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Investigating the properties of lightweight concrete containing high contents of recycled green building materials

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HIGHLIGHTS

- The addition of recycled green building materials can increase the slump and effectively reduce the unit weight.
- The setting time prolongs the 1.5 times, and the bleeding is increased by 1.4 times.
- The addition of RGBM can reduce the strength of concrete.
- The surface resistance is increases. The maximum value (50% replacement) is 1.8 times that of the control group.

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ABSTRACT

In this study, the cement and aggregate used in lightweight aggregate concrete were replaced with recycled green building materials (e.g., waste LCD glass sand and waste tire rubber particles). The influence of the maximum replacement amount on the fresh mixture (slump, unit weight, setting time, bleeding), hardened (compressive strength and ultrasonic pulse velocity) and durability (quadruple type resistance and length change) was investigated to determine the influence of high contents of recycled aggregate and recycled pozzolanic admixtures on the properties of the concrete. The findings showed that the addition of recycled green building materials maintained good workability of the concrete as the replaced amount increased. The unit weight was reduced by approximately 1.4 times (600 kg/m^3); the setting time and bleeding rate were increased by 1.5 times (73 min and 190 min) and 1.4 times (8%), respectively. The compressive strength, ultrasonic pulse velocity and length change were reduced by 9.8 times (37.18 MPa), 1.4 times (1131 m/s) and 3.7 times (−0.115%), respectively. The resistance was increased by 1.8 times (27.8 kΩ cm). A database will be constructed in the future for related studies to facilitate an increase in waste recycling value and to maximize the environmental protection benefits.

1. Introduction

With the social and technological advances in Taiwan, the production of industrial waste (waste liquid crystal displays and waste scrap tires) is continuously increasing, and environmental considerations of reducing and recycling this waste have emerged. The construction industry is using recycled materials to produce green building materials for environmental protection. This study uses multiple recycled materials at different levels of addition to determine the influence of various recycled materials on lightweight concrete and to establish data for future research.

The ecological and environmental benefits of alternative supplementary materials include (1) the diversion of non-recycled waste from landfills for useful applications; (2) a reduction in the negative effects of producing cement powder, namely the consumption of non-renewable natural resources; (3) the reduction in the use of energy for cement production; and (4) the corresponding reduction of greenhouse gasses [1].

Silt has been a long-standing problem for reservoirs in Taiwan; therefore, silt needs to be recycled to optimize its benefits. The yield of reservoir silt in Taiwan has currently exceeded 9 million cubic meters, and the lost service discharge is 20 million cubic meters. If reservoir silt cannot be used efficiently, then the increasingly severe reservoir silt must be reduced [2]. In recent years, with advancements in the optoelectronics industry and in software and hardware technologies, including the liquid crystal glass industry, the number of products has increased. The throughput of Taiwan's TFT-LCD panels accounts for 25% of the global market. As a result, a large amount of waste materials that are difficult to treat have been produced [3]. Among the types of solid waste, glass has been widely studied as a substitute for coarse and fine aggregates and even for cements [4]. The densities of glass and concrete are 2400 kg/m^3 and 2500 kg/m^3, respectively. The compressive strength of glass is 880–930 MPa, which is greater than that of concrete by 30–80 MPa. The heat transfer coefficient of glass is 3 W/

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mK, and the elastic modulus of waste glass concrete is higher than that of standard concrete (40 GPa); furthermore, the price of waste glass concrete is less than that of standard concrete [5–7]. Glass powder has high silica content and is amorphous, which are the primary requirements for a pozzolanic material. Previous studies have reported hydration and strength development in glass powder-modified cement pastes [8] and the mechanical and durability properties of concrete containing glass powder [9,10]. The use of waste glass particles as fine aggregates would reduce the flowability and density of mortar; however, their use would increase its air content. Except for shrinkage during drying, the mechanical properties were compromised due to micro-cracking within the glass sand and weakened bonds within the cement paste. However, the durability was enhanced, especially in terms of the resistance to chloride ion penetration [11].

An estimated 1 billion tires reach the end of their useful lives every year [12]. At present, considerable quantities of tires are already stockpiled (whole tire) or landfilled (shredded tire), with 3000 million inside the European Union and 1000 million in the US [13]. By the year 2030, the number of tires from motor vehicles is expected to reach 1200 million, representing almost 5000 million tires to be discarded on a regular basis. Tire landfilling represents a serious ecological threat [14]. Recycling end-of-life vehicle tires as alternative aggregates to produce a new class concrete is an innovative option that has environmental, economic and performance benefits. Using shredded and/or crumb rubber particles as a replacement for concrete aggregate has been widely researched [15]. Recycled rubber has been researched and developed [16]. The recycled rubber particles are mixed with asphalt to produce recycled paving material. Previous studies have found that the fatigue abatement, shock absorption, water and slip resistance and durability of the pavement with an asphalt layer are improved. The rubber particles with a mesh size of 5 (screen mesh # 4) are cut out using an advanced water jet cutter to replace fine aggregate in Taiwan [17,18]. However, adding an excessive amount of rubber particles can reduce the workability and compressive strength but increase the extended flexibility of non-primary structures, such as road safety islands and roadblocks, which were unexpected results. The addition of rubber particles contributes to improving the overall hydrophobic and floating properties of cement structures. This improvement can be helpful for rainwater discharge off of a sloping field [10–12].

