lagos. The glass whose chemical composition was given by the Company as 72.1%SiO_2, 0.74%Al_2O_3, 0.088%Fe_2O_3, 8.54%CaO, 3.91%MgO, 13.70%Na_2O, 0.33%K_2O, 0.11%TiO_2, 0.038%ZrO_2, 0.010%Cr_2O_3 and 0.02% SO_3 was thoroughly ground in a laboratory mill. Grinding was done to fine particles in order to eliminate the effects of alkali-silica reaction (ASR) as well as to ensure proper pozzolanic reaction when used in concrete (as reported by Marsh, 2003). Then ground glass was later sorted into three particle grain sizes of ≤0.300mm, ≤0.150mm and ≤0.075mm. These were used as partial replacement for cement in concrete in varying proportion of 0% to 30% at 5% interval. The Portland cement used was obtained from West African Portland Cement Company (WAPCO) depot in Ile-Ife, Nigeria. The major chemical composition of the cement as given by WAPCO is 45%$3CaO.SiO_2$, 15%$2CaO.SiO_2$, 7%$3CaO.Al_2O_3$ and 9%$4CaO.Al_2O_3.Fe_2O_3$.

Particle size analyses were carried out on the ground glass, fine and coarse aggregates to determine their gradation. Normal sharp sand which had minimum and maximum grain sizes of about 0.075 and 4.75 mm respectively was used as fine aggregate and the minimum and maximum sizes of coarse aggregate (crushed stones) used was 6.3 mm and 14mm respectively. Concrete was prepared using these materials in 1:2:4 prescribed mix with water-binder ratio of 0.68. The water-binder ratio was arrived at based on an earlier trial mix carried out on the concrete mix of 1:2:4.

The properties of concrete both in fresh and hardened states were assessed. These properties include determination of slump values using slump test; initial and final setting times using Vicat apparatus as well as compressive strength at different curing days using compression testing machine to determine the crushing load. A total of 270 concrete cubes were cast and tested for strength at the curing ages of 3-day, 7-day, 14-day, 21-day, 28-day and 56-day respectively.

3 RESULTS AND DISCUSSION

3.1 Particle Size Distribution Curves, Setting Times and Workability

Figure 1 shows the particle size distribution curves for the sharp sand (fine aggregate), ground glass and crushed stones (coarse aggregate) that were used in this study. It can be observed that the shape of the curve for the sharp sand is steep. The uniformity coefficient (C_u) for the sharp sand is 2.0 According to Fang and Daniels (2006), the smaller the value of C_u, the more uniform the material; the lower theoretical value is 1.0 while values for weathered soils can reach as high as 400. Therefore, the sand is good for concrete production as the smaller particles would be filling the interstices between the larger particles. The ground glass is also shown to be finely ground while the size of the coarse aggregate is acceptable. The values of C_u for ground glass and coarse aggregate are 2.9 and 1.7 respectively. The specific gravity of the sharp sand and the ground glass was found to be 2.60 and 2.53 respectively.

Table 1 shows the summary of the properties of fresh 1:2:4 concrete mixes with ground glass as partial replacement for cement at 0, 5, 10, 15, 20, 25 and 30% levels. The 0% ground glass concrete served as control in this study. The properties of the concrete include workability (as measured by slump) as well as initial and final setting times. It was observed that both the initial and final setting times of the concrete with varying percentages of ground glass as partial replacement for cement were progressively increasing with increase in the quantity of ground glass. For initial setting time, the maximum time difference between the 0% and 30% of $\leq$ 0.075 mm, $\leq$ 0.150 mm and $\leq$ 0.300 mm ground glass sizes replacement for cement are 35, 57 and 58 minutes respectively; while the difference are 37, 56 and 58 minutes respectively for final setting times under the same laboratory conditions. According to Neville and Brookes (1993), setting is mainly caused by selective hydration of tricalcium aluminate (C_3A) and tricalcium silicate (C_3S) and is accompanied by temperature rises in cement paste. This indicates that setting time (stiffening) of concrete will be influenced by the chemical composition of the cement and temperature. Although, BSI 1881 (1970) specifies that the mixing of concrete has to be undertaken at a temperature of $20 \pm 2\,^0$C, this work was carried out in tropic where temperature is high and the average laboratory temperature was 29 ± 2^0C while the chemical composition of cement was varied through the increase in the quantity of ground glass replacement for cement. The advantage of increase in the setting times can be appreciated in the hot climate when the rate of hydration is very high and concrete could become unworkable after a few minutes of mixing with water. This can lead to poor quality concrete in which proper compaction is usually difficult to achieve. This can lead to formation of micro-cracks. Also the slow hydration which would result in low rate of heat development can be used to advantage in ,Portland pozzolan cement or a partial replacement of Portland cement with the pozzolan in mass concrete construction (Neville and Brooks, 1996). Therefore, with increased setting times the rate of hydration would have been lowered by which better compaction and steady strength development could be achieved with low chance of micro-cracks formation. Formation of micro-cracks is usually due to high rate of hydration in the concrete. It can be observed that for particle sizes of ≤ 0.300 mm and ≤ 0.15 mm ground glass replacement for cement, the effect on the setting times are of the same magnitude at the same replacement level. The effect of size ≤ 0.075 mm ground glass replacement for cement is of lower magnitude on the setting times. This indicates that ≤ 0.300 mm and ≤ 0.15mm glass sizes are more effective in prolonging the setting times of the concrete than ≤ 0.075mm ground glass. This can be attributed to the larger surface area for chemical reaction to take place in ≤ 0.075 mm ground glass as compared to that of ≤ 0.300mm and ≤ 0.150mm sizes. However, the difference is not substantial as can be observed in Figure 2.

