Partial Replacement of Coarse Aggregate with Broken Ceramic Tiles in Concrete Production

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Abstract— The study reports on experimental investigation on the suitability of the use of broken tiles as partial replacement for crushed granite in concrete production. Control mixing ratio of 1:2:4 batched by weight with water – cement ratio of 0.55 was used. The percentage replacement varied from 0% to 40% at intervals of 5%. The slump test was used to assess the workability of the fresh concrete. The compressive strengths and densities of cured concrete cubes of sizes 150mm x 150mm x 150mm were evaluated at 7days, 21days and 28days. A total of 81 concrete cubes were cast and tested. Increase in the percentage replacement of crushed granite with broken tiles reduces workability, density and compressive strength. The compressive strength and density increased with days of curing. The compressive strength and density are maximum for concrete cubes with 100% crushed granite and minimum when broken tiles content is 40% with equivalent strength of (23.5N/mm^2 and 20.3N/mm^2) and density of (2622 and 2441kg/m^3) respectively. Compressive strength tests showed that variation up-to 40% of the broken tiles in replacement for crushed granite was quite satisfactory with no compromise in compressive strength requirements (20N/mm^2).

Keywords— Compressive strength, concrete production, density, slump test

1.0 Introduction

Concrete is a composite material composed mainly of water aggregate and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical and mechanical properties of the finished material.

Cement and aggregate (river sand and crushed stone), are the most important constituents used in concrete production. This inevitably leads to a continuous and increasing demand of natural materials used for concrete production. Parallel to the need for the utilization of the natural resources emerges a growing concern for protecting the environment and a need to preserve natural resources, such as aggregate, by using alternative materials that are either recycled or discarded as a waste.

Ceramics are often used in the manufacture of wall and floor tiles, bricks and roofing tiles. Sanitary ceramics, as with all other ceramic products, are produced from natural materials which generally contain kaolin, china clay, feldspar, potassium, and quartz (Pacheco and Jalali, 2010). Ceramics industry includes the following sectors: ceramic flooring and wall coverings (ceramic floor and wall tiles, respectively), ceramic sanitary ware, bricks and roofing tiles, refractory materials, ceramics for technological applications (insulators, etc.), and ceramic objects for domestic and decorative purposes (tableware and ornaments). Construction industry as the end user of almost all the ceramic materials, is well poised to solve this environmental problem which is partly its own. The use of waste products in concrete is not only economical but also solves some of the waste disposal issues. Crushed ceramic aggregate can be used to produce lightweight concrete, without affecting strength (Senthamarai *et al.,* 2005). The high consumption of raw materials by construction sector, results in chronic shortage of building materials and the associated environmental damage. In the last decade, construction industry has seen various researches conducted on the utilization of waste products in concrete in order to reduce the utilization of natural resources.

Khaloo (1995) investigated the use of crushed tile as a source of coarse aggregate in concrete. The crushed tile had a lower density and a much higher water absorption value compared to those of natural crushed stones. The resulting concrete made with 100% crushed tile as the coarse aggregate had a lower density and higher compressive (+2%), tensile (+70%) and flexural (+29%) strengths.

D. Tavakoli (2012) Using ceramic wastage in concrete production causes no remarkable negative effect in the properties of concrete. The optimal case of using tile wastage as sand are amounts of 25% to 50%, besides, the best case of their use as coarse aggregate are as amounts of 10% -20%. In these measures, not only an increase happens in compressive strength, but also a decrease in unit weight and lack of remarkable negative effect on water absorption is reported.

Nevertheless, researches carried out so far by reusing ceramic wastes in concrete are scarce and do not fully evaluate mechanical properties of the new concrete, which are key issues. This therefore forms part of a study area that needs to be fully looked into. Above studies suggest that there is a strong need to use recycled ceramic aggregates materials in concrete in an environmental friendly way.

The study is aimed at investigating the "Effects of Replacing Partially Coarse Aggregate with Broken Ceramic Tiles in Concrete Production" while the objectives are to determine physical properties of aggregates to be used, determine workability of fresh concrete via slump test and compacting factor test and

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Curing of hardened concrete for a period of 7, 21 & 28 days as well as obtaining their mechanical Properties.

