.Original Research Article

The Strength Characteristics of Concrete Blended with Recycled Concrete, Quarry Dust and Broken Glass

ABSTRACT

Conventional concrete mixes produced from naturally occurring aggregates offer benefits in strength, workability, volume stability and permeability, as well as a wide range of properties. However, with increasing availability of construction waste materials, such as demolished concrete and broken glass, there is the need to explore the feasibility of using recycled concrete and glass as replacement for natural crushed aggregates in Portland cement concrete, and determine their compressive and tensile strength in comparison with conventional concrete. Concrete specimens produced with varying percentages of replacement aggregates using recycled concrete and glass were tested for their workability, compressive strength and tensile strength. Six different concrete mixes were designed for the study, with percentage replacement of recycled concrete and broken glass of 0, 25, 50 and 75 by volume of natural aggregate in 1:2:4 concrete mix. In total, 54 cubes and 54 cylinders were cast for compressive strength and split tensile strength, respectively. Recycled concrete and broken / crushed glass were found to be good replacements for natural aggregates in concrete production, although the percentage by volume of recycled concrete and glass used in the concrete mix was an important controlling parameter. With regard to the workability of the concrete, it was found that recycled concrete and broken / crushed glass concrete had similar characteristics to conventional concrete mixes. Partially replaced recycled concrete and broken glass aggregates showed strength variation of between 15% to 30% from natural crushed aggregate concrete. It is recommended that concrete

produced using recycled concrete and glass can be utilised for mass concrete works and structural members subjected to low loads.

Keywords: **Concrete strength characteristics, Recycled concrete, broken glass.**

I. INTRODUCTION

Concrete is the most widely used construction material and its waste therefore constitutes a significant waste stream of construction and demolition (C&D) debris (Mobasher, 2008). Several waste concrete aggregates are only found appropriate as either fill material or building foundation (Gilpini et al.,2014; Olikonomou, 2015; Wilburn and Goonan, 2013; Meyer, 2009). However, it has been found that the use of recycled concrete aggregate (RCA) in concrete is a sustainable and cost – effective substitute for Natural aggregate (NA) and is also useful for non-structural concrete where there is no severe stress. A blend of RCA and NA has been used in concrete pavements in China. RCA's most frequent applications are in road pavements and sub-bases (Li, 2009; Tošić et al., 2015). In spite of RCA's positive applications in concrete members, Martinez et al, (2013 and Heeralal et al. (2009) showed that, as opposed to NA, the RCA had a detrimental influence on the fresh and hardened concrete characteristics. On the other hand, Quisrawi and Marie (2012) found that concrete that used twice recycled aggregate had better properties,

Recycled broken concrete aggregate is a viable source of aggregates especially where there is shortage of natural, crushed aggregate (Agrela et al., 2012; Sagoe – Crentsil et al., 2011) There are strong environmental advantages to recycle and reapply waste concrete. Recycling of concrete waste as aggregates lowers the volume of waste and conserves environmental resources. This decreases the burden on the capacity of landfills with rising waste concrete from construction and demolition (Zega and Maio, 2011; Hsiao et al., 2012). Moreover, the use of recycled concrete aggregate (RCA) leads to decreased greenhouse gas emissions from the production of virgin aggregate. Furthermore, the use of RCA has financial advantages as well and assists in regulatory compliance. Processed RCA has proven more economical than virgin aggregate in the area of transportation cost and increased expense of landfill C&D debris (Meyer, 2009; Wilburn and Goonan, 2013).

Old concrete can be broken and recycled as aggregates in several applications in civil engineering practice, including road paving, sub-basements, soil stabilization and fresh concrete processing. Wilburn and Gooran (1998) found that RCA produced in stationary recycling plants were equivalent to crushed NA. Usually processing includes crushing, removing contaminants and screening. In re-used concrete aggregate, the volume of mortar and cement paste from the original concrete remains attached to the stone particles when waste concrete is crushed (Merino et al., 2010). A significant factor influencing the density, porosity and water absorption characteristics of RCA is residual adhered mortar on aggregate. Due to the attached mortar, the RCA density is about 7 – 9 percent lower than the NA. RCA's connected mortar has higher porosity (4 -6%) and water absorption (up to 2.5%) than NA (Tam, 2018).

