Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 7, No. 05, May, 2021

Developing a Sustainable Concrete using Waste Glass and Rubber for Application in Precast Pedestrian Slabs

Asish Seeboo [1*], Chetanand Choollun [1]

[1] *Civil Engineering Department, University of Mauritius, Reduit, Moka 80837, Republic of Mauritius.*

Received 27 January 2021; Revised 12 April 2021; Accepted 17 April 2021; Published 01 May 2021

Abstract

In this piece of research, n attempt was made to produce a sustainable concrete with the partial replacement of both fine and coarse natural aggregates with two different non-biodegradable wastes. The selected wastes were fine glass and shredded rubber tires. Fine glass passing through 4.75 mm BS sieve was utilised for the partial replacement of fine natural aggregates. Coarse natural aggregates were partially replaced with shredded rubber passing through 20 mm sieve and retained on 6.30 mm sieve. Several mixes with varying % of fine glass but with a fixed 10 % of shredded rubber were tested. Optimum fine glass content was determined to be in the order of 20 %. The resulting concrete exhibited lower plastic and hardened densities (2040 and 2117 kg/m^3 respectively) in comparison to normal plain concrete. The static modulus of elasticity was found to be 18.3 GPa (mean value), while the splitting tensile strength was 2.37 MPa. The flexural strength showed a significant increase of 20.3% compared to the control mix. The results concluded that the concrete thus produced is a viable means of disposing of such non-biodegradable wastes (rubber and glass), thus reducing the loads at landfills. This new genre of concrete was produced at a lower cost than normal concrete because of the very low pre-treatment costs of the recycled wastes used. Furthermore, the properties tend to indicate that the concrete could be applied where lower strength and high durability properties are warranted. Hence precast slabs were made from the new design concrete and were tested along a stretch of a highly trafficable pedestrian walkway on the University campus. The slabs were continuously monitored for defects such as cracks, broken corners and slabs for a period of 24 consecutive weeks. After the test period it was observed that only 4 out of the 80 precast slabs had hairline cracks. Hence concluding the enhanced durability properties of the new design concrete.

Keywords: Recycle Materials; Shredded Rubber; Fine Glass; Sustainable Concrete; Precast Slabs.

1. Introduction

Worldwide, with increasing population and continuous development in the society, the amount of waste generated is on the rise. Resulting waste types are becoming more intricate, problematic to treat, and to dispose [1, 2]. Proper dumping of the non-biodegradable wastes is time bound; it may take years or even decades [3]. Recent research works have focused on the partial substitution of natural aggregates in one of the most important building materials, concrete, with a reasonable percentage of waste. Recycled wastes used include demolished concrete, glass and plastic among others [4, 5]. Past investigations report on many advantages, which include; (i) lesser emission of heat and carbon dioxide from the chemical reaction of cement; (ii) lower cost of the recycled concrete thus produced; (iii) abundance of recycled wastes; and (iv) reduction of air, water and soil pollution in landfill sites [6-8].

* Corresponding author: a.seeboo@uom.ac.mu

http://dx.doi.org/10.28991/cej-2021-03091690

By heating silicon dioxide, calcium carbonate among others at extremely high temperatures, a liquid is formed. After cooling a crystalline transparent material, glass, is obtained. Worldwide a high amount of waste glass is produced yearly. Waste glass, with properties matching that of fine natural aggregates, has been used in concrete [3, 9, 13]. Resulting recycled glass concrete has numerous benefits, which include; (i) lower consumption of embodied energy; (ii) lower pre-treatment cost; (iii) depending on usage, a larger amount of glass can be recycled in the concrete; and (iv) noxious glass elements are confined in the concrete matrix [9, 10]. The study by Etris et al. [14], with partial replacement of coarse aggregates by waste glass, reported a decrease in both the compressive and flexural strength of the concrete. Investigations carried out by Zainab and AL-Hashmi [15] showed a reduction in the fresh density of concrete, which is attributed to the low specific gravity of waste glass. Furthermore, with 20% partial replacement of the fine aggregates, a notable increase in both the flexural and compressive concrete strengths in the order of 10.99% and 4.23% respectively were observed after 28 days [15]. Supplementary replacement resulted in a decrease in the compressive strength due to incomplete adhesion between the glass and cement particles [16]. Lower % replacement of fine aggregates resulted in an increase in both, compressive and flexural strengths with densification of the mortar structure [17]. The densification is a result of the clustering of the finer fraction of the glass, which in turn induces an improved distribution of the cement paste thus increasing the mechanical strength [18]. Other studies showed increased durability of the recycled glass concrete, making them more resistant to electricity and sulphate attacks [19]. Furthermore, the drying shrinkage of the concrete decreases with increasing amount of recycled fine glass since fine glass does not absorb water in the matrix [20, 21].

Another non-biodegradable waste is rubber, which is obtained when tires have reached their end life. Mostly obtained from the automobile industry, its production rate, worldwide, is around 1 billion tonnes worldwide per annum [22, 23]. The global stock of such waste is about 4 billion [23]. In 2017, in the U.S. only, approximately 40 million waste rubber tires were disposed in landfills [24]. Disposal of such waste is done in landfills, some are exported or dumped illegally, and/or buried in mine sites [25]. Waste rubber is an environmental threat for the following reasons; (i) on catching fire harmful gases are released [26]; and (ii) provides breeding habitats for rats, mosquitos and vermin that can trigger health issues [27]. Many research works have been carried out on the performance of concrete whereby, both fine and coarse aggregates, were partially replaced by waste rubber [27] in numerous forms (powder [28], crumb rubber [29-31] and tire chips [32]). Resulting concrete's performance was poor [33-35]. Around 85% and 50% reduction in both compressive and split tensile strengths were observed [27]. Both the elastic modulus and the flexural strength of the resulting concrete were inferior to normal concrete [36, 37]. However, improvements were noted in; (i) post-peak behaviour [38]; (ii) ductility [39]: (iii) dynamic properties [40]; (iv) resistance to crack [39-41]; and (v) freeze-thaw attack [42].

Concrete remains a sustainable means of disposing of inert non-biodegradable waste such as glass and rubber [1-3]. Resulting recycled concrete have higher cost of production because of the cost incurred for the pre-treatment of the waste before usage. Inclusion of such materials produces concrete with inferior performances [4, 5, 7]. Most research works have so far focused on the partial substitution of either fine or coarse aggregates with one waste material [29-31]. A few investigations have looked into the partial replacement of both aggregates with one waste material [32]. The intent of this current piece of research is to investigate the properties of the resulting concrete, fresh and hardened, after partially substituting both the fine and coarse natural aggregates with recycled glass and shredded rubber tires respectively.

2. Research Methodology

The methodology adopted in this piece of research work was as per Figure 1.

2.1. Concrete Control Mix

The concrete mix used as control mix comprised of ordinary Portland cement, fine and coarse natural basaltic aggregates and fine glass as well as shredded rubber as fine and coarse aggregates substitutes. The mix was designed according to the Department of Environment (DOE) method, which is based on charts developed at the Building Research Establishment and British Cement Association. The physical properties of natural basaltic aggregates 0/4 mm, 6/10 mm and 14/20 mm were determined, Table 1.

Table 1. Physical properties of fine and coarse aggregates

Aggregate Size	0/4 mm	6/10 mm	14/20 mm
Relative Density on oven dried basis	2.69	2.74	2.71
Relative density on saturated surface dried basis	2.75	2.79	2.77
Apparent relative density	2.86	2.90	2.88
Water absorption (% of dry mass)	2.22	2.11	2.14

The grading curve of the basaltic aggregates is illustrated in Figure 2.