This research will go a long way in reducing the high consumption of natural resources (Crushed Granite) used in producing concrete which in turn will reduce environmental & human hazards arising from crushing granite. On the other hand, using ceramic waste as a partial replacement of coarse aggregate will reduce the volume of solid waste generated from ceramic industry to be disposed as well as the cost of disposal. More so, cost of concrete production will be greatly reduced.

2.0 Research Methodologies

The procedure of research involved carrying out identification test on the aggregate broken ceramic tiles and crushed granite. The results of the tests were compared to standard given in texts. These tests include sieve analysis, specific gravity, water absorption, and bulk density. The fresh concrete mixes were tested for workability, slump and compacting factor. Nine (9) cubes of size (150mmx150mmx150mm) with mix proportion 1:2:4 were casted for every mix ratio that is ceramic tile to crushed stone ratio (0:100, 5:95, 10:90, 15:85, 20:80, 25:75, 30:70, 35:65, 40%:60%), with constant water cement ratio of 0.55. A total of 81 cubes where casted. After 24 hours, the cubes were removed from mould and cured in water. The cubes were cured for different period of time (7, 21 & 28days) respectively. The cubes were then weighed and crushed under machine to determine their compressive strengths. 3 cubes where crushed per mix ratio per curing age.

3.0 Results of Experiment and Discussions

3.1 Sieve Analysis Test

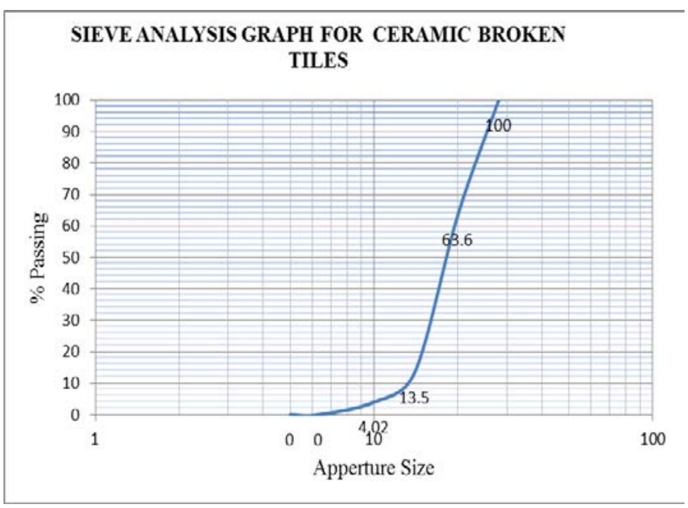

Figure 1: Sieve Analysis Graph for Broken Ceramic Tiles

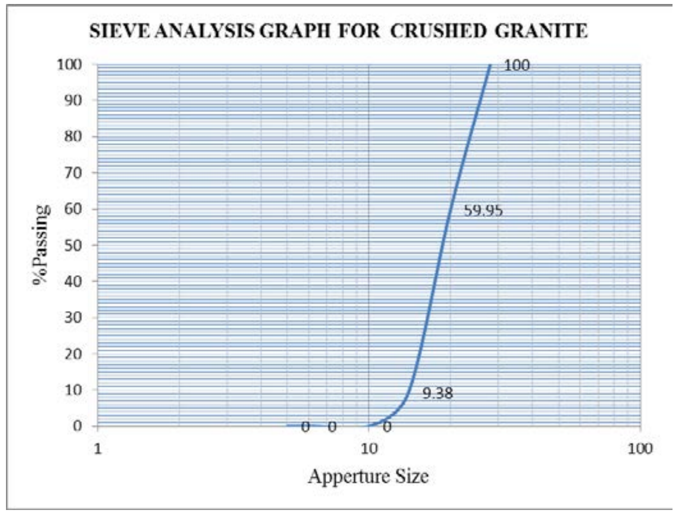

Figure 2: Sieve Analysis Graph for Crushed Granite

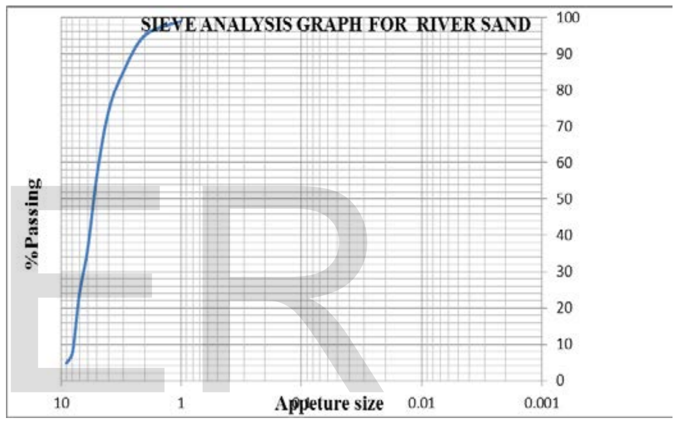

Figure 3: Sieve Analysis Graph for Natural Sand

Figures 1: Sieve analysis result for broken ceramic tiles, shows that percentage passing sieve 28.00mm, 20.00mm, 14.00mm, 10.00mm, 6.30mm, 5.00mm was 100, 63.6, 13.5, 4.02, 0, and 0 respectively. Thus the aggregate can be classified as single sized (20mm) coarse aggregate in accordance to Table 3 (B.S 882-103.1)