Globally, advancement in the area of recycled concrete application differs from one country to another due to different national policies and goals such as accessibility or availability of technical standards, recycling technology and extent of government funding. More than half of the concrete debris created in the United States were dumped in landfills until 1998 (Oikonomou, 2015; Wilburn and Goonan., 2013). Among all the recycled concrete rubble, eighty five percent became useful as road foundation, while recycled concrete aggregates are progressively used in such road construction applications as concrete mix and top-course asphalt to substitute natural aggregates. The lower costs involved in transporting recycled waste concrete aggregates motivated its use.in the United States (Gilpin et al., 2014**).** In an effort to make RCA popular in all concrete implementations, particularly those in structural elements, the structural characteristics of RCA must foremost be recognized.

Another waste material appropriate for recycling is glass which is a solid, crystalline material and has been developed for human use since 12000 BCE and has been available in various forms. Glass is a blend of silica, lime and soda (Bajad et al., 2011; Bashar and Ghassan, 2009). As natural material, silica is available as quartz sand, while Na□O and CaO are known as soda ash (Na□CO□) and limestone (CaCO□), respectively. In order to add texture, other materials are also applied to the mixture (Egosi, 2012). Fundamentally, glass can be grouped as follows depending on the major compositions: vitreous silica, alkali silicates, soda-lime glasses, borosilicate glasses, lead glasses, barium glasses and aluminosilicate glasses (Shi et sal.,2004). The main constituents and their proportions in glass are as follows: Silica (72.5%, Alumina (22%), Lime (0.8%), Iron oxide (0.36%), Magnesia (4.18%), Sodium oxide (13.1%), Potassium oxide (0.26%), and Sulphur Trioxide (0.18%) (Lalitha et al., 2016). Glass has been utilized as an aggregate in various areas of the construction industry. The use of recycled glass saves energy and the realisation of the rate of recycling of glass focuses in different fields on the use of waste glass in various ways. The design area in which waste glass has been reused for concrete manufacturing is one of the major contributions (Bashar and Ghassan, 2009). Improvement is still required in the application of glass in architectural concrete. Accordingly, many researches have shown that a solid, waste glass is a safe and inexpensive alternative to sand in concrete (Bashar and Ghassan, 2009; Yehia and Abdelfatah, 2016; Shao et al, 2010. Shao et al. (2010), however, found that the shear strength between cement paste and glass aggregate was less than with natural crushed aggregate. Furthermore, Alkali – Silica reaction (ASR) is considered to be a significant obstacle to the use of recycled glass concrete. According to Caijun et al.(2005), ASR gel has the ability to absorb water with a consequent tendency to swell, Due to the ever-growing use of glass goods, the amount of waste glass has increased over the years. Most of the glass wastes are poured into landfill sites. As they are not biodegradable, the land filling of waste glasses is undesirable, which causes them to be less environmentally pleasant. The usage of waste glass in the concrete construction industry has great prospect. The price of making concrete would decrease as waste glasses are reused in making concrete products (Chen et al., 2016; Topcu and Canbuz, 2014).

2. MATERIALS AND METHODS

2.1 Materials

The concrete mix was comprised of the following main original constituent materials: **o**rdinary Portland cement which satisfies the requirement of BS 12:1991**;** crushed granite (quarry dust) as fine aggregate; crushed granite as coarse aggregate; and potable water. In addition, fine recycled aggregate and broken glass were added to the concrete **Figure 1 shows the coarse aggregates used in the study.**

2.1.1 Fine Recycled Concrete Aggregates (RA)

Fine graded crushed concrete was also used as replacement for fine aggregates in the concrete mixes. This was sourced from existing concrete structures (beams and columns) which were crushed, and the rubble hammered to the required size of recycled aggregates for this testing. The hammering was done to separate the aggregates from the mortar, with the mortar hammered to form fine aggregates. Sieve analysis was done to separate the fine and coarse aggregates into the required sizes.