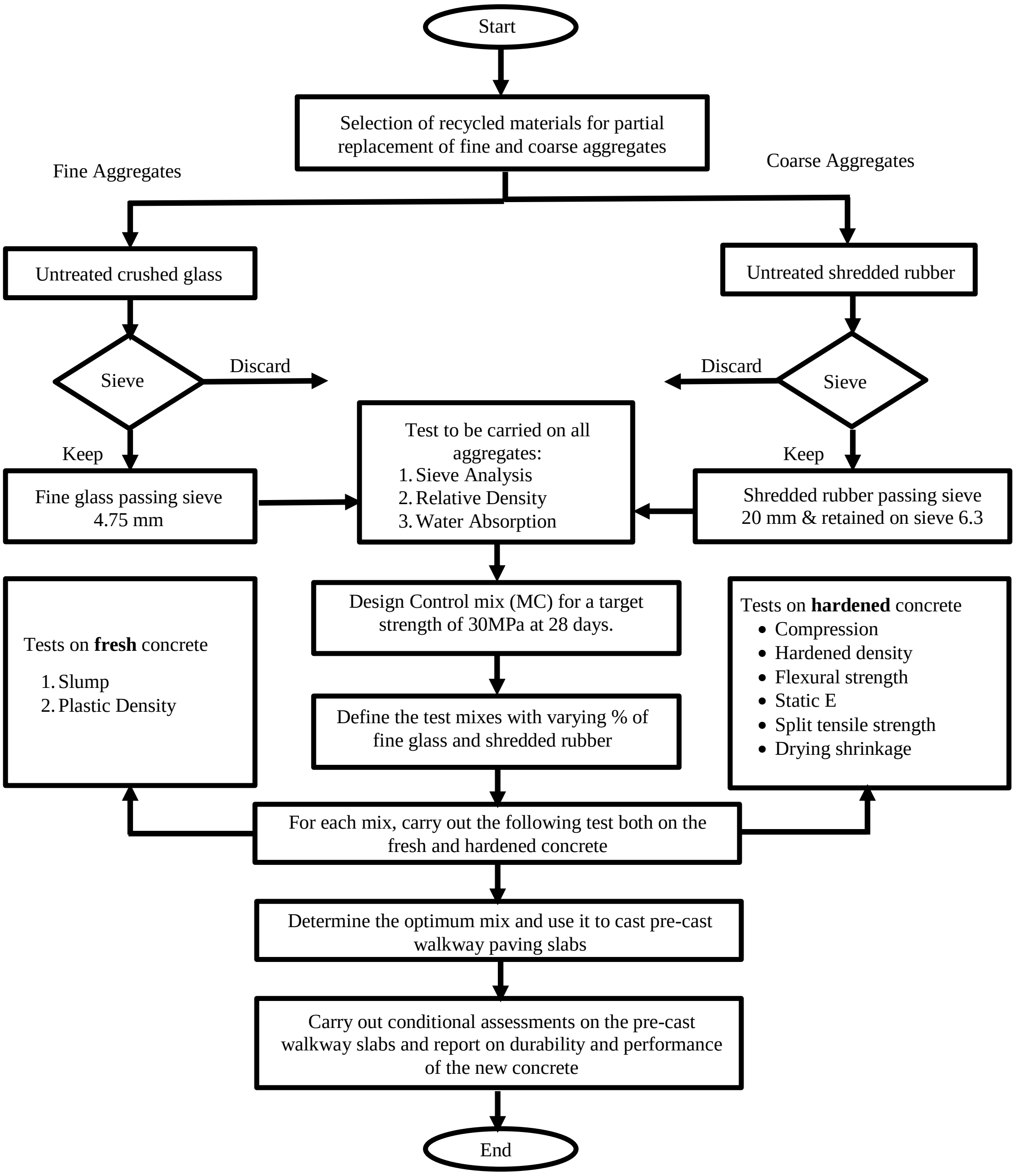

Figure 1. Methodology adopted for research

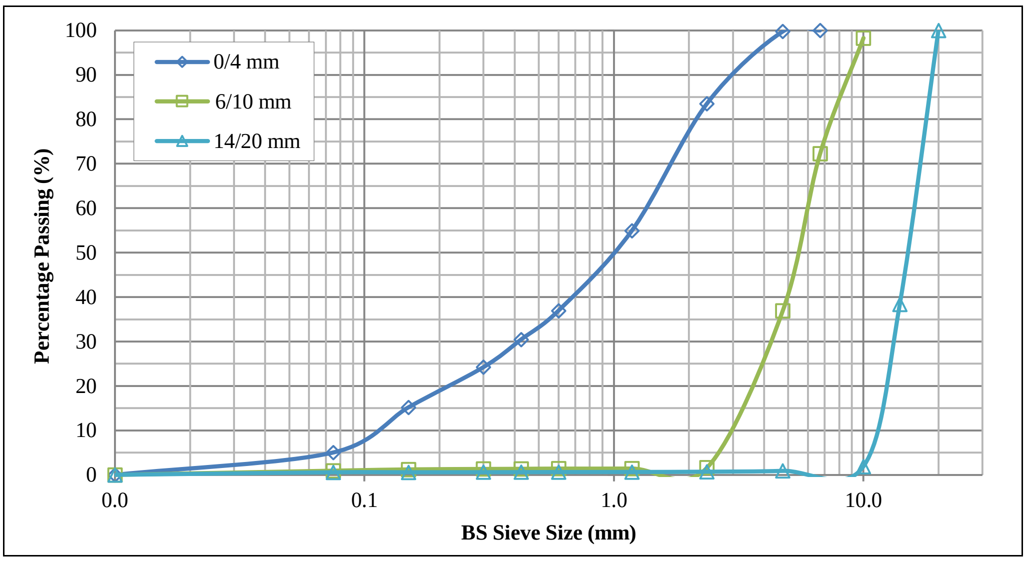

Figure 2. Grading curve of basaltic aggregates

The aggregates and cement used in the tests conformed to British Standards. The control mix design (MC) was batched for a target mean strength of 30 N/mm^2 at 28 days, Table 2.

Table 2. The composition of the control mix-MC

Parameters	Unit	Value
Cement Content	(kg/m^3)	387.93
Fine aggregate content	(kg/m^3)	845.05
Coarse aggregate content	(kg/m^3)	992.01
W/C ratio		0.58
Water content	(kg/m^3)	225

2.2. Fine Aggregates Substitute

Untreated Crushed glass was used for the partial replacement of fine natural aggregates of size 0/4 mm. The fine glass used was obtained after sieving through sieve of aperture size 4.75 mm, Figure 3. The apparent density of glass was determined to be 2.53 while the water absorption was found to be 0%. The grading curve for fine glass, Figure 4, shows that it can be used to partially replace the fine natural aggregates in this experimentation.

Figure 3. Fine glass after sieving

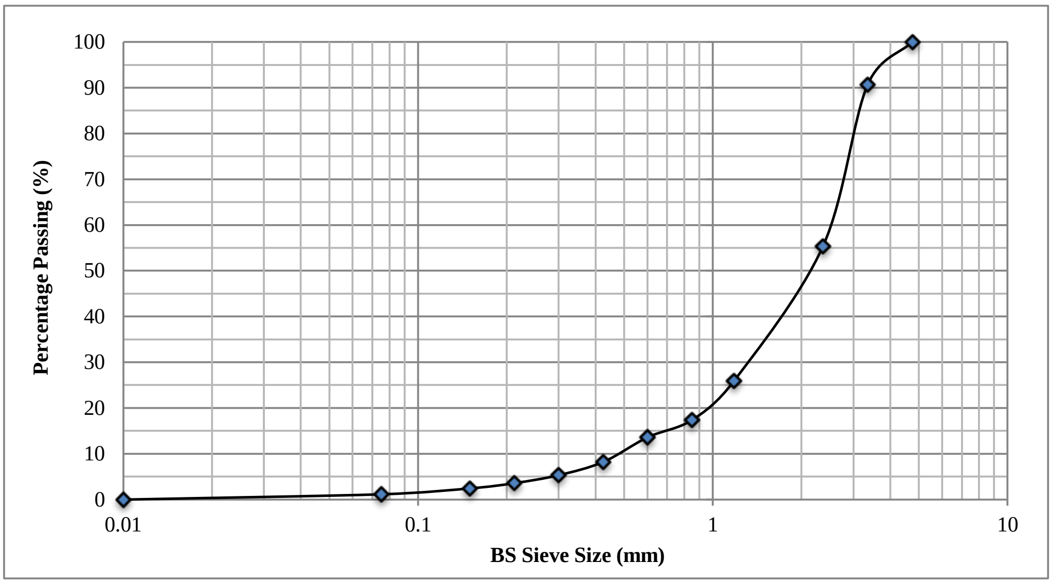

Figure 4. Sieve analysis of fine glass

2.3. Coarse Aggregates Substitute

From previous research works it was found that the optimum amount of rubber waste that can be partially substituted with coarse natural aggregates is 10% [43]. This was kept fixed in the present investigation. Untreated shredded waste rubber passing through 20 mm aperture sieve and retained on 6.30 mm sieve was utilised, Figures 5 and 6. The apparent density of rubber was found to be 0.89. Similar to fine glass, the water absorption was found to be 0% mainly since shredded rubber is a non-porous material, whereby the water is adsorbed on the surface of the material only.

