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Prediction of density and compressive strength for rubberized concrete blocks

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ABSTRACT

The influence of rubber content within the range of 5–50% as the replacement for sand volume and water/cement (*w/c*) ratio (0.45–0.55) on the density and compressive strength of concrete blocks was investigated. All the mixtures were proportioned with a fixed aggregate/cement ratio of 5.6. A total of 50% of the total aggregate was fine aggregate. Based on the experimental results, the density and strength reduction factors for rubberized concrete blocks were calculated by considering the dependent factors of rubber content and *w/c* ratio. Linear and logarithm equations derived, based on the results from experimental work are proposed to predict the density and compressive strength of rubberized concrete blocks.

1. Introduction

The disposal of waste tyres in landfill poses serious environmental problems, primarily due to this kind of waste not being biodegradable. In the past few decades, numerous studies have been conducted in relation to making good use of this recycled waste, especially as fine aggregate in cement mortar and concrete [1–5]. Khatib and Bayomy [6] found that the use of rubber aggregate had a bad effect on workability. Almost zero slump (not workable manually) of fresh concrete has been detected with increases in rubber aggregate up to 40% as the replacement for total aggregate volume. Khaloo et al. [7] reported that it could be beneficial to apply 25% volume of recycled tyre as the total aggregate replacement in concrete to improve its toughness. However, they suggested that the use of rubber aggregates must not go beyond this limit due to the decline in ultimate compressive strength of concrete. Similar observations were also reported in other studies [8–12].

It is well-known that an optimal water/cement (*w/c*) ratio for any given mix can enhance the performance of concrete properties [13]. Haach et al. [14] observed the influence of *w/c* ratio on the workability and hardened properties of mortars. They noted that there was a 32–40% reduction in compressive strength as *w/c* changes from 0.6 to 0.8. According to Newman and Choo [15], sufficient water in the mix assists in reducing macroscopic entrapped voids, but excessive water increases the microscopic capillary voids. Although decreasing the water content can result in the existence of closely packed cement particles, it may increase the difficulty of expelling air voids due to the associated reduction in lubrication and mobility [16].

The density and compressive strength of the final rubberized concrete products depend mainly on the relative amounts of the two components: rubber aggregate and water [4,17,18]. Some of the desirable characteristics of these products are low density, better sound insulation, and higher impact strength and toughness. These advantages make rubberized concrete products ideal for wider acceptance in civil engineering applications. Therefore, the objective of this study is to establish equations derived from results determined from experimental testing to predict the density and compressive strength of rubberized concrete blocks.

2. Experimental procedure

Materials used in this study consist of ordinary Portland cement complying with ASTM Type I standards. The natural aggregates used were natural river sand as the fine aggregate, having a maximum particle size of 4 mm and fineness modulus of 2.62, and crushed granite with a nominal size of less than 10 mm and fineness modulus of 5.84 as the coarse aggregate. Recycled crumb rubber produced by mechanical shredding, ranging from 1 to 5 mm in size was used as a sand replacement by volume.

All the mixtures were proportioned with a fixed aggregate/cement ratio of 5.6 and the coarse to fine aggregate ratio was kept at 1:2 throughout the whole experiment. Nine different concrete block mixtures were designed to evaluate the effect of rubber content on the density and compressive strength of the concrete blocks. The amounts of rubber to replace the sand volume were 5%, 10%, 15%, 20%, 25%, 30%, 40% and 50%. To compare the results, all nine mixtures were prepared with three different *w/c* ratios of 0.45, 0.50 and 0.55.

All the concrete constituents were mixed for 5 min before being poured in two layers of approximately equal depth into a steel mould with the dimensions of 200 × 100 × 60 mm. After each layer was filled, compactions were applied by dropping a 1.86 kg square hammer (25 × 25 mm) 50 times directly onto the mixture from a height of 10 cm. Finally, to ensure the mixture was well compacted, empty

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Nomenclature

a	a constant value intersect at y-axis of a linear equation (density reduction factor vs. rubber content)	$R_{CS(w/c)}$	strength reduction factor
b	density reduction factor-gaining rate	$R_{d(w/c)}$	density reduction factor
D_c	density of a control concrete block (kg/m^3)	S_c	compressive strength of control concrete block (MPa)
D_r	density of a rubberized concrete block (kg/m^3)	S_r	compressive strength of rubberized concrete block (MPa)
r	rubber content by total sand volume	w/c	water/cement ratio

spaces within the mould, if any, were filled and re-flattened using a trowel. The fabricated rubberized concrete blocks in the steel moulds were left in the laboratory environment at a room temperature of 30 ± 3 °C and relative humility of 65 ± 5% for 1 day. After 1 day, all the specimens were removed from the steel moulds and further kept in the laboratory environment in air until the testing day.