2.1.2 Glass waste

The glass was colourless soda-lime silica glass bottle of density 2.5g/cm^3 with some contaminants, and came from a soft drink Bottling Company broken glass waste disposal site.

The glass fragments were produced after the raw material had been measured, cleaned, dried, compressed and sieved.

Figure 1: Coarse aggregates

2.2 Sieve Analysis

Tests of particle size distribution of the aggregates and silt content in fine aggregates were conducted in accordance with BS 812 Part 103 (1985)..

2.3 Design of test specimens

Tables 1 and 2 present the details of test specimens for six different mixes as outlined in the following:

Type A – cement, quarry dust, aggregates.

Type B – cement, broken glass as coarse aggregates, quarry dust.

Type C– cement, recycled concrete particles as fine aggregate, and recycled concrete aggregates.

Type D– cement, quarry dust, 25% glass, 75% recycled concrete aggregates.

Type E – cement, quarry dust, 50% glass, 50% recycled concrete aggregates.

Type F– cement, quarry dust, 75% glass, 25% recycled concrete aggregates.

Table 1: Details of compressive strength test specimens.

TYPE OF TEST SPECIMEN	**MIX RATIOS** 1:2:4, W/C 0.55			
	CURING DAYS			
		7	14	28
A (CONTROL)	Cement, quarry dust, aggregates	3	3	3
B	Cement, broken glass as coarse aggregates, quarry dust.			
		3	3	3
C	Cement, recycled particles as fine aggregate, recycled concrete aggregates			
	Cement, quarry dust, 25% glass, 75% recycled concrete aggregates.	3	3	3
D	Cement, quarry dust, 50% glass, 50%			

	recycled concrete aggregates.	3	3	3
E	Cement, quarry dust, 75% glass, 25% recycled concrete aggregates.	3	3	3
F		3	3	3
Total Number of cubes		54		

Table 2: Details of tensile strength test specimens.

TYPE OF TEST SPECIMEN	**MIX RATIOS** 1:2:4, W/C 0.55			
	CURING DAYS			
		7	14	28
A (CONTROL)	cement, quarry dust, aggregates	3	3	3
B	cement, broken glass as coarse aggregates, quarry dust.	3	3	3
C	cement, recycled particles as fine aggregate, recycled concrete aggregates	3	3	3
D	Cement, quarry dust, 25% glass, 75% recycled concrete aggregates.	3	3	3
E	Cement, quarry dust, 50% glass, 50% recycled concrete aggregates.	3	3	3
F	Cement, quarry dust, 75% glass, 25% recycled concrete aggregates.	3	3	3
TOTAL NUMBER OF CUBES		54		

2.4 Preparation of Concrete Test specimens

2.4.1 Mix Design

Concrete mix proportions of 1:2:4 (cement; fine aggregates; coarse aggregate) by weight with water / cement ratio of 0.55 were used to prepare the concrete. The concrete mix design was in accordance with IS: 10262 (1982). The cement content of 380 kg / m³ was used to meet a minimum requirement of 300 kg / m³ in order to avoid balling effect. 12.5 mm as the average size of the coarse aggregate. A sieve analysis and silt test conforming to BS 1377 (part 1): 1990 were carried out for both the fine and coarse aggregate. A silt test was conducted on the fine aggregates in accordance with BS 1377 (part 2):1990.

2.4.2 Mixing, Casting and Curing

Mixing of the concrete was done mechanically in a concrete mixer. The proportions of fine aggregates and cement were first batched into the concrete mixer, followed by the coarse aggregates, Mixing of the constituent materials was done in the dry state for about two minutes, and then batched water was progressively added to the dry mixed materials in the mixer.

Mixing was standardized and had a consistent hue in a plastic mix. For thorough mixing, the time for blending was 1.5 to 2 minutes per rotation. The concrete mixer’s output was 15 to 20 mixtures per hour. Slump test was conducted to determine the workability of the concrete. A total of 54 concrete cubes measuring 150mm x 150mm x 150mm and 54 cylinders measuring 150mm x 300mm were cast to study the compressive strength and split tensile strength of the concrete mixes. Concrete for each test specimen were cast in four layers and each layer was compacted by tampering 25 strokes using a rod. Figures 2a,b show the concrete cubes and cylinders.