Figure 5. Shredded rubber after sieving

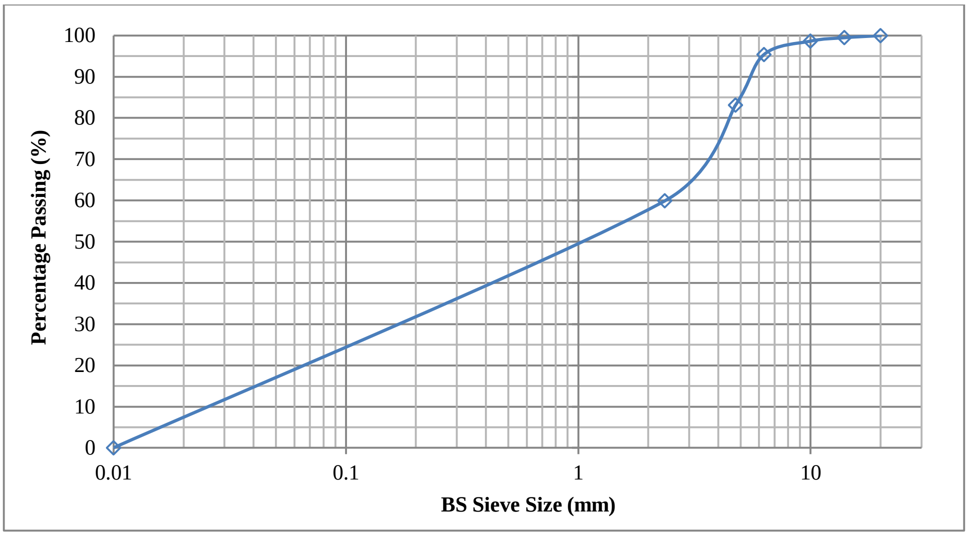

Figure 6. Sieve analysis of fine glass

2.4. Test Mix Preparation

As discussed in the previous section, the optimum amount of shredded rubber that can be substituted is 10% by mass, which was maintained in all the other mixes. On the other hand, the percentage of replacement by mass of fine glass was 5, 10, 15, 20, 25, 30 and 35% as per Table 3.

Table 3. Test concrete mixes – recycled materials content

Mix	Glass Content (%)	Rubber Content (%)
MC	CONTROL	CONTROL
M1	5	10
M2	10	10
M3	15	10
M4	20	10
M5	25	10
M6	30	10
M7	35	10

The free water content for mix MC was kept constant while for the different batches the free water content was adjusted targeting a slump ranging between 140 to 160 mm. The mix composition for the production of 1 cubic meter of concrete is as tabulated below (Table 4), however, for this experimentation only 0.03085 cubic meters of concrete was required and consequently Table 5 provides all information pertaining to the exact amount of the different ingredients required for each mix.

Table 4. The composition of the different concrete mix for 1 m^3

Mix	Cement Content (kg)	Fine aggregate content (kg)	Coarse aggregate content (kg)	Fine Glass (kg)	Coarse Rubber (kg)	Absorption water (kg)	Free Water content (kg)	Total Water (kg)
MC	387.93	845.05	992.01	NIL	NIL	39.89	225	264.89
M1	387.93	802.80	892.81	42.25	99.20	39.89	225	264.89
M2	387.93	760.55	892.81	84.51	99.20	39.89	225	264.89
M3	387.93	718.29	892.81	126.76	99.20	39.89	225	264.89
M4	387.93	676.04	892.81	169.01	99.20	39.89	225	264.89
M5	387.93	633.79	892.81	211.26	99.20	39.89	225	264.89
M6	387.93	591.54	892.81	253.52	99.20	39.89	225	264.89
M7	387.93	549.28	892.81	295.77	99.20	39.89	225	264.89

Table 5. Mass of material for a volume of 0.03085 m^3

Mix	Cement Content (kg/m^3)	Fine aggregate content (kg/m^3)	Coarse aggregate content (kg/m^3)	% by mass replacement of fine glass	Fine Glass (kg/m^3)	Coarse Rubber (kg/m^3)	Absorption water (kg/m^3)	Free Water content (kg/m^3)	Total Water (kg/m^3)
MC	11.97	26.07	30.60	Nil	0	0	1.23	6.94	8.17
M1	11.97	24.77	27.54	5	1.3	3.06	1.23	6.94	8.17
M2	11.97	23.46	27.54	10	2.61	3.06	1.23	6.94	8.17
M3	11.97	22.16	27.54	15	3.91	3.06	1.23	6.94	8.17
M4	11.97	20.86	27.54	25	5.21	3.06	1.23	6.94	8.17
M5	11.97	19.55	27.54	30	6.52	3.06	1.23	6.94	8.17
M6	11.97	18.25	27.54	35	7.82	3.06	1.23	6.94	8.17
M7	11.97	16.95	27.54	40	9.12	3.06	1.23	6.94	8.17

2.5. Batching Sequence

The sequence of batching and mixing of concrete will be carried out as outlined hereunder;

- Coarse aggregates (including coarse rubber) will be added to the concrete mixer with half the amount of water required and mixed for half a minute;
- The cement will then be loaded into the mixer with the free water and allowed to mix for half a minute;
- Fine aggregates (including fine glass) will be added to the mix as well as the remaining absorbed water;
- The mixing process will be stopped when the concrete will appear uniform after 1 and a half minutes of mixing;
- Slump will be measured for the fresh concrete;
- The plastic density of the resulting concrete will be determined;
- The concrete will be poured in the moulds in 3 layers while compacting the concrete with the help of a vibrating table;
- The concrete will be demoulded after 1 day and will be placed in a curing tank maintained at a uniform temperature.

For each mix the following tests, both on fresh and hardened concrete, will be performed in accordance with relevant testing standards (British Standards), namely;

- Fresh Concrete properties
  - Slump; and
  - Plastic Density;
  - Hardened Concrete properties;
  - Compressive Strength;
  - Slump;
  - Plastic Density.

- Hardened Density,
  - Flexural Strength;
  - Static Modulus of Elasticity;
  - Split Tensile Strength; and
  - Drying Shrinkage.

The tests required a precise time frame as prescribed in the standard codes. A planning schedule for each batch was made as described in Table 6.

Table 6. Test scheduling of batches

Day(s)	Test as prescribed in the standard codes
0	Batching, Casting and testing of fresh properties of concrete
1	De-moulding of specimens and curing
7	Compressive strength on 100 mm cube and hardened density
28	Compressive strength on 100 mm cube and hardened density Static Modulus of Elasticity on 300 ×150 mm Cylinder Tensile Splitting Test Wet measurement of prism for drying shrinkage
42-44	Drying Shrinkage measured as at 42nd day over 3 consecutive days oven dried at 55°C – 60°C
45	Flexural Strength test after re-immersion in water for a minimum of 12 hours after non-destructive test with prism

2.6. Sample Slab Preparation

The resulting concrete, once optimised, will be tested as walkway pre-cast slabs. The concrete slabs will be cast off-site against a hard concrete surface using timber as formwork. The finished unreinforced slab dimensions will be 450 mm by 450 mm by 50 mm deep. The resulting slabs will be cured using chemical compounds. Once in place the deterioration following frequent usage will be assessed weekly over a period of 24 consecutive weeks.

3. Results and Discussion

3.1. Fresh Properties of Tested Mixes

For each mix investigated, the water requirement had to be reduced, to maintain a target slump within the range of 140-160 mm. It was found that the hydrophobic nature of fine glass (0/4 mm) reduces the water requirement of the concrete. Furthermore, it was observed that the smooth surface of the recycled material increases the fluidity of the mixes. The elongated surface of the shredded rubber is hypothesized to adsorb water at its surface, providing a thin film of water between the cement paste and the rubber. With increased fluidity of the mix, the workability also augmented.

Table 7 shows the plastic density of the different batches. The control batch has a higher density compared to the substituted aggregate concrete batches. Figure 7 illustrates the decrease in plastic density with increasing replacement of fine glass. This can be attributed to the fact that both aggregates have lower densities [44] compared to basaltic aggregates. Shredded rubber apparent density is 69.1% less compared to coarser aggregates while fine glass is 11.9% less than fine basaltic aggregate. Increasing the percentage of fine glass results in a concrete mix with lower mass [15]. Also, the shredded rubber strips will entrap air and consequently result in more air voids within the resulting concrete matrix. Hence, a lower plastic density compared to the control mix. Air bubbles can be seen from Figures 8 and 9.

Table 7. Plastic Density of different mix

Batch	Plastic Density (kg/m^3)
MC	2420
M1	2150
M2	2110
M3	2070
M4	2040
M5	2010
M6	1980
M7	1950

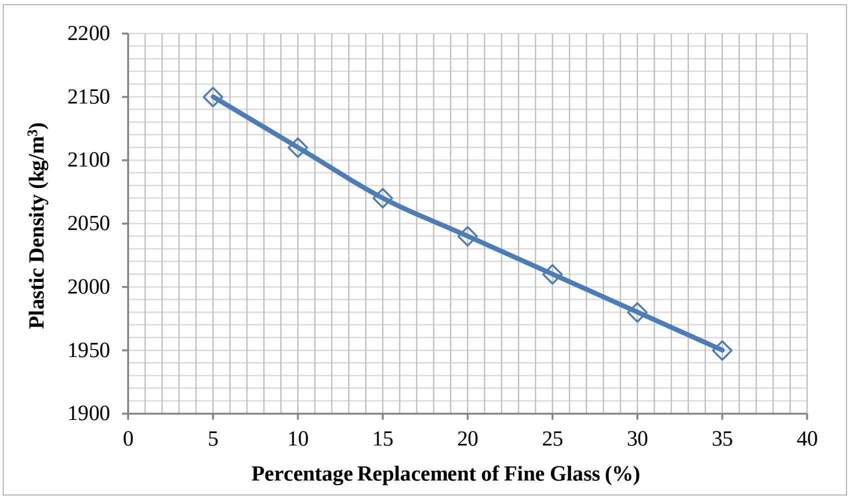

Figure 7. Variation of plastic density with increasing fine glass

Figure 8. Presence of air bubbles in concrete

Figure 9. Presence of bubbles in concrete

3.2. Hardened Properties of Tested Mixes

The hardened densities of the different mixes under study were determined at both 7 and 28 days respectively, Table 8. All cubes were cured in water maintained at ambient temperature. The hardened density was the lowest, 2044.41 kg/m^3, for the mix with the highest % of fine glass recycled material (35%) substituted. Hence, the new concrete thus produced was lighter than the normal concrete mix by approximately 22%. A decrease in hardened density was observed at 7 and 28 days, Table 8. The decrease in density is attributed to the increased amount of fine glass, which has a lower density [15] than basaltic fine aggregate. Also, the presence of entrapped air due to the presence of the shredded rubber [44] contributed to an increased amount of air voids thus causing a decrease in the overall mass of the specimen under investigation.

