International Journal on Advanced Science Engineering Information Technology

Vol.8 (2018) No. 4
ISSN: 2088-5334

Characteristic of Concrete Containing Glass and Tyre Particles as Replacement of Fine Aggregate

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***Abstract*—This paper presents the results of an experimental investigation into the behavior of concrete containing glass sand and tire sand as replacement for natural sand. Various properties: concrete slump, density, compressive, split tensile, flexural strength and water absorption were investigated through single replacement mechanism in which full portion of glass sand and 10%, 20%, 30% of tire sand replacing fine natural aggregate. Concrete strength observations refer to ASTM C39-10, ASTM C496-04 and ASTM C78 provision. Test results indicate that all replacement mechanisms exhibit undesirable physical behavior and lower concrete strength than conventional concrete. The mortar containing 100% glass sand and higher tire sand content generates higher slump value and lower density. The mortar of R3 batch shows higher slump value, followed by GS100, R2, and R3, while the GS100 batch yields the lowest fresh and hardened density. Specimen R1, R2, R3 and GS100 yield lower compressive strength, split tensile and flexural capacity than the original specimen due to the reduction in bond strength and adhesiveness between particles and cement matrix of modified concrete. There is an insignificant difference in water absorption rate between control concrete and modified concrete. However, lower tire particle content in R1 absorbs less water than specimen R2 and R3 and GS100.**

***Keywords*— concrete strength; glass; rubber; particles; replacement**

I. INTRODUCTION

The advancement in concrete technology has been widely improved in line with the rise of options of material combination to replace Portland cement and aggregates. The ultimate purpose of the replacement is likely to increase the strength and to provide sufficient serviceability of a structural element. Instead of the benefit, concrete comprises several drawbacks such as lower tensile strength compared to steel, a lower ratio of its strength and weight, lower ductility, vulnerable to cracks and certain environmental impacts. The latter is due to the high carbon emission in the cement production process contributing around 9.5% to global carbon dioxide emission [1]. Research into composition material of a university in Malaysia shows that the waste glass is around 0.7% and the amount of recyclable materials is found about 55%, the composed material is around 30% and non-recyclable is about 15% [2].

Besides economic considerations towards the material cost of conventional concrete, it might be necessary to utilize environmentally friendly materials such as recycled materials. The increase in recycled aggregate considerable reduces concrete workability [3]. The characteristics of recycled materials in the form of glass and rubber particles such as waste glass sand (GS) and waste tire rubber sand (TS) have been tested to replace conventional concrete. The compressive strength of the recycled material is mainly affected by types of aggregate, curing period, a portion of replacement, water penetration level, and moisture content [4].

Numbers of investigations show that the minimum capacity of modified concrete could be increased by multiple replacement mechanisms thereby creating a better concrete performance. This practical idea tends to be a promising alternative regarding concrete strength and green construction. This study aims to determine physical and mechanical characteristics, and water absorption capability of concrete containing waste glass sand and waste tire rubber sand obtaining from waste recycle center as replacement of natural sand in the concrete mix.

Studies into the utilization of glass sand as a replacement of conventional sand have been widely conducted and resulted in various strength characteristics. An investigation of [5] and [6] shows strength reduction about 10 MPa while that of [7] shows a linear increase of compressive strength from 32 MPa to 43 MPa because of the variation in strength and surface texture of natural sand and glass. Modulus of elasticity of glass concrete decreases with the addition of 50% glass sand in the mix [8].

Twenty percent of replacement produces optimum compressive strength [9], tensile strength [10] and flexural strength [11] of glass concrete. The increase of flexural strength reaches over 50% than conventional concrete when replacement ratio greater than 50% [12]. The capacity of concrete with GS was comparable to the normal concrete at the replacement ratio of 15% [13]. Drying shrinkage of modified concrete can be reduced by replacing 45% natural sand with GS, and the length change of normal concrete was greater around 0.0038% than concrete with glass sand, around 0.0031% [14]. The investigation into the replacement of natural sand with cathode glass particle [15] shows an acceptable range of drying shrinkage level. Water absorption level of normal concrete is about 1.2%, and by the addition of 40% glass sand the absorption level falls to 0.52%, which possibly due to the nature of glass particles as a waterproof material [9].