Table 1 also shows that the slump of fresh concrete increased as the quantity of ground glass increased but decreased as the particle size of the ground glass increased. The concrete with 0% ground glass had the lowest workability (52 mm) and the concrete with 30% ground glass had the highest workability (81 mm) for all particle size ranges. This means that under the same conditions, the use of ground glass would result in the use of lower water content for concrete of the same mix proportion.

Therefore, concrete of higher compressive strength and durability is expected to be obtained because the lower the water-cement ratio the better the quality of concrete produced.

4.2 Compressive Strength

Generally, no visible crack was seen on any of the tested concrete cubes prior to crushing. This means that the effect of alkali-silica reaction (ASR) usually associated with concrete containing ground glass as pozzolan was not noticeable within the curing days considered. The compressive strength of the hardened concrete cubes (with and without ground glass) was found to be increasing as the curing ages increased but at comparative different rates. This can be seen from Figures 3a to 3c which shows that the rate of strength development was very low for all the concrete within the first 7-day curing while the rate is considerably higher in concrete without ground glass than those with ground glass between 7 and 35 days of curing. However, beyond 35 days the values of the compressive strength of the concrete tends to converge at 56-day of curing. The rate of convergence is most pronounced in the glass particle sizes of ≤ 0.075 mm while it is least pronounced in the glass particle sizes of ≤ 0.300 mm at all levels of replacement. This shows that for compressive strength, the most effective particle sizes for cement replacement are ≤ 0.075 mm while the least effective particle sizes are ≤ 0.300 mm, though the difference is not much. This can be attributed to the fact that particle sizes of less than ≤ 0.075 mm are closer to cement particle sizes with larger surface area available for the hydration reaction.

Furthermore, a close observation of Figures 4a to 4f shows that the effects of the particle sizes of ground glass on compressive strength gave negative gradients; this is inverse relationship of compressive strength with particle sizes of binder. The correlation coefficients of concrete strength at 28-day curing for 5%, 10%, 15%, 20, 25, 30% ground glass are 0.9057, 0.982, 0.2357,0.7406, 0.7749 and 0.8929 respectively; while that of 56-day curing are 0.9733, 0.9961, 0.9959, 0.9909, 0.7458 and 0.8929 respectively. These indicate that the quantity and sizes of the ground glass used in this study have no serious adverse effects on the compressive strength of concrete. Similarly, Table 2 shows among others that the pozzolanic activity index (PAI), which is the ratio of compressive strength of concrete mix with a specified replacement of cement by pozzolan to the strength of same concrete mix without replacement, was reducing as the quantity of ground glass replacement for cement was increasing for all the three sizes of ground glass considered. However, comparative study of this index for 28 and 56 days of curing revealed that the rate of reduction of the index was lower at 56-day than at 28-day curing. This further underscores the possibility of the concrete with ground glass as partial replacement for cement to develop compressive strength that is closer or equal to that of concrete without ground glass (pozzolan) at higher curing days.

Generally, the values of the compressive strengths of the concrete up to 30% replacement for cement compared well with the value recommended by BS 8110 (1997). However, the variation in the strength of concrete with and without ground glass can be explained by the changes in the chemical composition of the birders (cement on one hand and cement plus ground glass on the other hand) especially the change in the tri-calcium silicate (C_3S) and di-calcium silicate (C_2S) that would have been affected in the concrete with 5 - 30% ground glass content. Jackson and Dhir (1996) had stated that cement containing relatively high percentage of tri-calcium silicate (C_3S) gain strength rapidly than those rich in di-calcium silicate (C_2S). The two silicates account for about 50.7% and 22.5% respectively of the chemical composition of cement (Neville and Brooks, 1994). The silicates actually contain minor oxides in solid solution which has some effects on its atomic arrangement, crystal form and hydraulic properties.