Figure 2: Sieve analysis result for crushed granite, shows that percentage passing sieve 28.00mm, 20.00mm, 14.00mm, 10.00mm, 6.30mm, 5.00mm was 100, 59.95, 9.38, 0, 0, and 0 respectively. Thus the aggregate can be classified as single sized (20mm) coarse aggregate in accordance to Table 3 (B.S 882-103.1)

Figure 3: Sieve analysis result for natural sand shows that percentage passing sieve 5.00mm, 2.36mm, 1.18mm, 850 µm, 600µm, 425µm, 300µm, 150µm and Pan was 99.04, 95.12, 85.31, 74.40, 56.80, 36.00, 23.99, 7.83, and 4.89 respectively. Thus natural sand can be classified as coarse sand, medium sand and fine sand in accordance to Table 4 (B.S 882-103.1).

3.2 Results of Water Absorption Test

Table 3-1: Water Absorption Test for Crushed Stone

Trial	Trial 1	Trial 2	Trial 3
Weight of dry sample (M_1)g	68.6	37.6	44.0
Weight of wet sample (M_2)g	69.1	37.9	44.3
Increase in mass ($M_2 – M_1$)g	0.5	0.3	0.3
Specific gravity	0.73	0.8	0.68
Average specific gravity = 0.74			

Table 3-5: Water Absorption Test for Ceramic Broken Tiles

Trial	Trial 1	Trial 2	Trial 3
Weight of dry sample (M_1)g	171.5	166.0	173.0
Weight of wet sample (M_2)g	189.8	181.3	190.5
Increase in mass ($M_2 – M_1$)g	18.3	15.3	17.5
Specific gravity	10.1	9.2	10.1
Average specific gravity = 9.8			

The results obtained from water absorption test shows that crushed granite have a lower water absorption rate of 0.74, while ceramic tiles have an absorption rate of 10.3. This implies that increase in ceramic tiles requires increase in water – cement ratio to obtain same workability for crushed granite.

3.3 Specific Gravity Test

Table 3-6: Specific Gravity Test on Crushed Stone

Trial	Trial 1	Trial 2	Trial 3
Weight of cylinder (M_1)g	165.0	165.0	165.0
Weight of cylinder + sample (M_2)g	439.0	431.0	439.0
Weight of cylinder + water + sample (M_3)g	952.1	937.5	952.1
Increase in cylinder + water (M_4)g	780.5	780.5	780.5
Specific gravity	2.68	2.63	2.68
Average specific gravity = 2.66			

Table 3-7: Specific Gravity Test on Ceramic Broken Tiles

Trial	Trial 1	Trial 2	Trial 3
Weight of cylinder (M_1)g	165.0	165.0	165.0
Weight of cylinder + sample (M_2)g	333.8	365.4	333.8
Weight of cylinder + water + sample (M_3)g	844.1	860.8	844.1
Increase in cylinder + water (M_4)g	750.3	750.3	750.3
Specific gravity	2.25	2.23	2.25
Average specific gravity = 2.24			