The number of the global waste tire was predicted to reach 1.2 billion in the next 15 years [20]. This waste rubber should be extensively utilized as other alternative disposal methods to protect the environment such as a partial substitution to fine aggregate in concrete, which is technically termed: “rubberized concrete,” “rubber concrete,” “rubcrete,” or “rubber modified concrete.” The replacement of 5%, 10%, 15% and 20% of natural sand with tire rubber sand in mortar shows the variation of concrete strength owing to the difference of particle size, volume, specimen size, and applied load. Nevertheless, the deterioration of compressive strength (f’c), tensile strength (fct) and flexural strength (fcf) lies between 15% to 20%, 7% to 13% and 9% to 23% respectively every 5% addition of TS [16]. The precise composition of rubber concrete mixture may improve energy dissipation capacity, deformation and allowable damping [17]. The mixture of TS over 50% significantly reduces compressive strength over 50% and tensile strength of about 60% despite the additional treatment of waste tire rubber material [18].

Shrinkage levels increase every 5% addition of TS since the lack of bonding between the surface of the rubber particle with cement matrix at the age of 28 days and 90 days. It is recommended to add the NaOH solution into the mixture to enhance the surface bond between particles thereby intensifying strength and reducing porosity. Long-term crack can also be reduced by the method [19]. The bond behavior of concrete primarily relies upon the mechanical properties, surface condition, and geometry of the concrete [3]. There is an insignificant adverse effect on the replacement ratio of 5% as water penetrates just under 12 mm. Conversely, as the replacement ratio is increased to 20% the penetration level is tripled, although rubber concrete experiences better abrasion resistance because rubber particle emerges to the concrete surface and resists against scratching [20].

II. Material and Method

A. Material

Limestone in Fig. 1.a and natural sand in Fig. 1.b used in this study are provided by Concrete Laboratory of the University of Adelaide, whereas Portland cement is by Adelaide Brighton Cement Ltd. Rubber particle as is seen in Fig. 1.c passes sieve number 40 and is obtained from Tyrecycle Melbourne while glass sand in Figure 1.d., that Potters Australia produces. The characteristic of Portland cement and chemical compound of GS is listed in Table 1. and Table 2.

Fig. 1 Material (a) limestone, (b) natural sand, (c) tire sand (TS), (d) glass sand (GS)

TABLE I
PHYSICAL PROPERTIES OF CEMENT

Test	Typical Value
Fineness Index (m^2/kg)	370-430
Setting Time (hour: min)	
Initial	1:30
Final	3:00
Soundness(mm)	<1
Compressive Strength mortar bars (MPa)	
3 days	36
7 days	48
28 days	60
Mortar Shrinkage (micro-strain)	
28 days	650
Sulfate Expansion (micro-strain)	
16 weeks	610

Source: [21]

TABLE II
PHYSICAL PROPERTIES OF CEMENT

GS	Amount (%)	TS	Amount (%)
SiO_2	72.5	ZnO	37.8
Al_2O_3	0.4	SiO_2	22.3
Fe_2O_3	0.2	Lime	5.7
CaO	9.7	FeO	7.4
MgO	3.3	Sulfate ions	7
Na_2O	13.7	Others	5.9
K_2O	0.1		

Source: Potters Australia

There are four different particle sizes of GS: 0-0.3 mm, 0.3-1.0 mm, 1.0-1.5 mm and 1.5-4.0 mm. These glass particles are distributed based on the distribution of natural sand in the mix, and in this study, the replacement ratios are 10%, 20%, and 30% respectively.

B. Method

This investigation comprises three groups of concrete mix. A first group is a control group involving normal concrete mix, the second group involves glass concrete, and last is the rubber concrete mix group. The last two groups are termed as modified groups. The control group is noted as CC40; the second group replaces 100% natural sand with glass sand and is noted as GS100. The third group comprised three types of replacement ratio of 10%, 20%, and 30% and noted as R1, R2, and R3 in that order. The target of compressive strength is 40 MPa for all specimens. The specimen is a cylinder with a diameter of 100 mm and height of 200 mm.

The normal concrete mix design requires 375 kg/m^3 cement, 740 kg/m^3 sand, 1110 kg/m^3 limestone and 232 kg/m^3 water without superplasticizer and in this study, water to cement ratio (w/c ratio) is maintained at 0.57.