5 CONCLUSIONS

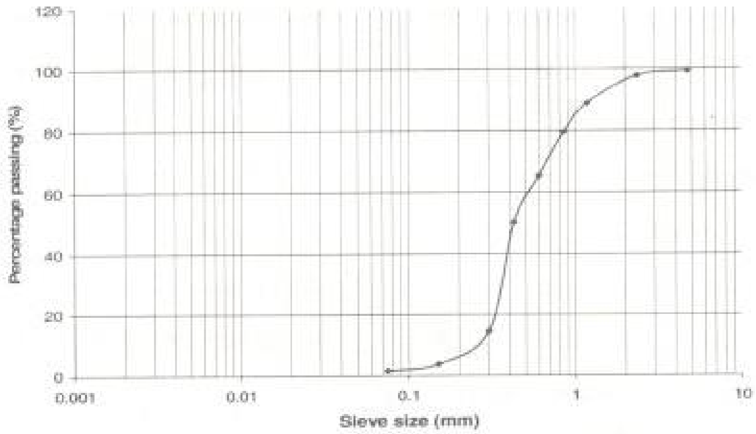
From this study, the following conclusions are made:

(i) All the three particle size ranges of the ground glass used in this study were found to be adequate as partial replacement for cement in concrete at all levels considered.

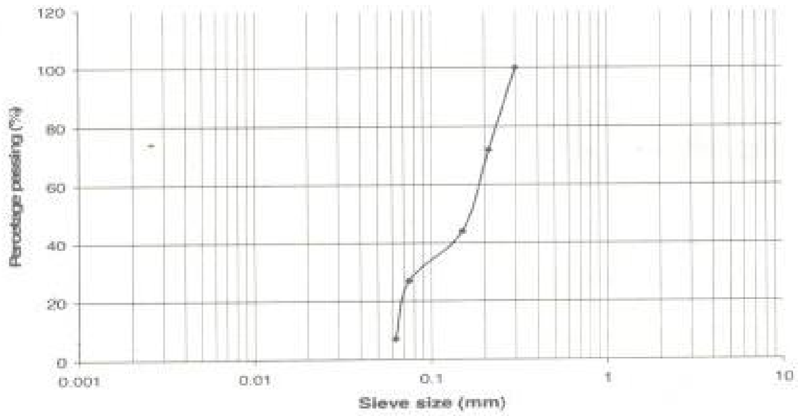
(ii) The use of ground glass of particle sizes less than $\leq$ 0.300 mm and up to 30% replacement for cement has no serious adverse effect on the compressive strength and durability of the concrete. The only adverse effect observed in this study was that the concrete with partial replacement for cement developed strength at slow rate compared with that of normal concrete at earlier age up to 28-day curing. However, at 56-day curing the compressive strength of the concrete was almost of the same magnitude for up 20% replacement. Therefore, where the concrete structure is unlikely to be subjected to design load earlier, up to 20% ground glass replacement for cement could be safely used.

(iii) Ground glass of particle sizes $\leq$ 0.075mm has been found to exhibit the most effective pozzolanic effects on the compressive strength of concrete up to 20% replacement for cement at 56-day of curing. Its compressive strength at 56-day curing compared favourably well with that of normal concrete.

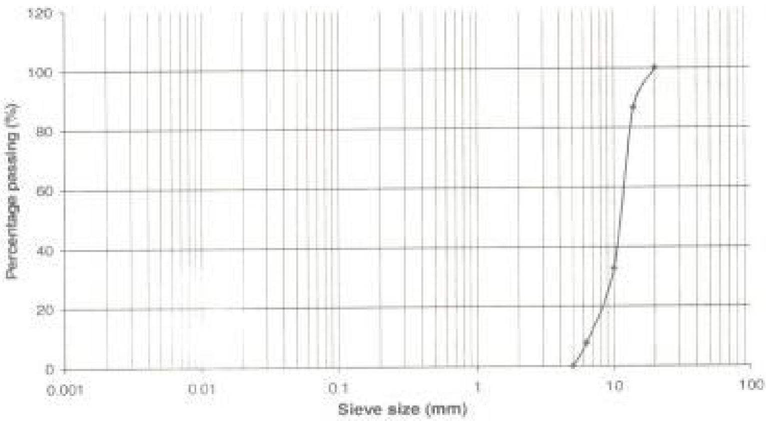
(iv) This work has shown one of the ways that waste glass cullet could be used to advantage when it is properly sorted out of solid wastes and ground to the required particle sizes with local mills.