Curing of the test cubes and cylinders was by full immersion in water at ambient average laboratory temperature of 28°C and 100 per cent relative humidity to avoid micro – cracking of the test specimens.

(a) Concrete test cubes

(b)Test cylinders

Figure 2: Concrete test specimens

2.5 Testing of Specimens

2.5.1 Compressive Strength

The test specimens were first weighed to determine the density of each concrete mix.. Test was conducted in 150mm x 150mm x 150mm concrete cubes in a compression testing machine after a curing period of 7 days, 14 days and 28 days, for 7th , 14th and 28th day strength, respectively. The cubes were loaded monotonically until failure at a rate of 140kg/cm^2 per minute in accordance with British Standards BS 1881: part 116 (1983). Figure 3a shows a concrete cube specimen under test.

The compressive strength of concrete was calculated using the formula as in equation 1;

f_{cu} = P/A Eq 1

where:

f_{cui} = Compressive strength of concrete (N/mm^2)

P = maximum compressive load (N)

A = Cross –sectional area of cube (mm^2)

2.5.2 Split Tensile strength

The split tensile test was carried out on 150mm x 300mm concrete cylinders and provided an indirect way of determining the tensile strength of the concrete. The test was carried out on the cylindrical samples after 7 days, 14 days and 28 days of curing respectively for the 7th, 14th and 28th day tensile strength of the concrete, respectively. The specimen was placed length-wise in a compression test machine as shown in Figure 3b, and loading was applied along its length until failure in accordance with BS 1881; part 116:1983. The tensile strength of the concrete was computed using the formula:

$f_t = 2P / \pi DL$ Eq 2

where:

f_t = tensile strength of concrete (N/mm^2)

P = maximum applied load (N)

D = diameter of cylinder (mm)

L = Length of cylinder (mm)

(a) Concrete cube under test

(b) Split concrete cylinder under test

Figure 3: Concrete specimens in test machine

3.0 RESULTS AND DISCUSSION

3.1 Sieve Analysis

Figure 4 shows the particle size distribution for the virgin coarse aggregate, broken concrete, broken glass, quarry dust fine aggregate and recycled concrete fine aggregate. The results show that the virgin coarse granitic aggregate, broken concrete and recycled broken glass lie within

6.3mm and 37.5mm. On the other hand, the fine aggregate component of recycled concrete and quarry dust fall within 0.15mm and 10mm

The effective size (D_{10}) of both recycled concrete fine aggregate and quarry dust aggregate is 0.46mm. The effective size is 15mmfor the broken glass, 17mm for broken coarse concrete, and 14.5mm for virgin coarse crushed granitic aggregate The coefficient of uniformity ($C_u = D_{60}/D_{10}$) for the different aggregates is 1.66 for the virgin crushed coarse; 1.44 for the recycled broken concrete; 1.43 for the broken glass; 1.96 for quarry dust; and 2.48 for recycled broken concrete fine aggregate. These values of C_u less than 5 indicate poorly graded soil materials**.** Although the recycled concrete fine particles showed a better grading with Cu greater than 2 compared with the other aggregates whose C_u values were less than 2. The poorly grade aggregates would tend to produce concrete of lower density and decreased strength.

The coefficient of curvature ($C_c = D_{30}^2 / D_{10}\ D_{60}$) for the different aggregates was as follows: Crushed virgin coarse aggregate = 1.27; crushed concrete coarse aggregate = 1.0; broken glass aggregate = 1.0; quarry dust = 1.0; crushed concrete fine aggregate = 1.0. With C_c of between 1.0 and 3.0, the grain sizes would be expected to be so arranged that dense packaging was possible (BS 410:1986; BS 812: 1973 1990; Neville, 1986). With C_c value of 1.27, the crushed coarse virgin aggregate would result in denser and stronger concrete compared with all the other aggregates whose C_c value was 1.0 and coincident with the lower limit.