TABLE III
TEST MATRIX

Specimen Notation	Limestone (%)	Fine Aggreggate (%)			
		TS	GS	Natural sand	Cement
CC40	100	0	0	100	100
R1	100	10	0	90	100
R2	100	20	0	80	100
R3	100	30	0	70	100
GS100	100	0	100	0	100

.

Six different tests were engaged in this study: slump test, compressive strength test, tensile strength test, flexural strength test according to ASTM standards as shown in Table 4, and water content, concrete density, and water absorption test.

TABLE IV
TEST STANDARDS

Test Type	ASTM#	Curing age (days)	Specimen type
Slump	ASTM C143	-	-
Compressive	ASTM C39-10	3,7,28,128	Cylinder
Tensile	ASTM C496-04	28	Cylinder
Flexural	ASTM C78	28	Prism

The water content test was conducted by measuring material weight before and after the material was stored in storage with 75°C in three days. Water content was then determined using Equation (1) where W_w is wet weight, and W_d is the dry weight of the sample.

$$W(\%) = \frac{W_w - W_d}{W_d} \times 100\% \qquad (1)$$

Slump test used standard apparatus with a bottom diameter of 30 cm and a top diameter of 10 cm and height of 30 cm. The mixed mortar was poured in three stages with 30% volume in each stage and was pounded with a round metal rod of 50 cm in length and 10-16 mm in diameter. Concrete density was determined using Equation (2) considering a constant volume.

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} = \frac{M_{ns}}{D_{ns}} = \frac{M_{GS}}{D_{GS}} = \frac{M_{TS}}{D_{TS}} \qquad (2)$$

The terminology *ns* refers to natural sand, *GS* refers to glass sand, and *TS* refers to tire sand. The type of concrete mixer used was Hallweld-Bennet P/L (Fig. 2.a.). Before the compressive strength test is performed, the top and bottom surface of a specimen should be ground so that both surfaces completely in contact with the compression machine. The grinder machine used is Hi-KENMA as shown in Fig. 2.b. The compressive and tensile strength tests used SEIDNER Multitasking Machine (Fig. 2.c.) whereas the flexural strength test used the device shown in Fig. 2.d. The compressive strength of a specimen is calculated by Equation (3).

$$f'_c\,(kg/cm^2) = \frac{\text{maximum working load}}{\text{surface area}} \qquad (3)$$

The working load applied in compressive strength test was 400 kN with the load rate of 39% and 12.5% for the tensile strength test. This study uses 3 samples of each test type and results were taken from the average value. The overall process of the study and the tests are illustrated in Fig. 3.