(a) :Normal sharp sand

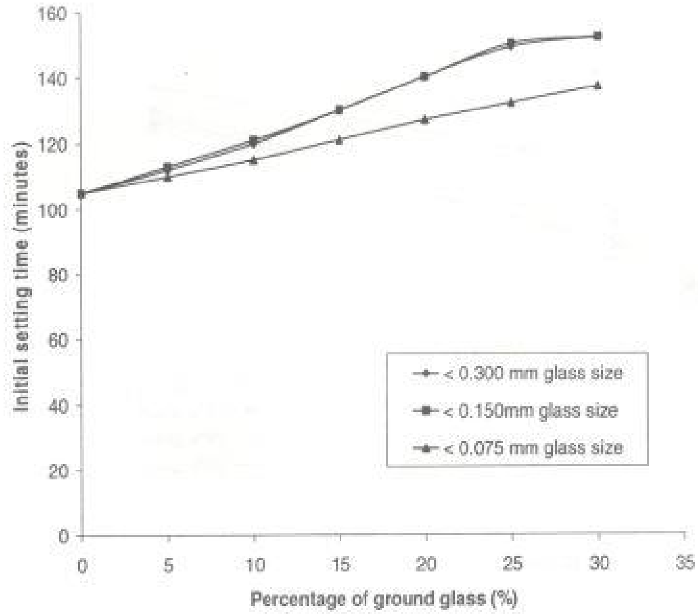


(b): Sorted glass

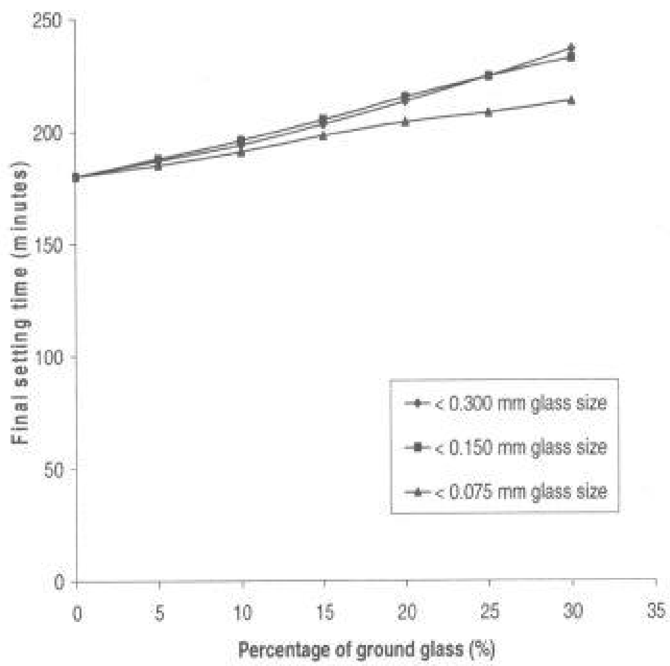


(c): Crushed stones

Figure 1: Particle size distribution curves for sharp sand, ground glass and crushed stones used in the study



(a): Initial setting time



(b): Final setting time

Figure 2: Effects of ground glass sizes on the setting time of 1:2:4 concrete mixes

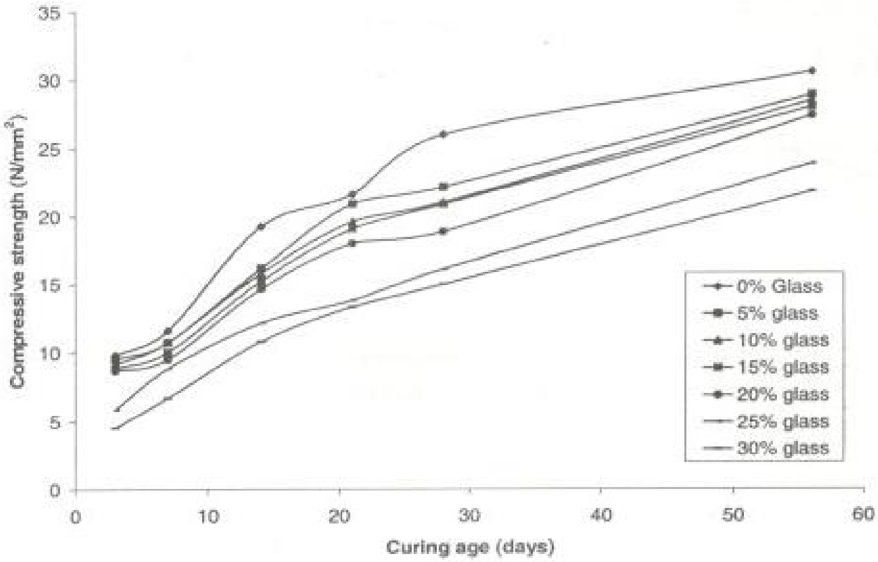


Figure 3a: Compressive strength development of 1:2:4 concrete mixes at different percentages of ground glass size ≤ 0.300 mm replacement for cement.