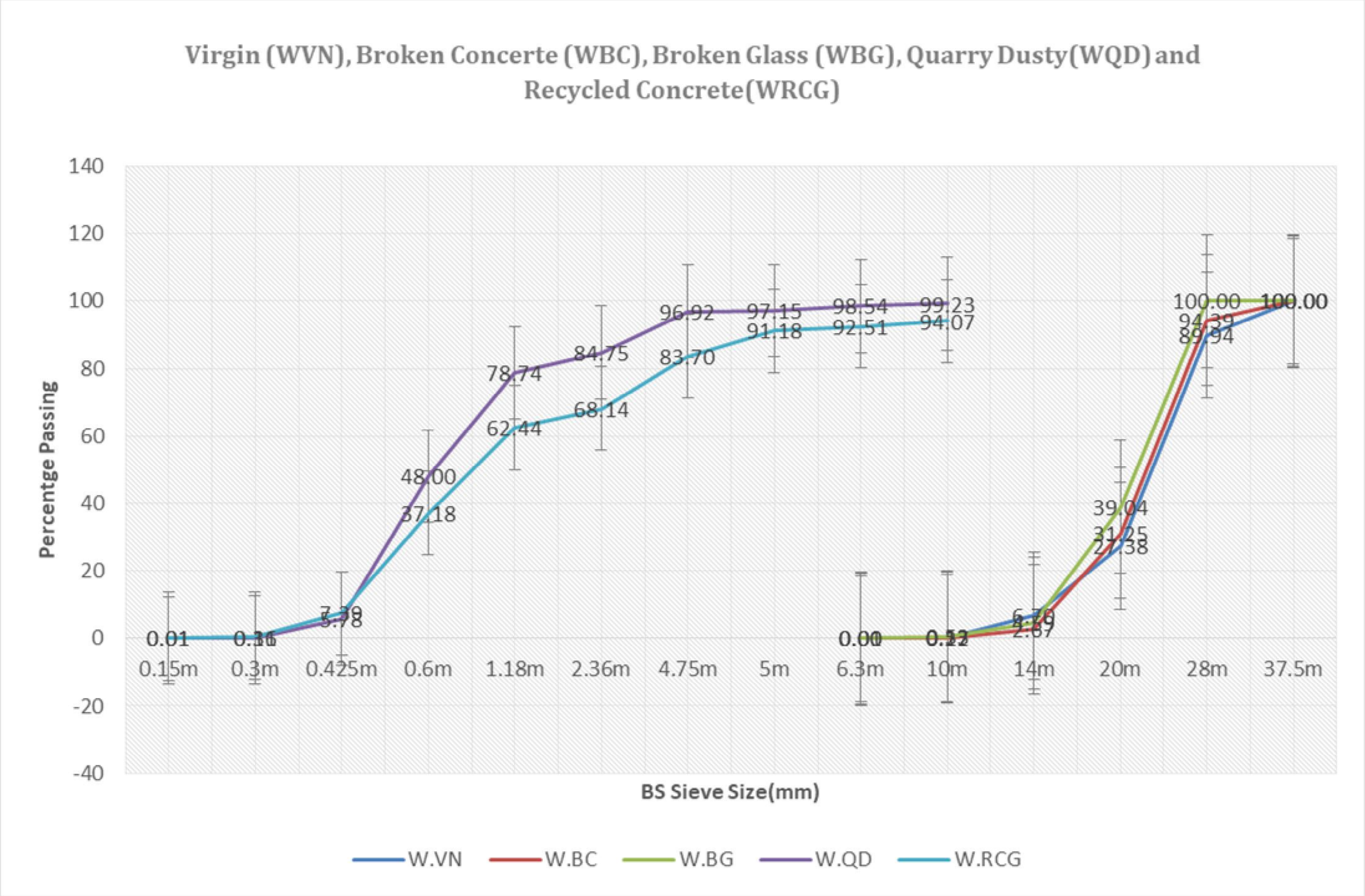

Fig 4 Particle Size Distribution of virgin coarse aggregate, broken concrete, broken glass, quarry dust and recycled concrete