Table 8. Variation of Hardened density with varying % of fine glass

% Replacement		Hardened Density (kg/m^3)	
		7 Days	28 Days
CONTROL	MC	2569.71	2620.85
5	M1	2330.96	2344.02
10	M2	2306.58	2329.64
15	M3	2293.83	2223.64
20	M4	2214.46	2116.77
25	M5	2149.41	2159.53
30	M6	2077.56	2066.51
35	M7	2009.61	2044.41

3.3. Compressive Strength of Tested Mixes

Likewise, the compressive strengths of the mixes were also determined at 7 and 28 days after casting, Table 9. Figure 10 illustrates the variation of the compressive strength with increasing fine glass while keeping the % of rubber fixed to 10. In Figure 10 a maximum compressive strength was achieved with 20% replacement of fine glass (Mix M4). Further replacement showed a decline in the strength properties. From Figure 11, Mix M4 showed a decrease in compressive strength of 64% at 7 days and 59% at 28 days when compared to the control mix (MC). The non-polar nature of rubber particles and their tendency to entrap air resulted in a concrete of higher air content, thus subsequently reducing the strength [44]. Moreover, the weak adhesive bond developed between the surface of waste glass aggregates particles and the cement paste reduced the compressive strength [16]. Further decrease in strength was not observed owing to the Pozzolanic properties of the fine glass particles, which appeared to offset the compressive strength at 28 days [15].

From Figure 10, the optimum amount of fine glass that can be replaced was found to be 20%. The failure mechanism of all the cubes tested were studied. Brittle failure was noted for the control cube and non-explosive failure for the different batches containing recycled aggregates. No detachment of the concrete was observed; however, presence of cracks was noted along the plane of the application of the force [44]. It was observed that the shredded rubber used were holding altogether the cube parts from opening. As a consequence, additional external force was required to separate parts of the failed cubes. Ductile failure occurred for the cubes [45]. Figure 12 and 13 illustrate the state of the cube after failure. Figure 14 shows the inside of the cube after the application of additional forces to split open the cubes. Both substituted aggregates, namely shredded rubber and fine glass, were visible. The failure mechanism of the concrete indicates that this new genre of sustainable concrete material can sustain impacts/loads without breaking apart. The applied loads/stresses are absorbed by the rubber present in the matrix.

Table 9. Compressive Strength with varying % of fine glass

% Replacement		Compressive Strength (kN/m^2)	
		7 days	28 days
CONTROL	MC	26.09	31.46
5	M1	2.43	7.04
10	M2	5.1	9.31
15	M3	7.32	11.33
20	M4	9.39	12.86
25	M5	7.81	11.46
30	M6	5.37	8.53
35	M7	2.72	5.47

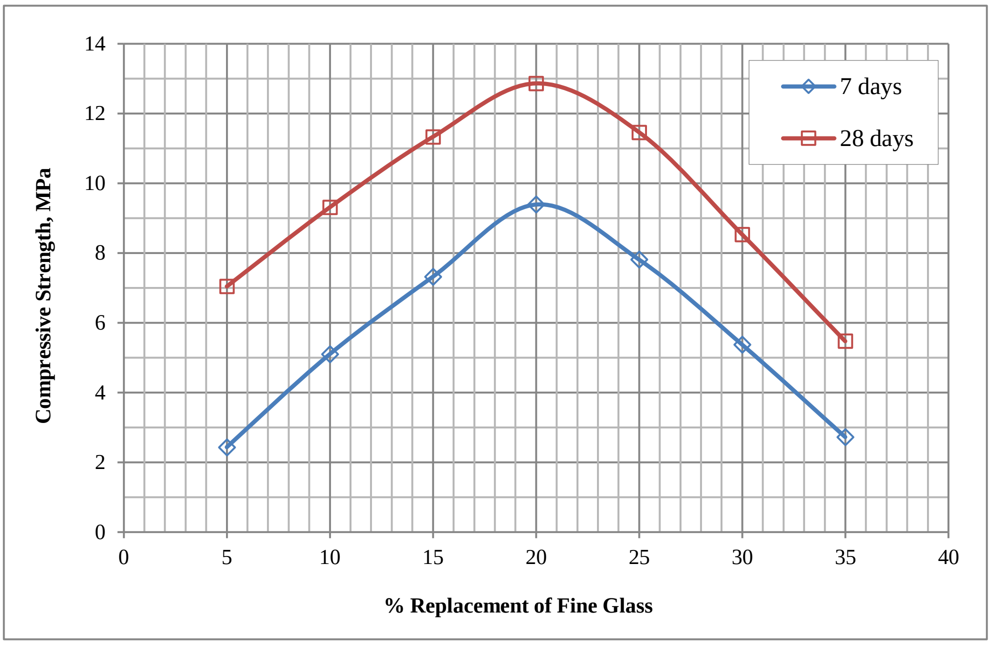

Figure 10. Compressive strength at 7 and 28 days

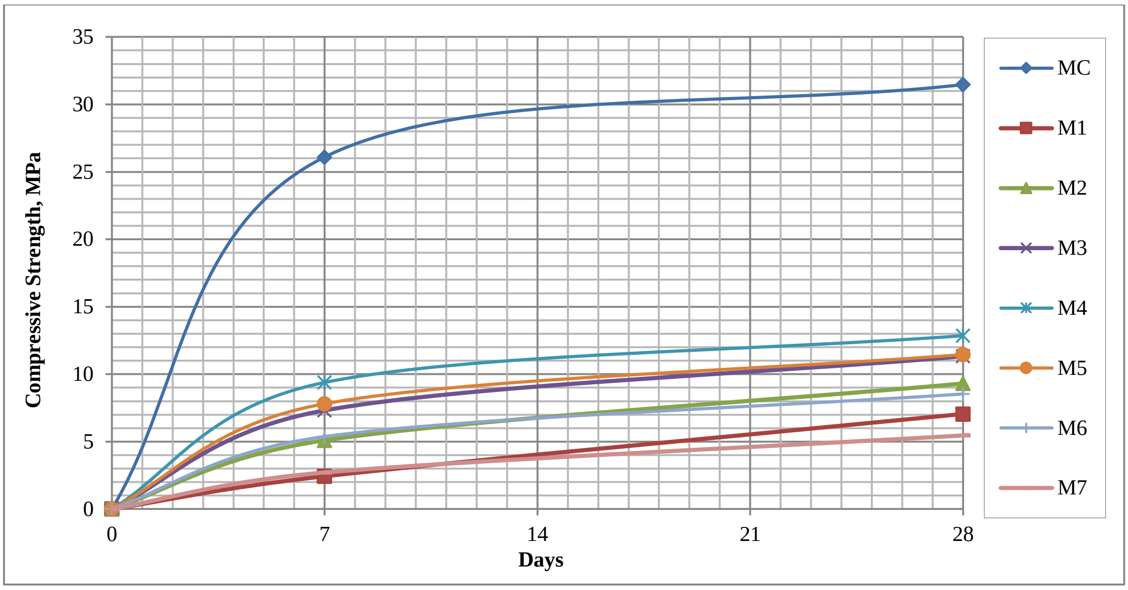

Figure 11. Compressive strength with different percentage of fine glass and the control batch

Figure 12. Failure of cube at 28 days

Figure 13. Batch M3 cube at 28 days after failure

Figure 14. Splitting of cube to reveal the presence of shredded rubber and fine glass particles

3.4. Static Modulus of Tested Mixes

The static modulus of elasticity for the different dosage of fine aggregates was determined, Table 10.