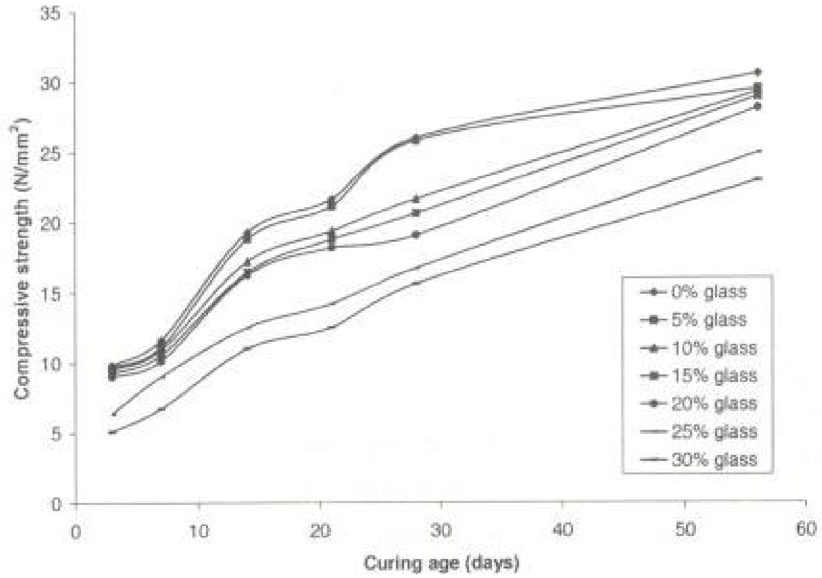


Figure 3b: Compressive strength development of 1:2:4 concrete mixes at different percentages of ground glass size ≤ 0.150 mm replacement for cement.

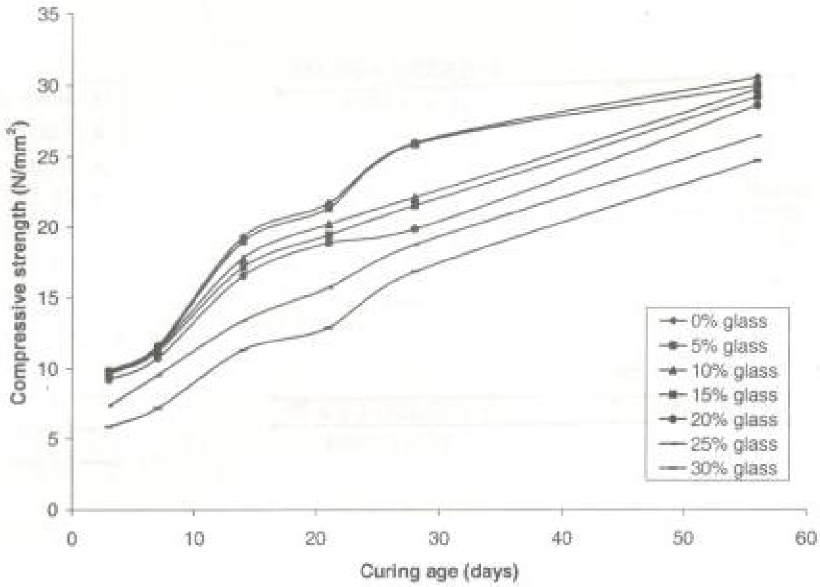


Figure 3c: Compressive strength development of 1:2:4 concrete mixes at different percentages of ground glass size ≤ 0.075 mm replacement for cement

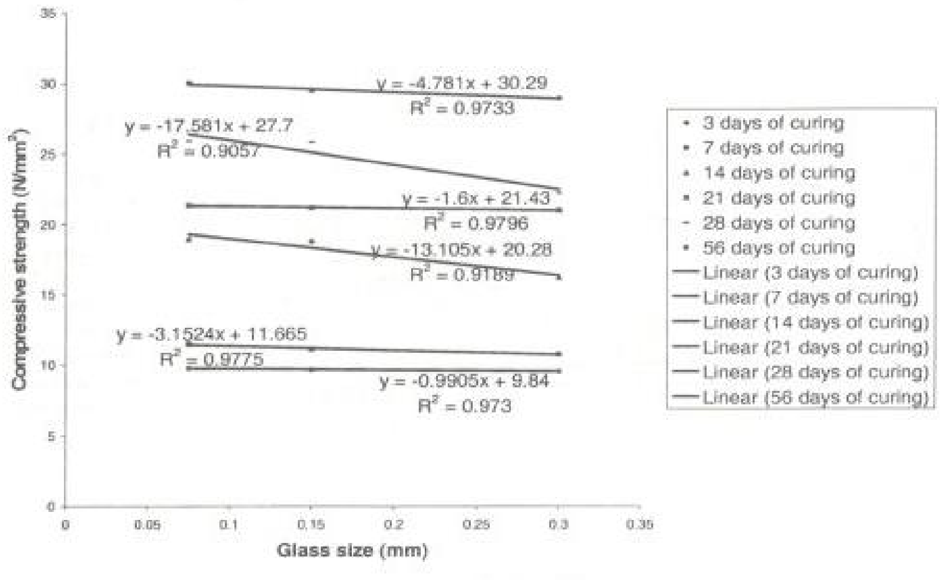


Figure 4a: Effect of particle sizes of 5% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages

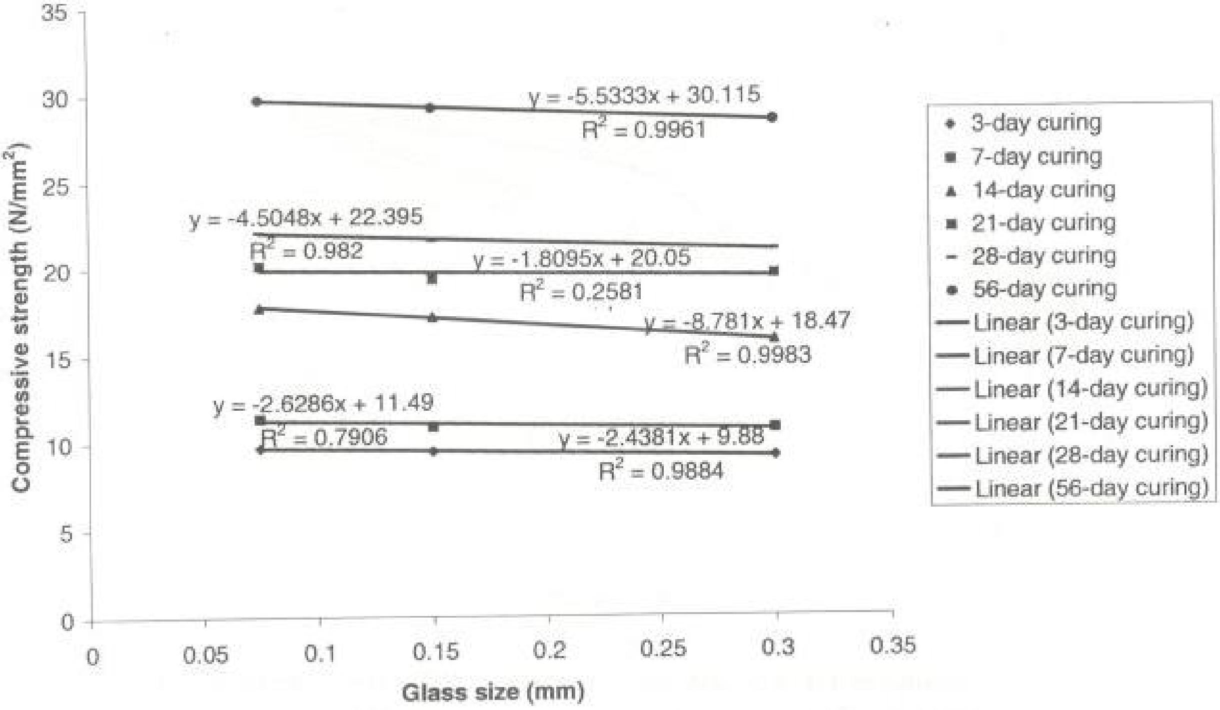


Figure 4b: Effect of particle sizes of 10% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages.

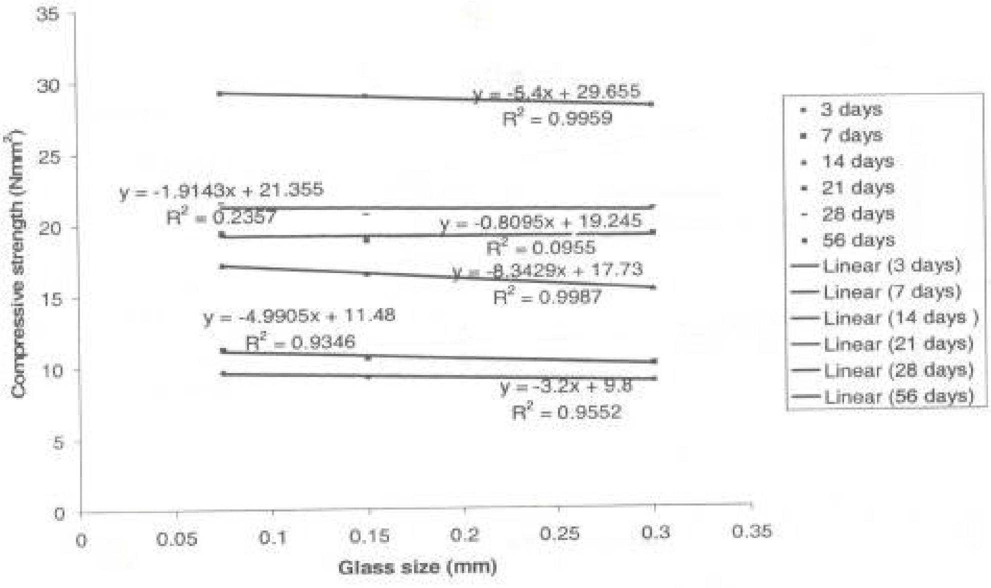


Figure 4c: Effect of particle sizes of 15% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages.