3.2 Density

The results of density of the various mixes are presented in Table 3. For all the mixes, the density of concrete increased as curing continued from 7 to 28 days. The percentage changes in density of mixes with respect to the control are shown in brackets where (–ve) denotes decrease and (+ve) denotes increase. It can be observed from the table that the density of all the mixes meets the standard requirements of normal weight of concrete. However, the density generally decreased with partial replacements of virgin (normal) granitic aggregates with recycled concrete aggregates and broken glass at all curing days. The optimum mix proportions for the partial replacements are found to be Type F (Quarry dust, 75% glass, 25% coarse aggregate and cement)

3.3 Silt Content

The test results of silt content in the fine aggregates, namely quarry dust and recycled concrete aggregates are presented in Tables 4 and 5, respectively. The average silt content recorded 3.33 percent and 5.83 percent in the quarry dust and recycled concrete fine aggregates respectively These values were less than the permissible maximum silt content limit of 8 percent of sand for concrete production (BS 882:1992).

Table 3: Density of concrete mixes

MIXES	**AVERAGE DENSITY** (kg/m^3)		
	7 DAYS	14 DAYS	28 DAYS
Quarry dust, coarse aggregate and cement (type A)	2387.93	2392.35	2438.13
Broken concrete as coarse aggregate, quarry dust and cement (type B)	2248.52 (-5.8)	2265.00 (-5.3)	2570.10 (-6.8)
Recycled concrete particles as fine aggregates, coarse aggregates and cement (type C)	2144.12 (-10.2)	2151.86 (-10.0)	2271.86 (-6.8)
Quarry dust, 25% glass 75% coarse aggregate and cement (type D)	2215.88 (-702)	2374.71 (-7.74)	2206.57 (-10.5)
Quarry dust, 50% glass 50% coarse aggregate and cement (type E)	2286.96 (-4.2)	2301.86 (-3.8)	2332.94 (-4.3)
Quarry dust, 75% glass 25% coarse aggregate and cement (type F)	2322.25 (-2.7)	2309.71 (-3.4)	2324.22 (-4.5)

(Percentage change for control (Type A) in brackets)

Table 4: Silt Content in Quarry dust

DETERMINATION OF SILT CONTENT				
OBSERVATION SHEET				
Number	**Description**	**Sample No**		
		Sample 1 (ml)	Sample 2 (ml)	Sample 3 (ml)
1	Level of content (ml)	150	150	150
2	Depth of sand without silt -V1 (ml)	80	80	80
3	Thickness of visible silt V2 (ml)	2	4	2
4	Volume of Water (ml)	70	70	70
5	Percentage by volume of Silt depth to sand thickness (%) $\frac{V2}{V1} \times 100$	2.5%	5%	2.5%
	Average Content	**3.33%**		

Table 5: Silt Content in recycled concrete fine aggregate

DETERMINATION OF SILT CONTENT				
OBSERVATION SHEET				
Number	**Description**	**Sample No**		
		Sample 1 (ml)	Sample 2 (ml)	Sample 3 (ml)
1	Level of content (ml)	150	150	150
2	Depth of sand without silt -V1 (ml)	80	80	80
3	Thickness of visible silt V2 (ml)	3	6	5
4	Volume of Water (ml)	70	70	70
5	Percentage by volume of Silt depth to sand thickness (%) $\frac{V2}{V1} \times 100$	3.75%	7.5%	6.25%

	Average Content	5.83%

3.4 Compressive strength

The compressive strength test for concrete measures the load bearing capacity of the concrete before failure. Concrete compressive strength goes from 15N/mm^2 to 30N/mm^2 for general loading on light structures and beyond for heavily loaded structures.

Table 6. Average compressive strengths achieved by concrete specimens

Curing Period (Days)	Compressive Strength (N/mm^2)					
	Type A Control	Type B	Type C	Type D	Type E	Type F
7	14.51	15.06 (+3.8)	14.51 (0)	12.78 (-11.9)	11.70 (-19.4)	13.45 (-7.3)
14	18.91	14.92 (-21.1)	17.05 (-9.8)	16.37 (-13.4)	16.11 (-14.8)	15.58 (-17.6)
28	21.32	17.18 (-19.4)	17.73 (-16.8)	15.19 (-28.7)	16.90 (-20.7)	16.65 (-21.9)