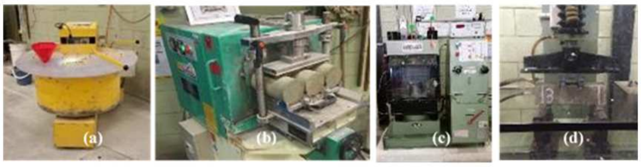


Fig. 2 (a) Concrete mixer; (b) Grinder; (c)-(d) SEIDNER Multitasking Machine

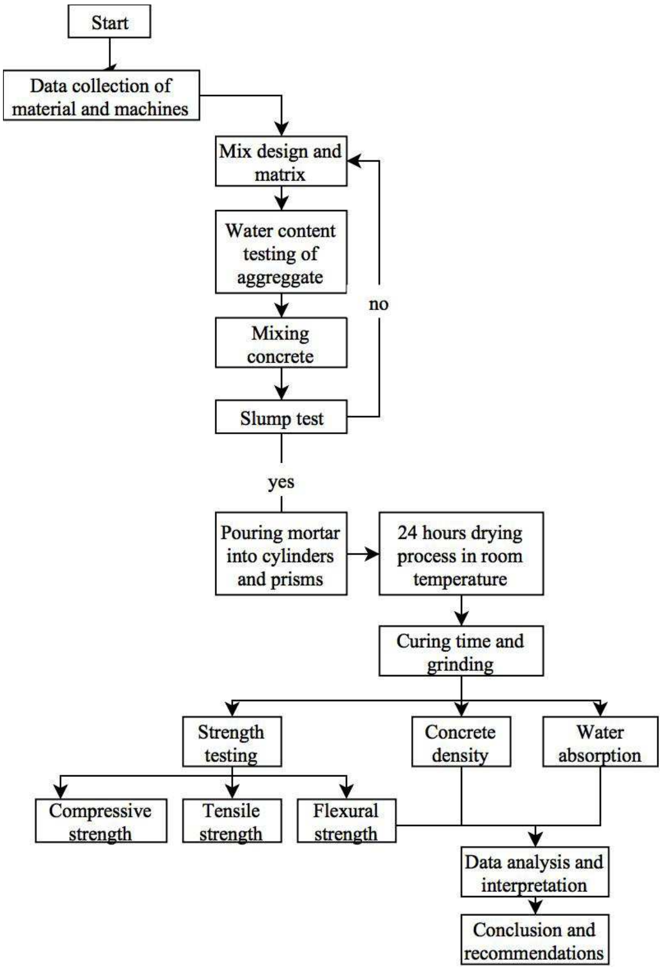


Fig. 3 Research procedure

III. Results and Discussion

A. Water Content

The measurement of limestone shows water content of 0.47% and natural sand shows 1.78%. That the alternative material, whether GS or TS hardly absorb water and natural sand absorbs more water than limestone. It is recommended that the presence of water in aggregate require carefully mix design adjustment so that w/c ratio could be maintained.

B. Consistency and Density

The result of the consistency test is shown in Table 5. The slump value of specimen R2, R3, GS100 increases as compared to the conventional specimen CC40 due to the reduction of the water absorption level of alternative materials, and the mortar of these specimens is less diluted than normal mortar. This condition, in turn, lessens concrete density. The density level of modified concrete is lower than normal concrete, although the decrease has been just around 6% as seen in Table 5.

TABLE V
SLUMP AND DENSITY CHANGE

Code	Slump (mm)	Slump change	Fresh density		Hardened density	
			kg/cm^2	Change	kg/cm^2	Change
CC40	65	0%	2344,14	0%	2322,52	0%
GS100	83	28%	2188,52	-6,6%	2161,23	-6,94%
R1	63	-3%	2286.19	-2.50%	2249.33	-3.15%
R2	85	31%	2257.33	-3.70%	2238.65	-3.61%
R3	92	42%	2209.92	-5.70%	2205.49	-5.04%

C. Compressive Strength

Fig. 4 depicts a linear decrease of compressive strength of specimen R1, R2, and R3 in 28 days. The compressive strength of normal and modified concrete shows a different pattern. The compressive strength of specimen CC40 increases from 21.73 MPa in three days to 30.57 MPa in the seventh day, 40.06 MPa in 28 days and 47.98 MPa in 128 days.

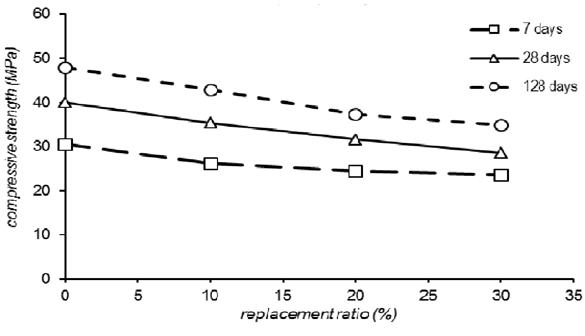


Fig. 4 Compressive Strength of R1, R2, and R3

Specimen R1 shows a lower compressive strength of 26.11 MPa, 35.32 MPa, and 42.80 MPa at the age of 7, 28 and 128 days, while the strength of specimen R2 is 24.38 MPa, 31.64 MPa, 37.36 MPa, and specimen R3 is 23.61 MPa, 28.58 MPa and 34.90 MPa at 7, 28 and 128 days respectively. Specimen GS100 reaches 28.24 MPa in 28 days.

Concrete containing rubber particle experiences a slight decrease in all replacement ratios and all curing ages. The compressive strength of R1 is 11.8% below CC40, whereas that of R2 and R3 are 21% and 28.7% below CC40 in that order. This result differs from the observation of [14, 15] since this study uses finer rubber particle size (0.075 mm) where the decrease level should be insignificant. The total replacement of natural sand by glass sand has resulted in the deterioration of the compressive strength of specimen GS100. At 7 days of curing age, the compressive capacity remains only 50% and stronger in 28 days as illustrated in Fig. 5.