Table 3-8: Specific Gravity Test on River Sand

Trial	Trial 1	Trial 2	Trial 3
Weight of cylinder (M_1)g	114.4	97.6	114.4
Weight of cylinder + sample (M_2)g	172.0	146.6	172.0
Weight of cylinder + water + sample (M_3)g	398.2	376.4	398.2
Increase in cylinder + water (M_4)g	362.5	346.5	362.5
Specific gravity	2.63	2.57	2.63
Average specific gravity = 2.61			

3.4 Bulk Density Test on Coarse Aggregate

Table 3-9: Result of Bulk Density for Crushed Stone

	Compacted			Uncompacted		
Trial	T1	T2	T3	T 1	T 2	T 3
Weight of empty cylinder (M_1)g	1.10	1.10	1.10	1.10	1.10	1.10
Volume of cylinder ($x10^{-3}$)m^3	1.69	1.69	1.69	1.69	1.69	1.69
Weight of sample divider + sample (M_2)	3.87	3.99	3.89	3.60	3.69	3.74
Weight of sample (M_2 - M_1)kg	2.77	2.89	2.79	2.50	2.59	2.64
Bulk density	1693	1710	1650	1479	1533	1563
Average		1667			1525	

Table 3-10: Result of Bulk Density for Ceramic Broken Tiles

	Compacted			Uncompacted		
Trial	T1	T2	T3	T 1	T 2	T 3
Weight of empty cylinder (M_1)g	1.10	1.10	1.10	1.10	1.10	1.10
Volume of cylinder ($x10^{-3}$)m^3	1.69	1.69	1.69	1.69	1.69	1.69
Weight of sample divider + sample (M_2)	3.13	3.19	3.15	2.82	2.89	2.87
Weight of sample (M_2 - M_1)kg	2.03	2.09	2.05	1.72	1.79	1.77
Bulk density	1201	1237	1213	1018	1059	1048
Average		1217			1042	

There was a decrease in the unit weight of hardened concrete with increase in percentage replacement of ceramic tiles as shown in Table 4.11 and Figure 5, the decrease though, not below acceptable limits of 2000-2600kg/m^3 for normal concrete.

3.5 Workability Test

Table 3-11: Compacting Factor and Slump Test

% Replacement	Slump (mm)	Weight of Uncompacted Sample Q1	Weight of Compacted sample Q2	Compacting factor Q1/Q2
0	24	12.13	14.52	0.84
5	23	13.20	14.82	0.89
10	23	14.18	14.74	0.96
15	18	13.40	14.43	0.93
20	17	13.20	14.56	0.90
25	18	12.86	14.45	0.89
30	18	13.33	14.28	0.93
35	17	13.42	14.30	0.94
40	16	13.40	14.40	0.93

The value of slump obtained was higher for concrete with 100% crushed granite compared to those replaced with ceramic tiles. This is due to increase in specific surface area as a result of the increase in the quantity of broken tiles, thus requiring more water to make the concrete workable.

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3.6 Bulk Densities of Concrete Cubes