Note: Figures in brackets denote percentage change of mix strength from control mix (Type A)

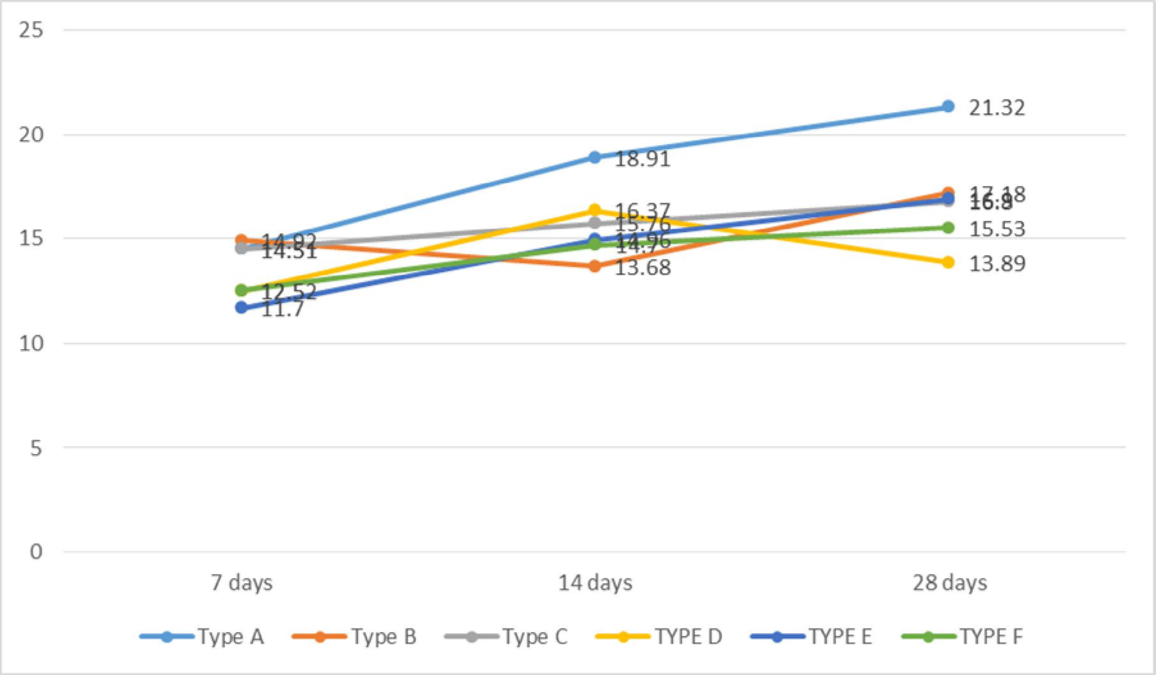

Figure 5. Compressive strength of concrete mixes at different ages

Table 6 presents results of average compressive strength for the various concrete mixes. They illustrate a general increase of strength with increasing curing days with the highest strength occurring as expected on the 28th day for all mixes. The results are also illustrated in Figure 5. This trend indicates a continuous hydration of the cement matrix in the mixes. The results also present the percentage changes in compressive strength of the blending mixes (Types B, C, D, E, and F) from the control mix (Type A). The table shows that Type C mix (cement, recycled concrete fine aggregate and recycled coarse concrete aggregate) gave the highest or best compressive strength for replacement of natural (virgin) crushed granitic coarse aggregate and quarry dust.

3.5. Split tensile strength

The split tensile test for concrete measures the tensile strength capacity of the concrete. Generally, the direct concrete tensile strength and the split cylinder tensile strength vary from 5 to 13 percent and the flexural strength from 11 to 23 percent of the concrete cube compressive strength. (Jackson and Dhir). These ratios may vary even further depending on the composition of the concrete mix.