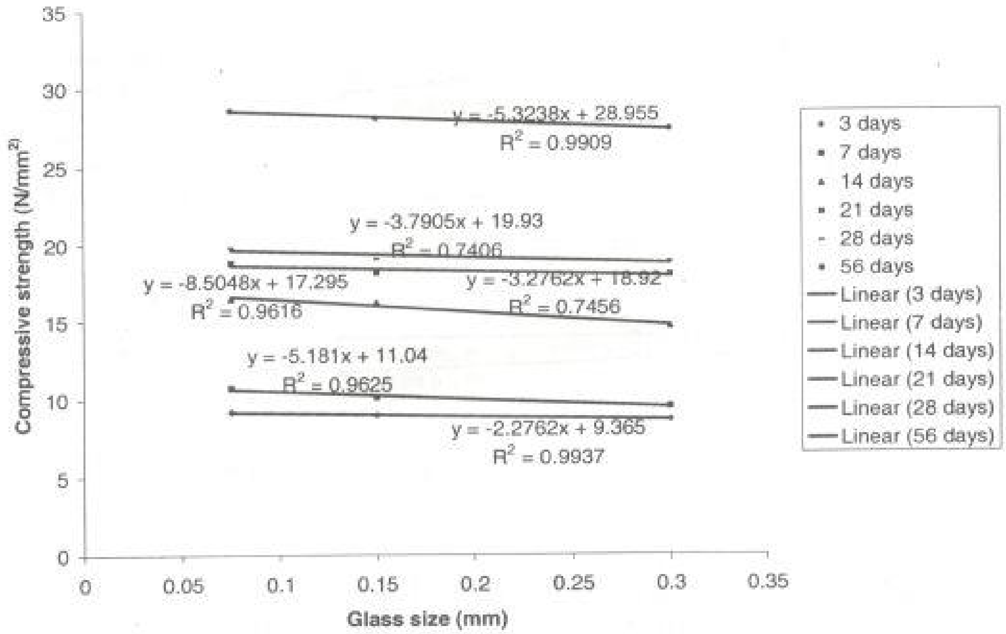


Figure 4d: Effect of particle sizes of 20% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages

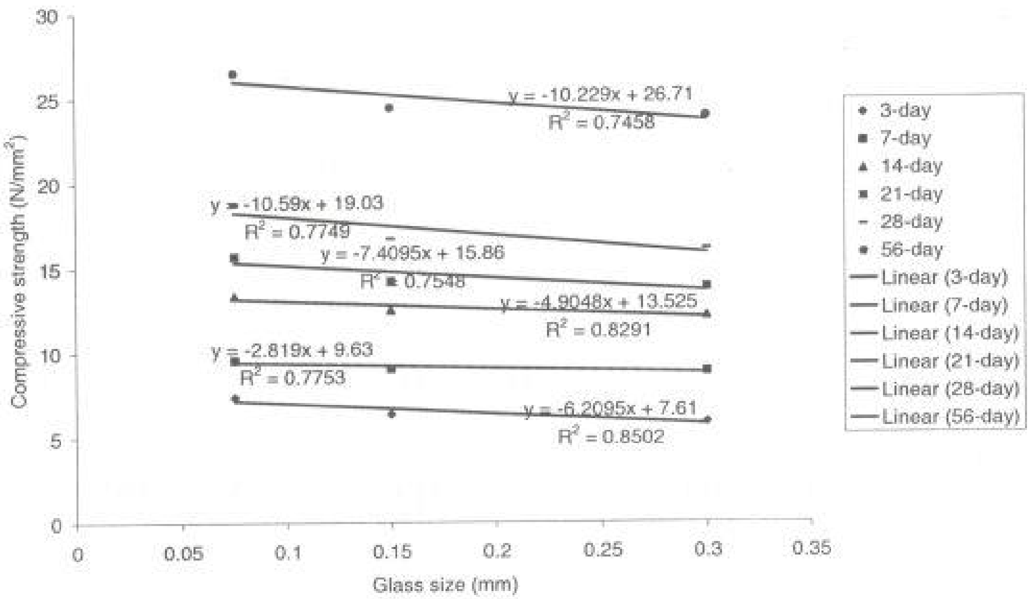


Figure 4e: Effect of particle sizes of 25% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages.