Table 3-12: Bulk Densities of Concrete Cubes

% Replacement	Cube no	Age (days)	Mass (Kg)	Density (Kg/m²)	Average density
	A1		8.70	2578	
	A2	7	8.56	2536	2541
	A3		8.47	2510	
0%	A4		8.71	2581	
	A5	21	8.99	2663	2622
	A6		8.85	2622	
	A7		8.71	2581	
	A8	28	8.99	2663	2622
	A9		8.85	2622	
	B1		8.40	2489	
	B2	7	8.43	2498	2553
	B3		9.02	2673	
5%	B4		8.76	2596	
	B5	21	8.45	2503	2539
	B6		8.50	2519	
	B7		8.92	2643	
	B8	28	8.70	2593	2621
	B9		8.81	2628	
	C1		8.60	2548	
	C2	7	8.49	2561	2508
	C3		8.30	2459	
10%	C4		8.63	2557	
	C5	21	8.66	2566	2572
	C6		8.75	2593	
	C7		8.87	2628	
	C8	28	8.75	2593	2593
	C9		8.63	2557	
	D1		8.70	2578	
	D2	7	8.50	2519	2544
	D3		8.56	2536	
15%	D4		8.12	2406	
	D5	21	8.62	2554	2485
	D6		8.42	2495	
	D7		8.12	2406	
	D8	28	8.62	2554	2495
	D9		8.52	2524	
	E1		8.90	2637	
	E2	7	8.43	2498	2579
	E3		8.78	2602	
20%	E4		8.53	2527	
	E5	21	8.19	2427	2471
	E6		8.30	2459	
	E7		8.40	2489	
	E8	28	8.53	2527	2531
	E9		8.70	2578	
	F1		8.40	2489	
	F2	7	8.26	2447	2448
	F3		8.13	2409	
25%	F4		8.05	2385	
	F5	21	8.08	2394	2403
	F6		8.20	2429	
	F7		8.09	2397	
	F8	28	8.21	2433	2430
	F9		8.30	2459	
	G1		8.60	2548	
	G2	7	8.42	2495	2528
	G3		8.58	2542	
30%	G4		8.21	2433	
	G5	21	8.59	2545	
	G6		8.45	2503	2494
	G7		8.59	2545	
	G8	28	8.45	2504	
	G9		8.30	2459	
	H1		8.30	2459	2503
	H2	7	8.12	2408	
	H3		7.94	2353	
35%	H4		8.40	2489	
	H5	21	8.43	2498	
	H6		8.52	2524	2504
	H7		8.40	2489	
	H8	28	8.43	2491	
	H9		8.52	2524	
	I1		8.20	2430	
	I2	7	8.10	2400	2381
	I3		7.81	2314	
40%	I4		8.21	2433	
	I5	21	7.86	2329	2409
	I6		8.32	2465	
	I7		8.32	2394	
	I8	28	8.08	2465	2441
	I9		8.31	2465	

3.7 Compressive Strenght Test on Concrete Cubes

Table 3-13: Compressive Strenght of Concrete Cubes

% Replacement	Cube no	Age (days)	Load (KN)	Strenght (N/mm²)	Average strenght
	A1		400	17.8	
	A2	7	370	16.4	16.6
	A3		354	15.7	
0%	A4		480	21.3	
	A5	21	480	21.3	21.5
	A6		495	22.0	
	A7		520	23.1	
	A8	28	530	23.6	23.5
	A9		535	23.8	

	B1		368	16.5	
	B2	7	454	20.2	17.5
	B3		350	15.6	
5%	B4		462	20.5	
	B5	21	550	24.4	22.1
	B6		480	21.3	
	B7		530	23.6	
	B8	28	515	22.9	22.9
	B9		500	22.2	

% Replacement	Cube no	Age (days)	Load (KN)	Strenght (N/mm²)	Average strenght
	C1		346	15.4	
	C2	7	372	16.5	16.1
	C3		370	16.4	
10%	C4		420	18.7	
	C5	21	425	18.9	19.1
	C6		440	19.5	
	C7		480	21.3	
	C8	28	490	22.0	21.6
	C9		480	21.3	
	D1		354	15.7	
	D2	7	330	14.7	16.7
	D3		445	19.7	
15%	D4		395	17.6	
	D5	21	410	18.2	18.2
	D6		425	18.9	
	D7		460	20.4	
	D8	28	470	20.9	20.9
	D9		480	21.3	

% Replacement	Cube no	Age (days)	Load (KN)	Strenght (N/mm²)	Average strenght
	E1		360	16.0	
	E2	7	372	16.5	16.6
	E3		390	17.3	
20%	E4		480	21.3	
	E5	21	494	22.0	21.8
	E6		495	22.0	
	E7		500	22.2	
	E8	28	500	22.2	22.1
	E9		490	22.0	
	F1		388	17.2	
	F2	7	402	18.0	17.7
	F3		400	17.8	
25%	F4		540	24.0	
	F5	21	468	20.8	22.2
	F6		488	21.8	
	F7		495	22.0	
	F8	28	540	24.0	22.7
	F9		495	22.0	

% Replacement	Cube no	Age (days)	Load (KN)	Strenght (N/mm²)	Average strenght
	G1		326	14.6	
	G2	7	388	17.2	16.5
	G3		401	17.8	
30%	G4		410	18.2	
	G5	21	422	18.8	18.3
	G6		400	17.8	
	G7		500	22.2	
	G8	28	480	21.3	21.5
	G9		470	20.9	
	H1		340	15.1	
	H2	7	380	17.0	16.5
	H3		391	17.4	
35%	H4		420	18.80	
	H5	21	400	17.90	18.3
	H6		410	18.30	
	H7		47	20.90	
	H8	28	480	21.30	20.9
	H9		460	20.40	