The density of the hardened concrete was determined according to BS 1881 - Part 114. A compressive strength test was performed in conformity with BS 6717 - Part 1 at 7 and 28 days after casting. Three samples were tested for each mix property and all the results reported are the average of the three tested samples.

3. Results and discussion

The hardened density and compressive strength as well as the strength reduction factor of the rubberized concrete blocks as a function of rubber content and w/c ratio are listed in Table 1.

3.1. Hardened density

The hardened density results of the rubberized concrete blocks shown in Table 1 indicate that the air dry density of rubberized concrete blocks decreased as the rubber content increased. The density was reduced by about 8% when 50% of the total sand was replaced by rubber, irrespective of the w/c ratio. This is mainly attributed to the low specific gravity of rubber particles (1.12 g/cm^3) as compared to natural river sand (2.61 g/cm^3) [10]. Siddiquw and Naik [19] mentioned that the non-polar nature of rubber particles may tend to entrap air if their rough surfaces increase, which in turn increases the air content and reduces the density of the concrete mixtures. In terms of w/c ratio, the density of the rubberized concrete blocks increased as the w/c ratio increased, for a given rubber content. This can be explained by the fact that the sufficient free water in the rubberized concrete mixes, which provides a better workability and good compaction, results in less empty spaces between the aggregate particles and the cement paste.

In order to analyze the density of the rubberized concrete blocks, experiments were first performed to correlate the density results obtained from experimental testing with a given rubber content and w/c ratio. The expression for determining the density reduction factor ($R_{d(w/c)}$) is given by Eq. (1) and the calculated values of the density reduction factors are tabulated in Table 1.

$$R_{d(w/c)} = \left(\frac{D_r}{D_c}\right)\left(1 - \frac{w}{c}\right)(r) \tag{1}$$

where D_r = density of a rubberized concrete block (kg/m^3), D_c = density of a control concrete block (kg/m^3), w/c = water–cement ratio, r = rubber content by total sand volume.

Statistical analysis was then carried out to establish a linear relationship between the calculated density reduction factor (Table 1) and the rubber content. A linear equation, Eq. (2), was de-

Table 1
The experimental testing results of density, compressive strength and calculated results of density and strength reduction factors.

w/c	Rubber content (%)	Density (kg/m^3)	R_d	7 day strength (MPa)	$R_{7d\text{-}CS}$	28 days strength (MPa)	$R_{28d\text{-}CS}$
0.45	0	2156	–	24.9	–	30.8	–
	5	2137	0.027	29.0	0.026	30.1	0.022
	10	2114	0.054	22.7	0.041	25.0	0.037
	15	2100	0.080	25.3	0.068	23.3	0.051
	20	2076	0.106	17.6	0.064	20.4	0.060
	25	2057	0.131	20.3	0.091	19.9	0.073
	30	2015	0.154	12.0	0.065	15.8	0.069
	40	1999	0.204	11.1	0.080	10.5	0.061
	50	1991	0.254	8.4	0.076	9.5	0.069
0.50	0	2178	–	28.2	–	32.4	–
	5	2164	0.025	31.4	0.028	35.4	0.027
	10	2143	0.049	29.4	0.052	32.7	0.050
	15	2156	0.074	25.8	0.069	28.2	0.065
	20	2117	0.097	24.1	0.086	26.4	0.082
	25	2119	0.122	22.8	0.101	24.8	0.096
	30	2068	0.142	17.0	0.090	20.2	0.094
	40	2053	0.189	12.8	0.091	15.4	0.095
	50	2014	0.231	10.6	0.094	12.5	0.096
0.55	0	2211	–	37.9	–	42.5	–
	5	2183	0.022	30.4	0.022	35.0	0.023
	10	2165	0.044	30.2	0.044	31.9	0.041
	15	2173	0.066	25.9	0.056	29.5	0.057
	20	2140	0.087	22.0	0.064	26.3	0.068
	25	2132	0.108	22.6	0.082	22.8	0.074
	30	2093	0.128	17.3	0.075	20.1	0.078
	40	2082	0.170	14.5	0.084	16.3	0.084
	50	2025	0.206	10.8	0.078	12.4	0.080