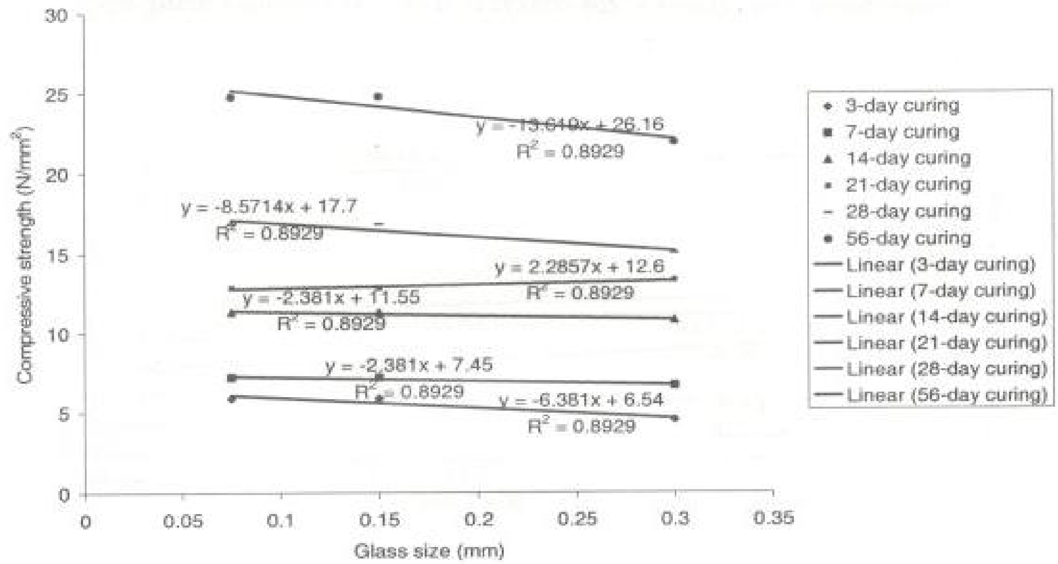


Figure 4f: Effect of particle sizes of 30% ground glass replacement for cement on the compressive strength of 1:2:4 concrete mixes at various curing ages.

TABLE 1: Summary of the properties of fresh 1:2:4 concrete mixes with and without ground glass as partial replacement for cement

Particle size of ground glass (mm)	≤0.075		≤0.300						≤0.150				
Percentage of ground	0	5	10	15	20	25	30	5	10	15	20		
25	30	5	10	15	20	25	30						
glass (%)													
Slump (mm)	52	60	64	70	72	74	77	58	64	69	72	76	8
Initial setting time (minutes)	105	110	115	121	127	133	140	113	121	130	140	151	1
Final setting time (minutes)	180	185	191	198	204	210	217	188	196	205	215	225	2

TABLE 2: Average compressive strength and pozzolanic activity index of hardened 1:2:4 concrete mixes with and without ground glass as partial replacement for cement at different curing ages

Particle size of ground glass (mm)	≤0.075							≤0.150						≤0.300					
Percentage of ground glass (%)	0	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30
Average compressive strength (N/mm^2)																			
3 days	9.83	9.78	9.72	9.62	9.21	7.37	5.87	9.67	9.48	9.23	9.00	6.34	5.08	9.55	9.16	8.87	8.69	5.86	4.53
7 days	11.61	11.47	11.41	11.22	10.74	9.55	7.20	11.13	10.92	10.56	10.13	9.01	6.70	10.74	10.76	10.04	9.53	8.85	6.70
14 days	19.29	18.96	17.78	17.13	16.51	13.35	11.30	18.82	17.20	16.44	16.24	12.50	11.00	16.18	15.82	15.24	14.67	12.15	10.80
21 days	21.67	21.33	20.18	19.40	18.84	15.67	12.84	21.16	19.38	18.80	18.18	14.20	12.50	20.96	19.64	19.11	18.02	23.82	13.32
28 days	26.00	25.89	22.11	21.51	19.84	18.73	13.80	25.80	21.64	20.62	19.07	16.70	15.60	22.18	21.07	20.93	18.89	16.10	15.00
56 days	30.53	30.00	29.73	29.22	28.60	26.46	24.73	29.47	29.24	28.89	28.09	24.90	22.93	28.87	28.47	28.02	27.38	23.90	21.87
Pozzolanic Activity Index (PAI)																			
28 days	1.000	0.996	0.850	0.827	0.763	0.720	0.646	0.992	0.832	0.793	0.733	0.642	0.600	0.853	0.810	0.805	0.726	0.619	0.577
56 days	1.000	0.983	0.974	0.957	0.937	0.867	0.810	0.965	0.958	0.946	0.920	0.816	0.751	0.946	0.933	0.918	0.897	0.789	0.716

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