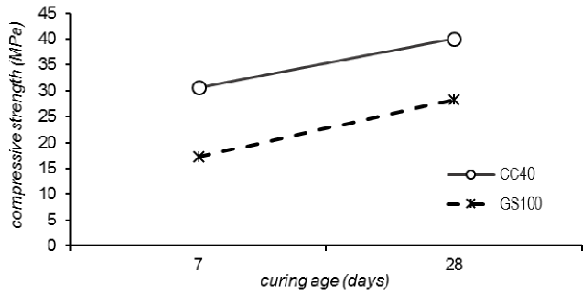


Fig. 5 Compressive strength development of GS100

Concrete compressive strength periodically increases along with the curing time. In 28 days of curing, the compressive strength of CC40 reaches the target strength of 40 MPa while other specimens are below the target. In 128 days, however, the strength of R1 reaches over 40 MPa followed by R2 and R3. Fig. 6 could not show the strength of GS100 in 128 days as the sample was broken during the testing process due to a technical issue.

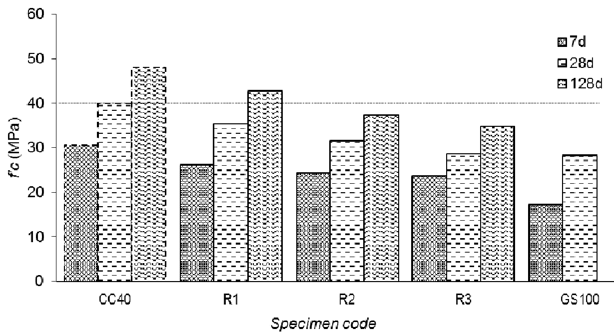
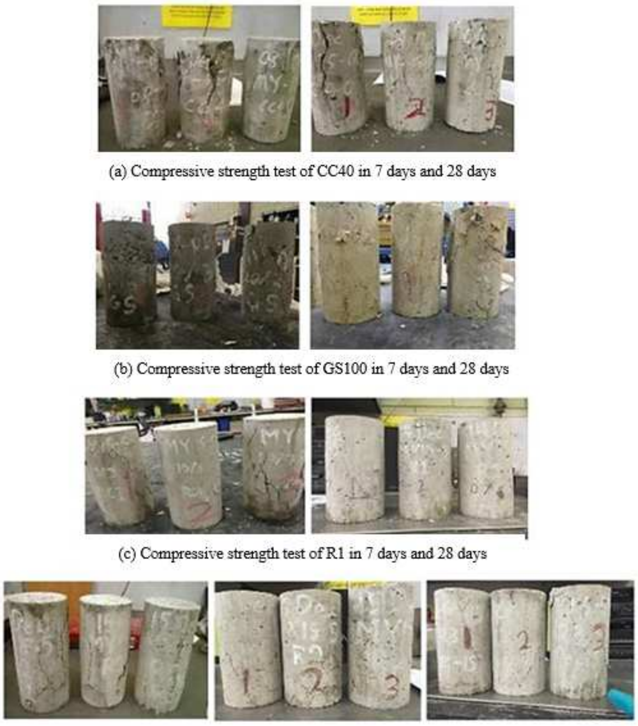


Fig. 6 Compressive strength of modified concrete

Cracks of normal and modified concrete during compressive strength test as seen in Fig. 7 shows a different crack pattern. The control specimens tend to crack along the height of the specimen with the variation of crack lines. Hence, it is clear that the mortar in control specimens yields better bond strength between the cement matrix and aggregate than modified concrete. Besides lower water absorption, specimens containing glass particle induce chemical reactions between cement matrix and glass particle known as an alkali-silica reaction (ASR). In contrast, the adhesive process of concrete with rubber sand requires a longer period as the material has low water absorption capability. Both conditions, therefore, significantly accelerate the segregation mechanism between particles in the concrete core.

D. Tensile Strength

The observed capacity of control concrete against the tensile load is 4.12 MPa. Meanwhile, specimen R1 yields nearly similar tensile strength to CC40 at the level of 4.11 MPa followed by R2 about 3.42 MPa and R3 about 3.22 MPa.