Table 10. E-value

Batch	E-Value (GPa)
MC	24.8
M1	3.55
M2	8.38
M3	15.54
M4	18.26
M5	14.03
M6	9.99
M7	5.99

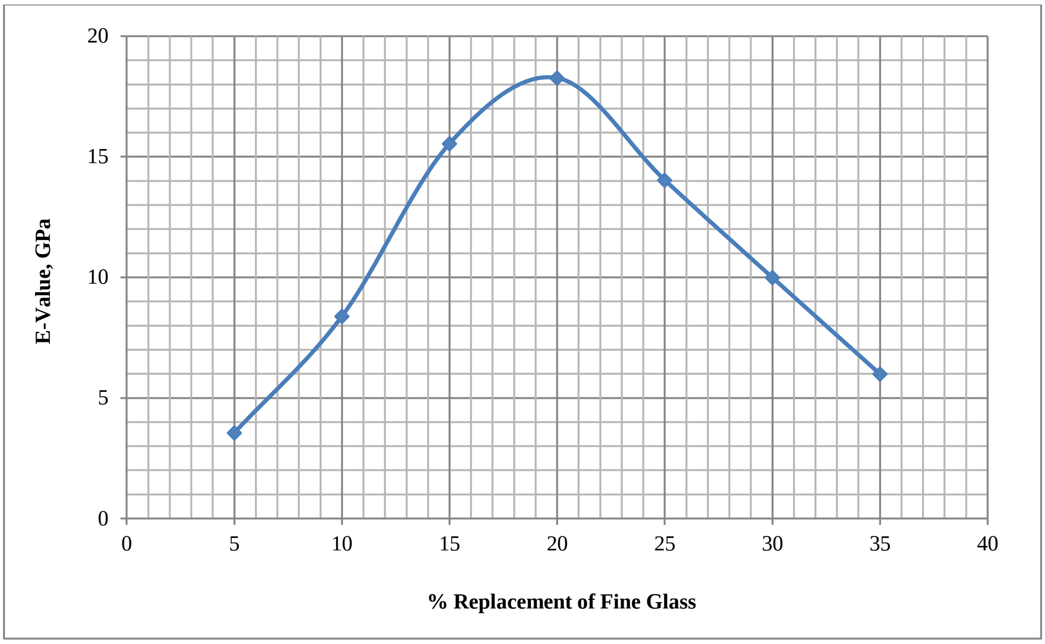

Figure 15. Variation of E-value for the different batches

Compared to the control specimen, a decrease of 25.4% was noted in the modulus of elasticity, Table 10. Both the properties and the volumetric ratio of the aggregates impact on the modulus of elasticity of the resulting concrete. Replacing the coarse aggregates with shredded rubber at 10% by mass resulted in a decrease in the observed values [46], due to rubber having a lower modulus of elasticity value in comparison to natural basaltic aggregates. Glass possesses higher modulus of elasticity compared to concrete and consequently, an increase in fine glass provides a better distribution of the particles in the cement paste [18], which in turn results in an increase in the static modulus values. As shown in Figure 15. However, there is a drop in the modulus of elasticity of the concrete, which is attributed to an increase in weak bond formation between the glass particles and the cement paste [16]. Maximum static modulus was witnessed with 20% replacement of fine glass in the concrete mix.

The rubber addition reduces the static modulus of elasticity of concrete, because rubber particles are effective in increasing deformability of concrete. Using rubber waste in concrete reduces the modulus of elasticity [47]. The modulus of elasticity is related to concrete compressive strength and the elastic properties of aggregates. The larger amount of rubber additives is added to concrete, the lesser modulus of elasticity is obtained. By using rubber waste in concrete, the dynamic modulus of elasticity also decreases comparing without rubber additives. The reduced both static and dynamic modulus of elasticity in concrete with waste rubber aggregates may be explained by the low modulus of elasticity of small rubber particles, which is much lower than the aggregate modulus of elasticity [48].

3.5. Split Tensile Strength

The table below shows the variation of the split tensile strength for the different batches.

Table 11. Variation of splitting tensile strength

Batch	Splitting Tensile Strength (MPa)
MC	4.56
M1	0.95
M2	1.63
M3	2.16
M4	2.37
M5	1.56
M6	0.88
M7	0.32

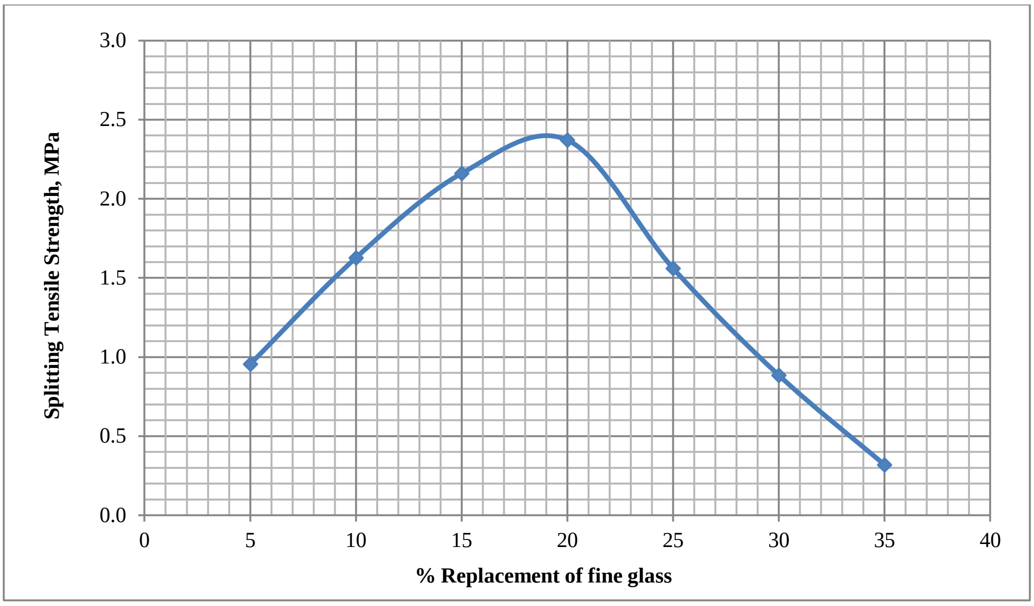

Figure 16. Variation of Split tensile strength

Table 11 gives the splitting tensile strength of the different mixes, while Figure 16 illustrates the variation across the different mixes with increasing % of fine glass. Compared to the control mix, a drop of 47.4% was observed. The decrease in splitting tensile strength was attributed to the weak bonding of the glass particles in the concrete matrix [16] and to the presence of air voids entrapped on the surface of the shredded rubber [21]. Figure 4.13 shows an increase before reaching a maximum splitting tensile strength, thereafter dropping in strength. Fine glass added increased the packing of the concrete, that is, it augmented the wall effect [49, 50] where the fine glass particles acted as mortar filling in the space between the coarse aggregates [18]. However, addition of more fine glass resulted in an increase in weak bond between the fine glass particles and the cement paste [16]. Addition of shredded rubber caused bridging of the aggregates in the concrete matrix. The shearing will occur along the shredded rubber and not through the shredded rubber. After failure occurs, the cylinder remains completely intact with presence of micro-cracks only. Figure 17 and 18 show the control specimen after splitting tensile test. The specimen would detach after application of a maximum load. From Figure 16, the optimum mix was found to be 20% replacement of fine glass.

Figure 17. Failure along plane of application of load

Figure 18. Cylinder splitting into halves

3.6. Drying Shrinkage

A decrease in drying shrinkage was observed from Figure 19. At 20% replacement of fine glass aggregates (Mix M4), the percentage drying shrinkage was 0.0177%. The control mix exhibited drying shrinkage of 0.0411%. Thus, an overall decrease of 56.9% in drying shrinkage was witnessed compared to the control mix [21]. Shredded rubber [46] and fine glass are both hydrophobic materials, having a tendency to adsorb water. Both aggregates decreased the water requirement of the mix thus resulting in lower drying shrinkage [20]. At 20% replacement of fine glass, an increase in drying shrinkage was observed. Finer glass particles (less than 75µm) have a tendency to act as Pozzolanic material [47]; thus, increasing the cementitious quantity of the mix resulting in a decrease in the required quantity of fine aggregates. This resulted in a decrease in the aggregate: cement ratio of the mix. According to Neville [47], shrinkage is larger since the drying shrinkage is inversely proportional to the aggregate to cement ratio. From Figure 19, the optimum mix was found to be 20% replacement of fine glass.