It is necessary to determine the optimal mixing proportion of fine aggregate replacements with consideration of both environmental factors and mechanical properties. In this study, glass is combined with lightweight aggregates (rubber particles) to produce new green building materials. The mixing proportions are varied, and the samples are exposed to appropriate environmental conditions according to the results of various experiments. Such an approach can reduce environmental pollution by minimizing the amount of concrete needed for an intended application [19–21].

2. Experimental

The ACI 211.2 lightweight concrete mix design specifications were used in determining the mixing proportions. The design strength was set at 210 kgf/cm^2. The cementing material was produced by mixing cement, fly ash and slag at ratio of 7:2:1 by weight. Two types of high recycled content material replacements were used, waste LCD glass sand and waste tire rubber particles. The glass sand was mixed with rubber particles in a 1:1 ratio to be used as the replacement for the fine aggregate (the total amounts replaced are 0% 10%, 20%, 30%, 40%, 50%, 60% and 70%). The properties of the fresh and hardened cement and the durability properties were investigated at curing ages of 1, 7, 28, 56 and 91 days.

2.1. Experimental material

The cement used in this study was Type I Portland cement produced by the Taiwan Cement Corp., conforming to the ASTM C 150 [22] Portland cement specifications. The cement was purchased as-sealed to guarantee quality. The fly ash was Class F fly ash produced by the Taiwan Power Shin-Ta Heat Power Plant. Its properties conformed to the ASTM C 311 [23] specifications. The slag was produced by the China Steel Corp., and it was powdered by the China Hi-Ment Corporation. Its properties conformed to the ASTM C 989 [24] specifications. The raw lightweight aggregate material was produced by dehydration, granulation and sintering of silt from the Taiwan Shi-Men Reservoir. The lightweight aggregates were separated by particle size using sieve analysis as per ASTM C 330 [25], thereby reducing the influence of water absorption. The waste tire rubber particles were waste tire rubber produced by the Taiwan Water Jet Cutter Company, and they were treated by water jet cutting to approximately 5 mesh particles (4 mm). The waste LCD glass sand was obtained by crushing TFC-LCD glass. The physical and chemical properties of the materials are shown in Tables 1 and 2.

Table 1
Physical and chemical property of materials.

Materials	Cement	Fly ash	Slag	LCD glass	Lightweight aggregate
Physical properties					
Specific gravity	3.15	2.20	2.89	2.45	1.35
Chemical contents (%)					
SiO_2	20.22	48.27	35.47	64.28	59.31
Al_2O_3	4.96	38.23	13.71	16.67	19.97
Fe_2O_3	2.83	4.58	0.33	9.41	6.53
CaO	64.51	2.84	41.00	2.70	1.41
MgO	2.33	–	6.60	–	2.02
SO_3	2.46	–	–	–	0.07
K_2O	–	1.16	–	0.20	0.08
Na_2O	–	0.20	–	0.64	0.01
TiO_2	–	1.42	–	0.01	–
P_2O_5	–	–	–	0.01	–
LOI	2.4	5.38	–	–	–

Table 2
Basic properties of aggregate.

Properties	Dmax (mm)	Specific gravity	Unit weight (kg/m^3)	Water absorption (%)	F.M.
Coarse aggregate	9.5	2.57	1507	1.0	–
Fine aggregate	–	2.64	1748	1.3	3.09
Lightweight aggregate	12.5	1.35	901	10.4(24 h)	–
Rubber	4.8	0.98	–	–	–
LCD glass	1.2	2.45	–	–	–

2.2. Experimental mixture

The lightweight aggregate to produce lightweight aggregate concrete, according to the ACI211.2 [26] lightweight aggregate concrete mix proportion. The mix design was based on the design strength of 210 kgf/cm^2. The cement, fly ash and slag were mixed in a ratio of 7:2:1 to produce the cementing material. The fine aggregate was added in proportions of 0%, 10%, 20%, 30%, 40%, 50%, 60% and 70%. The mix proportions by unit weight are shown in Table 3.

2.3. Experimental variables and methods

The lightweight aggregate was soaked in water for 24 h prior to mixing to absorb water sufficiently, to adjust the moisture content and to avoid influencing the mixing result. From each test group, samples were prepared with dimensions of $18 \times 10 \times 20$ cm and $375 \times 75 \times 285$ mm, and these samples were tested on days 1, 7, 28, 56 and 91. The fresh slump was tested as per ASTM C 143 [27]. The unit weight was tested as per ASTM C 567 [28]. The compressive strength was tested as per ASTM C39 [29] and ASTM C 192 [30]. The ultrasonic pulse velocity was tested as per ASTM C597 [31]. The durability was measured using a quadruple-type resistance test as per ASTM C876 [32]. The length change was tested as per ASTM C827 [33].

3. Results and analysis

3.1. Slump

Fig. 1 and Table 4 show that the slump of the fresh lightweight concrete increased with the substitution of recycled green building