(a) Compressive strength test of CC40 in 7 days and 28 days

(b) Compressive strength test of GS100 in 7 days and 28 days

(c) Compressive strength test of R1 in 7 days and 28 days

(a) Compressive strength test of R2 in 28 days and R3 in 7 days and 28 days

Fig. 7 Crack Pattern in the compressive strength test

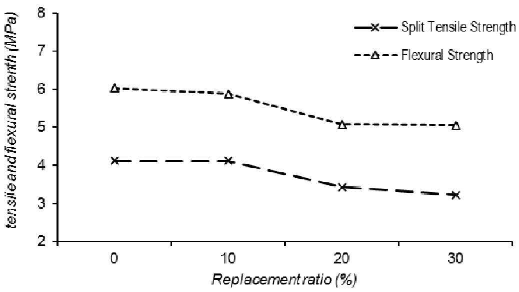


Fig. 8 Tensile Strength of R1, R2, R3 in 28 Days

As illustrated in Fig. 8, the adverse impact of 10% replacement of natural sand with waste tire rubber sand in specimen R1 could be neglected since the tensile strength of this specimen is comparable to the control specimen. Though, the replacement ratio of 20% and 30% notably reduces the tensile strength of specimen R2 and R3 respectively about 0.69 MPa or around 17%. The tensile strength of the specimen GS100 reaches 2.98 MPa or 30% below the original specimen as shown in Fig. 9. and the low tensile strength of all specimens in 28 days as a total portion of natural sand was changed to glass fine. The rough surface of natural sand is distributed evenly along its surface compared to the surface texture of glass fines comprising extreme edges and corners. Therefore, the condition limits the bonding process between particles and cement, which in turn may produce more tensile cracking in the core. In Fig. 10, it is hardly seen a significant difference in crack patterns between CC40 and R1 as both specimens yield comparable tensile strength.

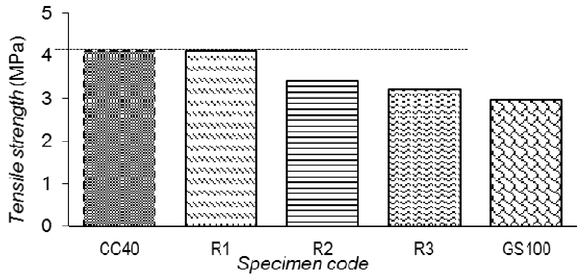


Fig. 9 Tensile strength of modified concrete in 28 days

Fig. 10 Tensile crack patterns of CC40 and R1 in 28 days

E. Flexural Strength

Flexural capacity of rubber concrete shows insignificant differences at the level below the capacity of control concrete. The flexural strength of CC40 is 6.04 MPa, while R1, R2, and R3 are observed about 5.88 MPa, 5.07 MPa, and 5.06 MPa in that order and GS100 is just under 4 MPa. In Fig. 8, the flexural strength of R1 reduces 3% as compared to CC40. The result confirms to the similar study by [20]. Insubstantial change of R1 indicates that the utilization of small amount of waste tire rubber sand possibly balances the flexural strength achieved by normal concrete in 28 days of curing time. For higher replacement ratios of 20% and 30%, the flexural strength pattern remains stable at around 5.07 MPa as illustrated in Fig. 11.

The use of GS as a total replacement of natural sand in specimen GS100 deteriorates the concrete strength against the flexural load. The flexural capacity of the specimen drastically reduces by about 34% as shown in Fig. 11.

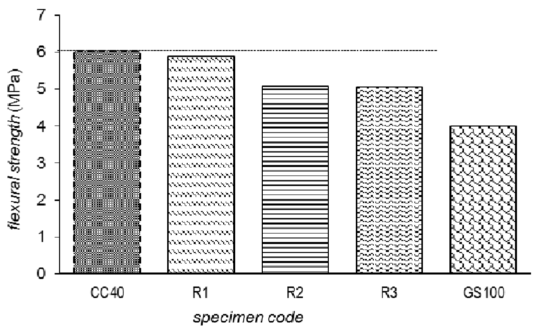


Fig. 11 Flexural strength of modified concrete in 28 days

It is linearly confirmed the research by [8]. The main causes of the extreme change in flexural capacity are due to the slippery surfaces of glass particles, angular shape and low water absorption as a reaction inhibitor between glass particles and cement matrix.