Table 12. % drying Shrinkage of all the mixes

Mix	Percentage Replacement by mass of glass (%)	Percentage Drying Shrinkage of Specimen (%)
MC	CONTROL	0.0411
M1	5	0.0798
M2	10	0.0733
M3	15	0.0409
M4	20	0.0177
M5	25	0.0470
M6	30	0.0660
M7	35	0.0976

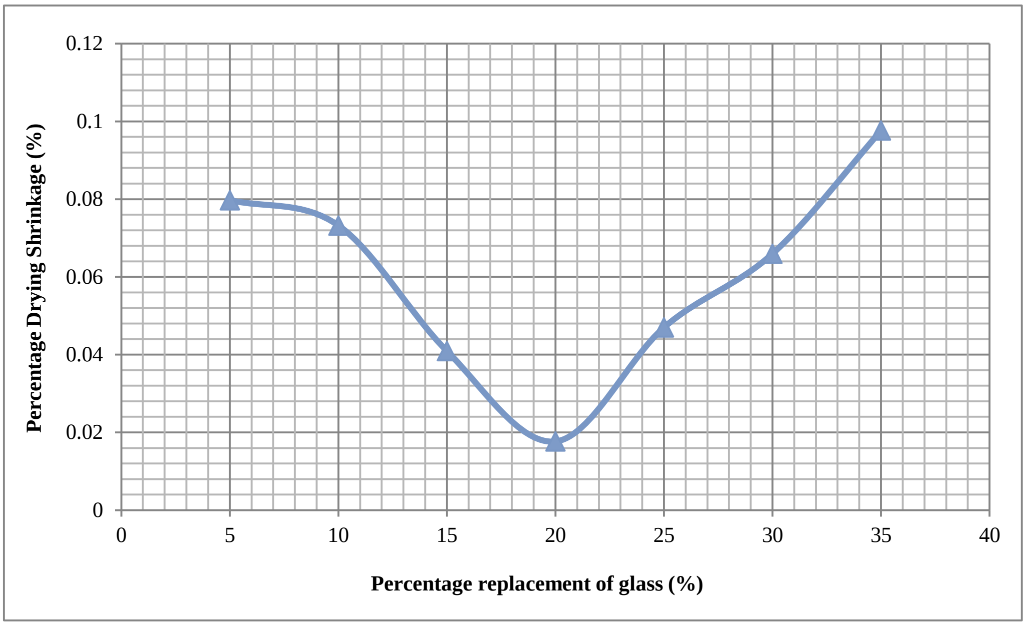

Figure 19. Variation of drying shrinkage

3.7. Flexural Strength

From Table 13 it was observed that the concrete using substitution aggregates showed an increased in flexural strength of 20.3% compared to the control specimen.

Table 13. Flexural strength of the mixes

Batch	Flexural Strength (N/mm^2)
MC	2.177
M1	0.581
M2	1.01
M3	1.812
M4	2.721
M5	2.229
M6	1.632
M7	1.088

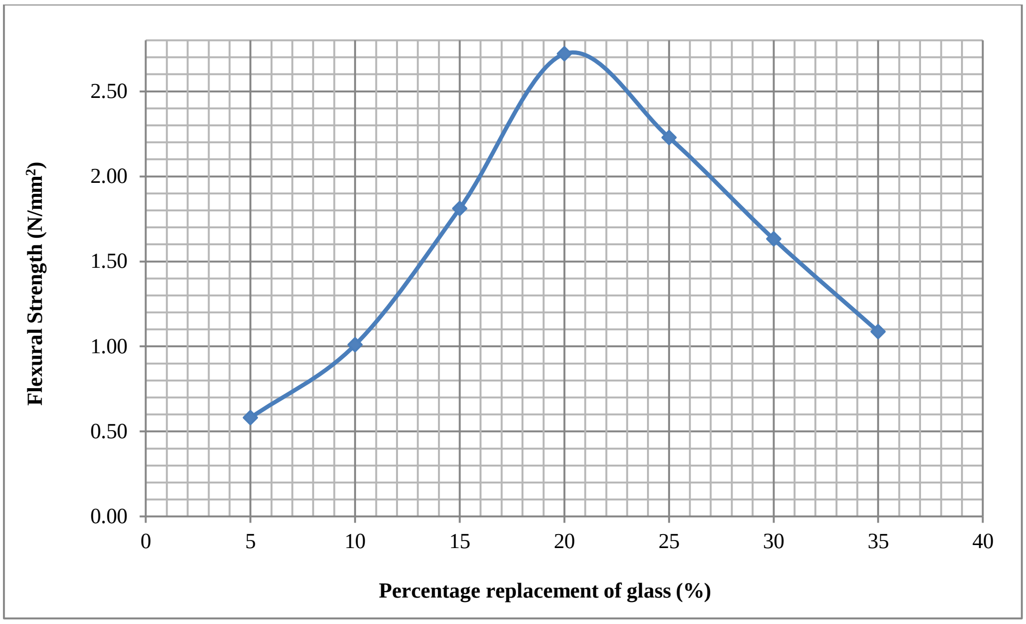

Figure 20. Variation of flexural strength

The increase is attributed to the presence of the shredded rubber. Concrete is weak in tension. The shredded rubber is ductile in nature; failure occurs at the shredded rubber-concrete interface is reduced (in the tension zone). From Figure 20, addition of fine glass increases the flexural strength to a maximum. Further addition of fine glass resulted in a drop in flexural strength. The quantity of fine glass particles acting as Pozzolanic material increases (1.2% of the fine glass content exhibits Pozzolanic effect). The cement content of the mix increases, consequently causing an increase in flexural strength [15]. However, the presence of fine glass particles increases the weak bonding at the concrete-glass interface. From Figure 20, the optimum mix was found to be 20.5% replacement of fine glass.

4. Application of New Concrete to Pedestrian Walkway Slabs

A specific section of a highly used pedestrian walkway was selected on the campus of the University for testing the new concrete, Figure 21. The existing pre-cast concrete slabs were 450 mm by 450 mm by 50 mm deep and were laid on rock-sand. A constant gap of 50 mm was maintained among the precast slabs in both directions. A condition assessment survey was carried out on each slab within the test zone. Observed defects included cracks, both horizontal and vertical, broken corners, as well as broken slabs, Table 14. On the whole, each of the slab within the test area had defects. All the slabs were replaced with new precast slabs made from the newly designed recycled concrete and monitored over a period of 24 consecutive weeks from Monday to Saturday. The pedestrian traffic flow within the test area was documented, Figure 22. A condition survey was carried out every week over the test period and defects observed were documented, Table 14. After the 24 weeks, hairline cracks were observed in the middle region of slabs F6, F7, G6, and G7. Hence, it can be concluded that the new genre of concrete exhibits high durability properties which is appropriate for application in precast walkway slabs.

Table 14. Defect's assessment

Observed Defects	Slab reference	
	With normal slabs	**With recycled concrete slabs**
1 # broken corner	0	0
2 # broken corners	A1, A4, B1, B4, C1, C4, D1, D4, G1-G4, G9 – G12, H1 – H4, H9 – H12, I1, I4, J1, J4, K1, K4, L1 , L4	0
3 # broken corners	G5, G8, H5, H8	0
4 # broken corners	A2, A3, B2, B3, C2, C3, D2, D3, E6, E7, F1-F12, G1-G12, H6, H7, I2, I3, J2, J3, K2, K3, L2 , L3	0
Horizontal cracks	A1, A4, B1, B4, C1, C4, D1, D4, I1, I4, J1, J4, K1, K4, L1, L4	0
Vertical cracks	E1-E4, E9-E12, H1-H4, H9-H12	0
Horizontal & vertical cracks	A2, A3, B2, B3, C2, C3, D2, D3, E6, E7, F1-F12, G1-G12, H6, H7, I2, I3, J2, J3, K2, K3, L2 , L3	0
Broken slabs	F5-F8, G5-G8	0