% Replacement	Cube no	Age (days)	Load (KN)	Strenght (N/mm²)	Average strenght
	I1		342	15.2	
	I2	7	328	14.7	15.5
	I3		375	16.7	
40%	I4		395	17.6	
	I5	21	408	18.1	17.9
	I6		403	18.0	
	I7		44	19.6	
	I8	28	460	20.4	20.3
	I9		470	20.9	

Table 3-14: Summary of Bulk Density and Compressive Strenght

%	Average density			Average strenght		
Replacement	7 days	21 days	28 days	7 days	21 days	28 days
0	2541	2622	2622	16.6	21.5	23.5
5	2553	2539	2621	17.5	22.1	22.9
10	2508	2572	2593	16.1	19.1	21.6
15	2544	2485	2495	16.7	18.2	20.9
20	2471	2579	2531	16.6	21.8	22.1
25	2448	2403	2430	17.7	22.2	22.7
30	2528	2494	2503	16.5	18.3	21.5
35	2407	2502	2502	16.5	18.3	20.9
40	2381	2409	2441	15.5	17.9	20.3

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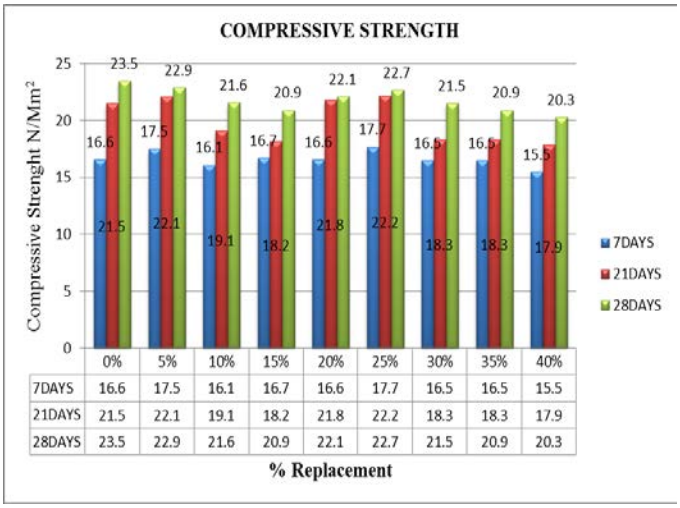