The observation into the crack path of specimens against flexural load shows that cracks in the specimen CC40 form a certain slope relative to the resultant load in the mid-span while the crack in the modified specimen forms a vertical pattern as shown in Fig. 12. The skewing crack pattern on normal concrete indicates that the shear effect has contributed to the concrete cube of CC40 in addition to the flexural load. The bond between the particles in the specimen attempts to resist the pure bending action resulting in shear stress. The flexural-shear combination causes the movement of the crack pattern outwards the resultant loading. In contrast, in nonconventional concrete, the crack pattern is in the perpendicular axis of the horizontal axis of the cube. The absence of shear stress along the cube span is likely due to the tensile stress working in the horizontal direction because of low bond strength between particles. Therefore, cracks occur in the perpendicular direction of the tensile stress.

Fig. 12 Flexural crack patterns in 28 days

F. Water Absorption

Investigations of water absorption are only performed on specimens CC40, R1, R2, and R3. In general, the smaller the rubber particle content in the concrete, the lower the water absorption capacity of the concrete produced. The R1 specimen absorbed only 3.47% water compared to CC40 of 3.61%.

Despite the changes in water absorption of R2 and R3 are very small, the amount of water penetrating the concrete cores of both specimens exceeds the normal concrete (3.68% and 3.71%). The water absorption of GS100 specimens is the highest of all specimens about 3.83%. Fig. 13 shows that the higher the particle content of rubber sand the higher the water absorption of the concrete produced because the process of water absorption is wholly devoted to natural sand and limestone which increases the absorbance rate of both materials.

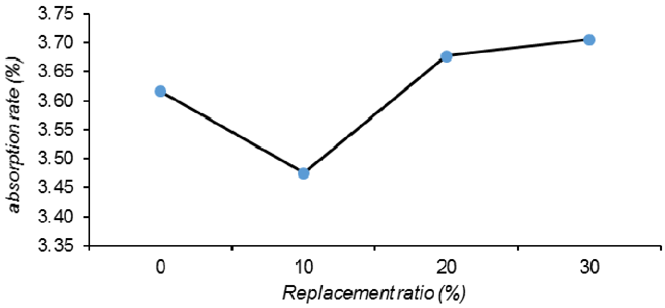


Fig. 13 Absorption rate of R1, R2, and R3

The overall strength and water absorption characteristics of normal and modified concrete are illustrated in the graph with the double ordinate as shown in Fig. 14. Generally, the strength and absorption capacity of the modified concrete that is almost equal to the conventional concrete is achieved by R1 and the worst by GS100.

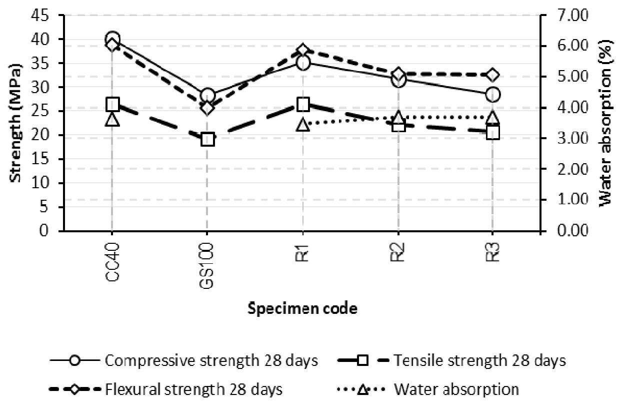


Fig. 14 Strength and water absorption of observed specimens

IV. Conclusions

Utilization of waste materials as an alternative to the concrete composition of this study generally yields lower carrying capacity regarding compressive, tensile and flexural strength than conventional concrete. Strength characteristics of modified concrete have more extreme degradation with the increase in glass and rubber sand content. Replacement of natural sand material with glass sand and rubber particles by smaller replacement ratios yields better compressive, tensile, and flexural capacity compared to replacement with higher replacement ratios. Concrete with minimum rubber particle content can maintain better water absorption rate than conventional concrete. Total substitution of natural sand with alternative materials decreases the adhesiveness of the particles in the mixture, thereby significantly reducing the strength of the concrete.

Further research is required with a replacement ratio of glass particles lower than 10%. The size of glass fines is a substantial factor in determining the strength of the concrete, and hence further research needs to perform a combination of glass particle size in addition to material replacement.

Acknowledgment

Special thanks are extended to laboratory technicians in Concrete Laboratory of the University of Adelaide.

Acknowledgment goes to Potters Australia, Tyrecycle Melbourne, Adelaide Brighton Cement Ltd. for the donation of the materials.

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