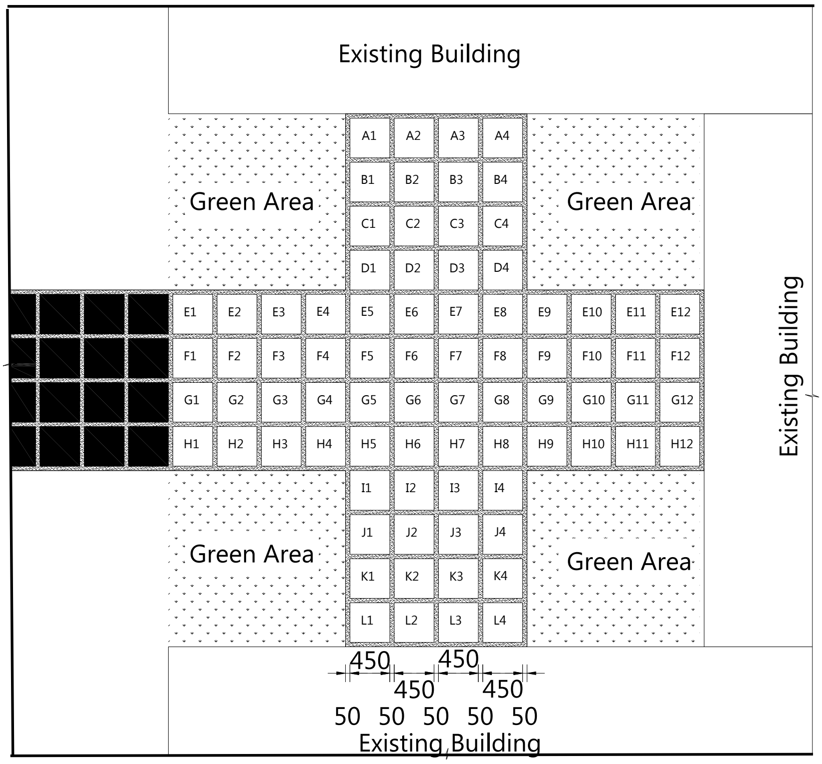

Figure 21. Walkway layout

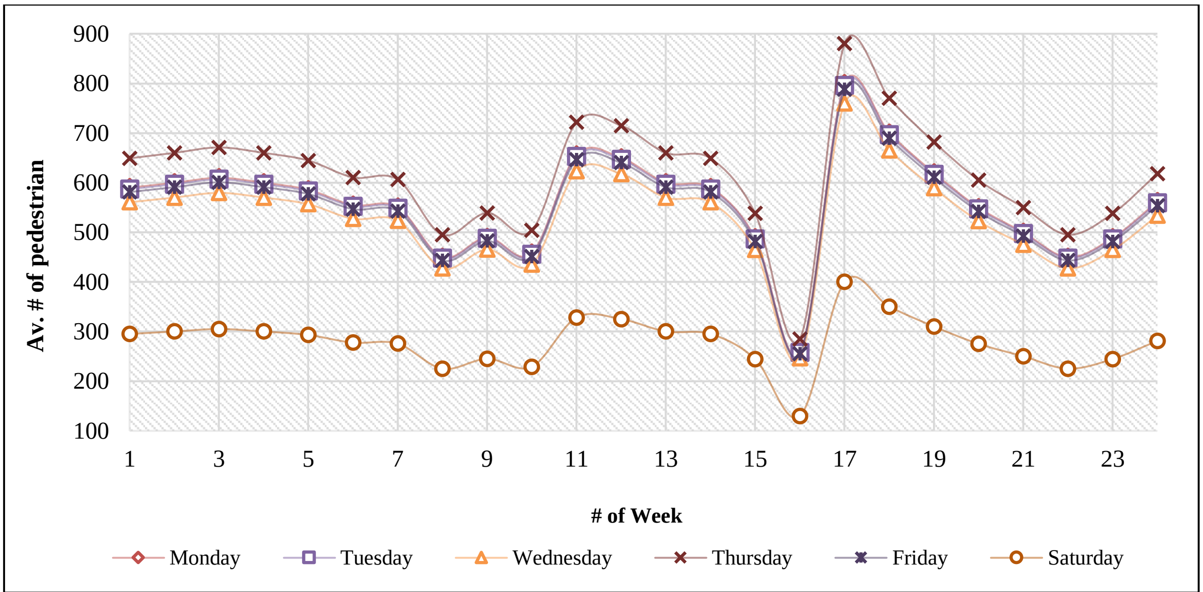

Figure 22. Pedestrian traffic over 24 weeks

5. Conclusion

In this piece of research work, a new type of concrete was produced by partially replacing both fine and coarse natural aggregates with two different non-biodegradable waste materials. Several mixes were tested and the concrete that exhibited the best properties had its fine and coarse natural aggregates substituted in the order of 20 and 10% respectively. Coarse aggregate substitutes comprised shredded rubber tires that passed through 20 mm BS sieves and were retained on 6.3 mm sieve. Fine aggregates were replaced by fine glass passing through sieve of aperture size 4.75 mm. The resulting concrete exhibited lower plastic and hardened densities (2040 and 2117 kg/m^3 respectively) in comparison to normal plain concrete. The static modulus of elasticity was found to be 18.3 GPa (mean value), while the splitting tensile strength was 2.37 MPa. The flexural strength showed a significant increase of 20.3% compared to the control mix. The results concluded that the concrete thus produced is a viable means of disposing of such non-biodegradable wastes (rubber and glass). Furthermore, the properties tend to indicate that the concrete could be applied where lower strength and high durability properties are warranted. Hence, an attempt is made to manufacture and test the newly designed sustainable concrete in walkway slabs, which is described in section 4.

6. Declarations

6.1. Author Contributions

Conceptualization, A.S. and C.C.; writing—original draft preparation, A.S. and C.C.; writing—review and editing, A.S. and C.C.; All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Acknowledgements

The authors acknowledge the contribution of the University of Mauritius more specifically the staffs of the concrete laboratory of the Civil Engineering Department.

6.5. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Sinha-Khetriwal, Deepali, Philipp Kraeuchi, and Markus Schwaninger. "A Comparison of Electronic Waste Recycling in Switzerland and in India." Environmental Impact Assessment Review 25, no. 5 (July 2005): 492–504. doi:10.1016/j.eiar.2005.04.006.

[2] Scharnhorst, Wolfram, Hans-Jörg Althaus, Mischa Classen, Olivier Jolliet, and Lorenz M. Hilty. "The End of Life Treatment of Second Generation Mobile Phone Networks: Strategies to Reduce the Environmental Impact." Environmental Impact Assessment Review 25, no. 5 (July 2005): 540–566. doi:10.1016/j.eiar.2005.04.005.

[3] Kishore, Kamal, and Nakul Gupta. "Application of Domestic & Industrial Waste Materials in Concrete: A Review." Materials Today: Proceedings 26 (2020): 2926–2931. doi:10.1016/j.matpr.2020.02.604.

[4] Tavakoli, Davoud, Masoumeh Hashempour, and Ali Heidari. "Use of waste materials in concrete: A review." Pertanika J Sci Technol 26, no. 2 (2018): 499-522.

[5] Khope, Rishikesh A., and Milind V. Mohod. "A review paper on recycled materials in concrete pavement." Int J Res Eng Sci Technol. 1, no. 8 (2015): 186-94.

[6] Prabhatkumar, A. K., & Khan, M. (2016). A review paper on experimental study for recycle concrete. International Research Journal of Engineering and Technology (IRJET) Vol. (03) (2016):1617–1619.

[7] N. Patel and P. Patel, ''Use of Demolished Concrete Materials in Concrete and Comparative Study of its Mechanical Properties: NDT Comparison," vol. 5. 4712–4721: (2016).

[8] Husain, Asif, and Majid Matouq Assas. "Utilization of demolished concrete waste for new construction." World Academy of Science, Engineering and Technology 73, no. 2013 (2013): 605-610.

[9] Federico, L.M., and S.E. Chidiac. "Waste Glass as a Supplementary Cementitious Material in Concrete – Critical Review of Treatment Methods." Cement and Concrete Composites 31, no. 8 (September 2009): 606–610. doi:10.1016/j.cemconcomp.2009.02.001.

[10] Mohajerani, Abbas, John Vajna, Tsz Ho Homan Cheung, Halenur Kurmus, Arul Arulrajah, and Suksun Horpibulsuk. "Practical Recycling Applications of Crushed Waste Glass in Construction Materials: A Review." Construction and Building Materials 156 (December 2017): 443–467. doi:10.1016/j.conbuildmat.2017.09.005..

[11] Rashad, Alaa M. "Recycled Cathode Ray Tube and Liquid Crystal Display Glass as Fine Aggregate Replacement in Cementitious Materials." Construction and Building Materials 93 (September 2015): 1236–1248. doi:10.1016/j.conbuildmat.2015.05.004.

[12] Chandra Paul, Suvash, Branko Šavija, and Adewumi John Babafemi. "A Comprehensive Review on Mechanical and Durability Properties of Cement-Based Materials Containing Waste Recycled Glass." Journal of Cleaner Production 198 (October 2018): 891–906. doi:10.1016/j.jclepro.2018.07.095.

[13] Rashad, Alaa M. "Recycled Waste Glass as Fine Aggregate Replacement in Cementitious Materials Based on Portland Cement." Construction and Building Materials 72 (December 2014): 340–357. doi:10.1016/j.conbuildmat.2014.08.092.

[14] Etris, SF, YR Fiorini, KC Lieb, IC Moore, AL Batik, and CD Johnston. "Waste Glass as Coarse Aggregate for Concrete." Journal of Testing and Evaluation 2, no. 5 (1974): 344. doi:10.1520/jte10117j.

[15] Ismail, Zainab Z., and Enas A. AL-Hashmi. "Recycling of Waste Glass as a Partial Replacement for Fine Aggregate in Concrete." Waste Management 29, no. 2 (February 2009): 655–659. doi:10.1016/j.wasman.2008.08.012..

[16] Ali, Esraa Emam, and Sherif H. Al-Tersawy. "Recycled Glass as a Partial Replacement for Fine Aggregate in Self Compacting Concrete." Construction and Building Materials 35 (October 2012): 785–791. doi:10.1016/j.conbuildmat.2012.04.117.

[17] Corinaldesi, V., G. Gnappi, G. Moriconi, and A. Montenero. "Reuse of Ground Waste Glass as Aggregate for Mortars." Waste Management 25, no. 2 (January 2005): 197–201. doi:10.1016/j.wasman.2004.12.009.