Figure 4: Increase in Compressive Strength with Increase Curing Days

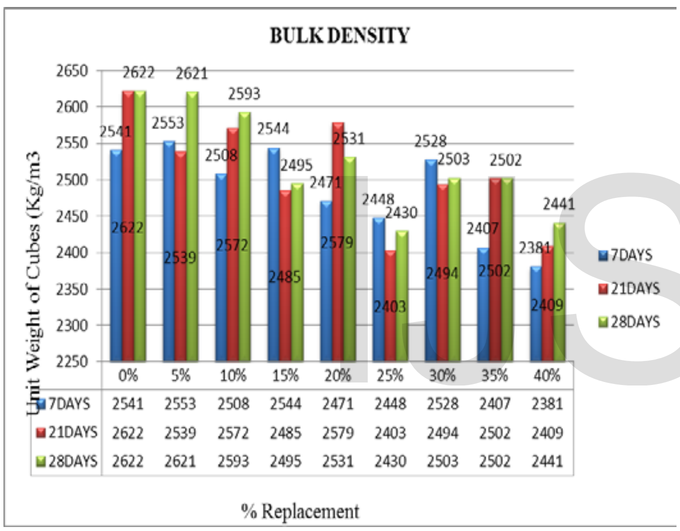

Figure 5: Density Reduces with Increase in Broken Tiles

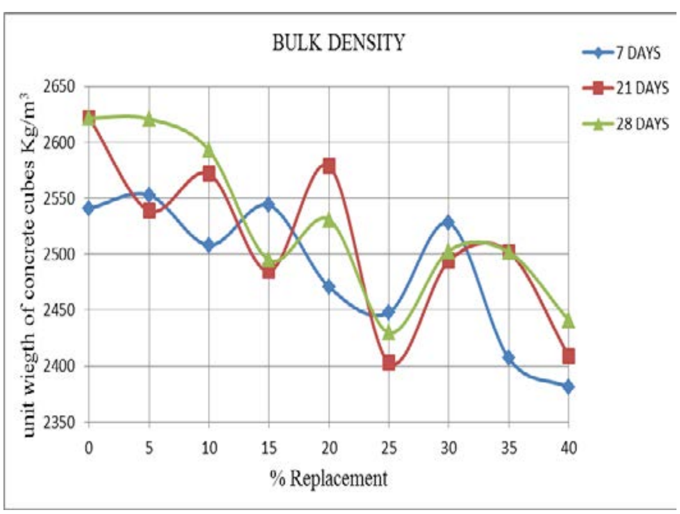

Figure 6: Graph Showing Bulk Density of Concrete Cubes

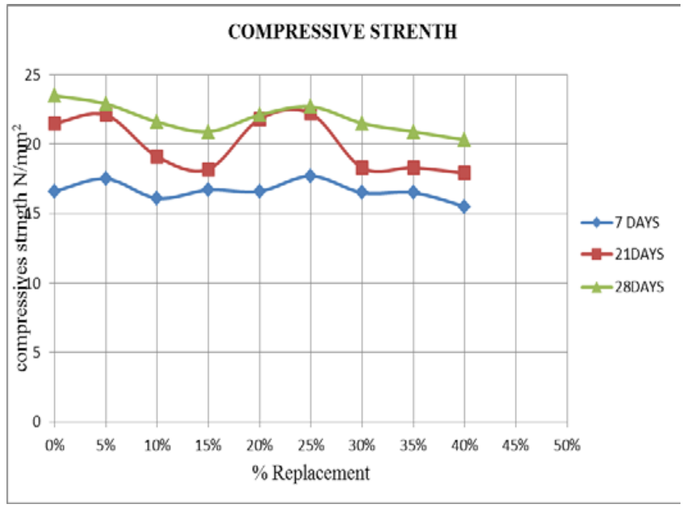

Figure 7: Compressive Strength of Concrete

The compressive strength of concrete cube for different percentages of broken tiles are presented in Tables 12. The effects of replacement of crushed granite with broken tiles on compressive strengths of the concrete cubes are shown in Fig. 5. It can be seen that the compressive strength decreases as the percentages of broken tiles content increases. The compressive strengths increase with days of curing. The compressive strength is maximum for concrete cubes with 100% granite (23.6N/mm²) and minimum when broken tiles content is 40% (20.36N/mm²) at 28days. The reason for this is that as the percentage of broken tiles content increases, the specific surface area increases, thereby requiring more cement paste to bond effectively with the broken tiles and since the cement content remains the same, the bonding is therefore inadequate. Strength depends to a large extent on good bonding between the cement paste and the aggregates. However, the minimum 28 – day cube strength values of 20N/mm² according to BS 8110 (1997) expected for concrete mixing ratio 1 : 2 : 4 could be achieved with 40% broken tiles replacement for granite.

4.0 Conclusion and Recomendations

4.1 Conclusion

Based on the investigation and experimental results, the following conclusions was made

- Based on the results obtained, replacement of 40% or less crushed granite with broken ceramic tiles can be used in reinforced concrete production.
- Their exist a similar trend in the variation of properties such as workability, unit weight and strength of concrete with an increase in the percentage replacement of crushed granite with broken ceramic tiles
- There exists a potential reduction in the cost of concrete production by replacing crushed granite with broken ceramic tiles.

4.2 Recommendations

Based on experimental results, the following recommendations were made:

Though the results indicated the possible use of broken tiles as a structural material, it is

- Recommended that its long - term behavior be investigated to evaluate this possibility.
- Further researches should be conducted to study other mechanical properties viz flexural strength, tensile strength of this category of concrete.

Using tile wastage in concrete leads to removal of those materials from environment, besides decreasing the use of raw materials, using the wastage is considered to be of great value economically and hence should be adopted in practice

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