Table 7. Average split tensile strengths achieved by concrete specimens

	Type A Control	Type B	Type C	Type D	Type E	Type F
7 Days	5.07	5.22 (+2.9)	5.06 (-0.2)	4.47 (-11.8)	4.11 (-18.9)	4.39 (-13.4)
14 Days	6.62	5.26 (-20.5)	5.01 (-24.3)	5.21 (-21.3)	4.78 (-27.8)	4.87 (-26.4)
28 Days	6.45	5.32 (-17.5)	5.23 (-18.9)	4.76 (-26.2)	5.29 (-18)	4.89 (-24.2)

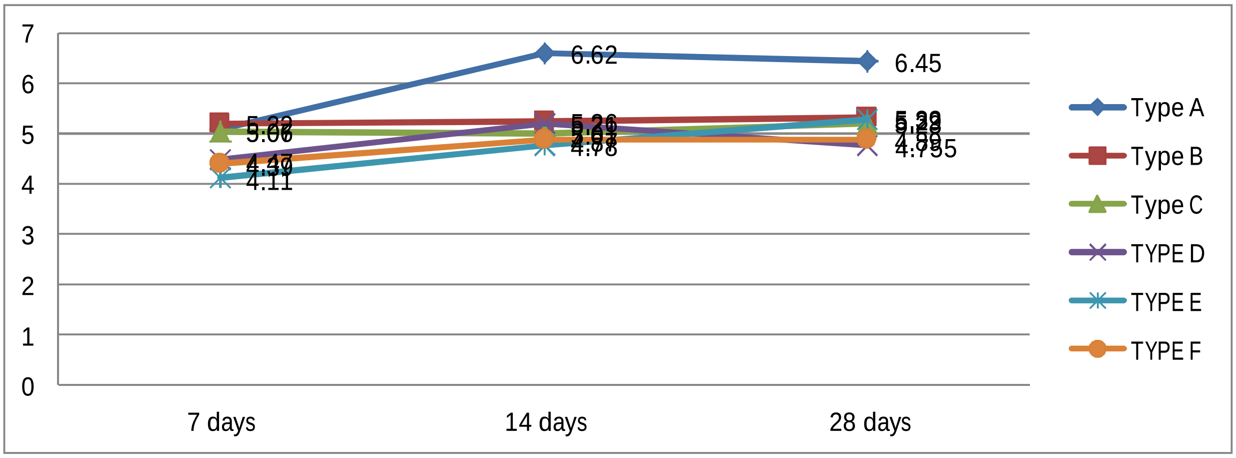

Figure 6. **Split tensile strengths of the concrete specimens at different ages**

The split tensile strength of the concrete generally increased with the curing days as illustrated in Table 7 and Figure 6. A comparison of the influence of the various aggregates replacements on the concrete mix shows that Type B mix which comprises ordinary Portland cement, broken glass as coarse aggregate and quarry dust as fine aggregate provided the best option as the percentage reduction of tensile strength was least relative to the control mix.

4. CONCLUSION

On the basis of the various tests results, it is concluded that recycled concrete and broken / crushed glass can serve as effective replacements for natural aggregates in concrete production, although their use should be dependent on the percentage volume of recycled concrete and glass that are utilized to replace conventional aggregates. In terms of the compressive and tensile strength of concrete produced with replacement recycled concrete and broken / crushed glass as aggregates, the results still point out clearly that conventional concrete mixes offer the highest compressive and tensile strength, and though mixes with glass and recycled concrete may show comparable strength achievement in the first 7 – 14 days, their strength gain was slower. Differences in strength of the concrete produced with recycled concrete and broken / crushed glass as replacement for natural aggregates, or even utilised in various percentages with the natural aggregates would often develop strength between 15% and 30% lower than conventional concrete at 28 days. However, the research did not conclude on the strength achievement beyond 28 days.

5. RECOMMENDATIONS

Conventional concrete which uses naturally sourced conventional aggregates remains the best recommendation for all types of concrete works, regardless of the mix ratio, though replacement of the natural aggregates by recycled concrete and broken / glass can offer inexpensive alternatives. However, in using these replacement materials it is recommended that:

(i) For general, non-load bearing concrete works recycled concrete as replacement for coarse and fine aggregates, can be utilized, and addition of broken glass up to 50% can achieve compressive strength above 15N/mm^2 and therefore usable.

(ii) It can also be used for minimal load bearing works, though further studies will have to be carried out to define the impact reinforcement inclusion will have on compressive strength.

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