[18] Gomes, João Castro, P. Santos, and Luiz António Pereira de Oliveira. "Optimization of pozzolanic reaction of ground waste glass." (2004). Available online: https://ubibliorum.ubi.pt/handle/10400.6/589 (accessed on November 2020).

[19] Wang, Her-Yung. "A Study of the Effects of LCD Glass Sand on the Properties of Concrete." Waste Management 29, no. 1 (January 2009): 335–341. doi:10.1016/j.wasman.2008.03.005.

[20] Ling, Tung-Chai, and Chi-Sun Poon. "Use of Recycled CRT Funnel Glass as Fine Aggregate in Dry-Mixed Concrete Paving Blocks." Journal of Cleaner Production 68 (April 2014): 209–215. doi:10.1016/j.jclepro.2013.12.084.

[21] Kou, S.C., and C.S. Poon. "Properties of Self-Compacting Concrete Prepared with Recycled Glass Aggregate." Cement and Concrete Composites 31, no. 2 (February 2009): 107–113. doi:10.1016/j.cemconcomp.2008.12.002.

[22] Thomas, Blessen Skariah, Ramesh Chandra Gupta, Pawan Kalla, and Laszlo Cseteneyi. "Strength, Abrasion and Permeation Characteristics of Cement Concrete Containing Discarded Rubber Fine Aggregates." Construction and Building Materials 59 (May 2014): 204–212. doi:10.1016/j.conbuildmat.2014.01.074.

[23] World Business Council for Sustainable development, "Managing end-of-life tires|", (2008):18.

[24] U.S.Tire Manufacturers Association, U.S. Scrap Tire Management Summary, (2017-2018):21.

[25] Senate, T. "Environment and Communications References Committee: Never waste a crisis: the waste and recycling industry in Australia." Parliament House Canberra ACT: Canberra, Australia (2018).

[26] Fang, Yi, Maosheng Zhan, and Ying Wang. "The Status of Recycling of Waste Rubber." Materials & Design 22, no. 2 (April 2001): 123–128. doi:10.1016/s0261-3069(00)00052-2.

[27] Siddique, Rafat, and Tarun R. Naik. "Properties of Concrete Containing Scrap -Tire Rubber – an Overview." Waste Management 24, no. 6 (January 2004): 563–569. doi:10.1016/j.wasman.2004.01.006.

[28] Al-Akhras, Nabil M, and Mohammed M Smadi. "Properties of Tire Rubber Ash Mortar." Cement and Concrete Composites 26, no. 7 (October 2004): 821–826. doi:10.1016/j.cemconcomp.2004.01.004.

[29] Bignozzi, M.C., and F. Sandrolini. "Tyre Rubber Waste Recycling in Self-Compacting Concrete." Cement and Concrete Research 36, no. 4 (April 2006): 735–739. doi:10.1016/j.cemconres.2005.12.011.

[30] Chan, C.W., T. Yu, S.S. Zhang, and Q.F. Xu. "Compressive Behaviour of FRP-Confined Rubber Concrete." Construction and Building Materials 211 (June 2019): 416–426. doi:10.1016/j.conbuildmat.2019.03.211.

[31] Mehdipour, Sadegh, Iman.M. Nikbin, Soudabeh Dezhampanah, Reza Mohebbi, HamidHabibi Moghadam, Shahin Charkhtab, and Abolhasan Moradi. "Mechanical Properties, Durability and Environmental Evaluation of Rubberized Concrete Incorporating Steel Fiber and Metakaolin at Elevated Temperatures." Journal of Cleaner Production 254 (May 2020): 120126. doi:10.1016/j.jclepro.2020.120126.

[32] Bompa, D.V., and A.Y. Elghazouli. "Creep Properties of Recycled Tyre Rubber Concrete." Construction and Building Materials 209 (June 2019): 126–134. doi:10.1016/j.conbuildmat.2019.03.127.

[33] Li, Guoqiang, Michael A. Stubblefield, Gregory Garrick, John Eggers, Christopher Abadie, and Baoshan Huang. "Development of Waste Tire Modified Concrete." Cement and Concrete Research 34, no. 12 (December 2004): 2283–2289. doi:10.1016/j.cemconres.2004.04.013.

[34] Topçu, Ilker Bekir. "The Properties of Rubberized Concretes." Cement and Concrete Research 25, no. 2 (February 1995): 304–310. doi:10.1016/0008-8846(95)00014-3..

[35] Wang, Jiaqing, Qingli Dai, Ruizhe Si, and Shuaicheng Guo. "Mechanical, Durability, and Microstructural Properties of Macro Synthetic Polypropylene (PP) Fiber-Reinforced Rubber Concrete." Journal of Cleaner Production 234 (October 2019): 1351–1364. doi:10.1016/j.jclepro.2019.06.272.

[36] Aslani, Farhad. "Mechanical Properties of Waste Tire Rubber Concrete." Journal of Materials in Civil Engineering 28, no. 3 (March 2016): 04015152. doi:10.1061/(asce)mt.1943-5533.0001429.

[37] Jalal, Mostafa, Navid Nassir, and Hamid Jalal. "Waste Tire Rubber and Pozzolans in Concrete: A Trade-Off Between Cleaner Production and Mechanical Properties in a Greener Concrete." Journal of Cleaner Production 238 (November 2019): 117882. doi:10.1016/j.jclepro.2019.117882.

[38] Eldin, Neil N., and Ahmed B. Senouci. "Rubber‐Tire Particles as Concrete Aggregate." Journal of Materials in Civil Engineering 5, no. 4 (November 1993): 478–496. doi:10.1061/(asce)0899-1561(1993)5:4(478).

[39] Ismail, Mohamed K., and Assem A.A. Hassan. "Shear Behaviour of Large-Scale Rubberized Concrete Beams Reinforced with Steel Fibres." Construction and Building Materials 140 (June 2017): 43–57. doi:10.1016/j.conbuildmat.2017.02.109.

[40] Moustafa, Ayman, and Mohamed A. ElGawady. "Dynamic properties of high strength rubberized concrete." ACI Spec. Publ 314 (2017): 1-22.

[41] Ismail, Mohamed K., and Assem A.A. Hassan. "Shear Behaviour of Large-Scale Rubberized Concrete Beams Reinforced with Steel Fibres." Construction and Building Materials 140 (June 2017): 43–57. doi:10.1016/j.conbuildmat.2017.02.109.

[42] Gesoğlu, Mehmet, Erhan Güneyisi, Ganjeena Khoshnaw, and Süleyman İpek. "Abrasion and Freezing–thawing Resistance of Pervious Concretes Containing Waste Rubbers." Construction and Building Materials 73 (December 2014): 19–24. doi:10.1016/j.conbuildmat.2014.09.047.

[43] Etefa, Gemeda, and Alemu Mosisa. "Waste Rubber Tires: A Partial Replacement for Coarse Aggregate in Concrete Floor Tile Production." American Journal of Civil Engineering 8, no. 3 (2020): 57. doi:10.11648/j.ajce.20200803.12.

[44] Khaloo, Ali R., M. Dehestani, and P. Rahmatabadi. "Mechanical Properties of Concrete Containing a High Volume of Tire–rubber Particles." Waste Management 28, no. 12 (December 2008): 2472–2482. doi:10.1016/j.wasman.2008.01.015.

[45] Toutanji, H.A. "The Use of Rubber Tire Particles in Concrete to Replace Mineral Aggregates." Cement and Concrete Composites 18, no. 2 (January 1996): 135–139. doi:10.1016/0958-9465(95)00010-0.

[46] Ganjian, Eshmaiel, Morteza Khorami, and Ali Akbar Maghsoudi. "Scrap-Tyre-Rubber Replacement for Aggregate and Filler in Concrete." Construction and Building Materials 23, no. 5 (May 2009): 1828–1836. doi:10.1016/j.conbuildmat.2008.09.020.

[47] Zheng, L., X. Sharon Huo, and Y. Yuan. "Strength, Modulus of Elasticity, and Brittleness Index of Rubberized Concrete." Journal of Materials in Civil Engineering 20, no. 11 (November 2008): 692–699. doi:10.1061/(asce)0899-1561(2008)20:11(692).

[48] Topçu, lker Bekir, and Nuri Avcular. "Analysis of Rubberized Concrete as a Composite Material." Cement and Concrete Research 27, no. 8 (August 1997): 1135–1139. doi:10.1016/s0008-8846(97)00115-4.

[49] Neville, Adam M. Properties of concrete. Vol. 4. London: Longman, (1995).

[50] Abdullah, Anas Ibrahim. "Structural Behavior of High Strength Laced Reinforced Concrete One Way Slab Exposed to Fire Flame." Civil Engineering Journal 5, no. 12 (December 1, 2019): 2747–2761. doi:10.28991/cej-2019-03091446.