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A study of the durability of recycled green building materials in lightweight aggregate concrete

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HIGHLIGHTS

- Recycled lightweight green concrete can be used effectively in recycling of waste resources.
- The slump increased or decreased with the addition of different types of recycled materials.
- The compressive strength was up to 56.1 MPa and it had better sulfate resistance.
- Add recycled materials may improve the durability of lightweight aggregate concrete.

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ABSTRACT

In this study, waste tire powder and waste liquid crystal display (LCD) glass sand are used as recycled materials. With a fixed water to binder ratio (W/B = 0.4), the use of fly ash and slag as cement-replacement materials. waste tire powder and waste LCD glass sand, which passed the sieve screen size # 30(0.595 mm), were used to replace fine aggregates at 0%, 5% and 10% in producing lightweight aggregate concrete. The fresh property test was processed in accordance with ACI concrete mix proportion design. Harden and durability tests were performed at 7, 28, 56 and 91 days. The results showed that the slump increased or decreased with the addition of different types of recycled materials, but still met the design slump of 150–180 mm. Concrete workability and the unit weight decreased after adding rubber powder to concrete. As the replacement rates of waste glass sand and waste rubber powder increase, the compressive strength tends to decrease. At 56 days, the ultrasonic wave velocity of normal concrete was higher than lightweight aggregate concrete; the lightweight aggregate concrete with 10% glass sand provided the highest ultrasonic wave velocity of the lightweight aggregate concretes. Sulfate resistance tests showed that the normal weight aggregate concrete was better than the lightweight aggregate. Mixing two kinds of recycled materials also resulted in better resistance. Studies showed that adding an appropriate amount of recycled materials might improve the durability of lightweight aggregate concrete.

1. Introduction

Reducing energy consumption and carbon emissions has become a global movement. With the shortage of sandstone and labor in Taiwan, there are urgent needs for optimal resource utilization and efficient quality construction in order to maintain economic development.

The major reservoirs in Taiwan are degraded and congested. Reservoir silt continues to build up and coarse/fine aggregates are increasingly scarce. The government has adopted a water resource policy to remove the reservoir silt and increase storage capacity [1,2]. Resource recycling techniques can be used to fully convert "waste" to another "new resource", offering environmental protection. If reservoir silt can be converted into lightweight aggregates for engineering purposes, the water storage function of reservoirs can be restored, and the sand shortages in Taiwan can be alleviated. Converting reservoir silt into lightweight aggregates can efficiently solve the problems associated with the disposition and treatment of reservoir silt.

Lightweight concrete has many favorable engineering properties such as its light weight, high strength, low expansibility, good heat insulation, sound dampening qualities, water and fire resistance, durability, stable volume, ease of use for construction, and low cost [3–6]. Compared with standard aggregates, lightweight aggregates have a lower water absorption and electrical resistance

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as well as better resistance to sulfate attack [7]. At present, lightweight aggregate is made from reservoir sludge in Taiwan, thus solving problems associated with the buildup and disposal of reservoir sludge, preserving the environment, and saving economic resources. The interface structure (i.e., transition zone) between the lightweight aggregate and the grout is dense and homogeneous. The rough surface and absorptive nature of the lightweight aggregate prevents penetration of moisture or cracking. The durability of high strength lightweight aggregate concrete is better than that of normal-weight concrete. An appropriate addition of pozzolanic material can improve the durability of lightweight aggregate concrete [8].

Lightweight aggregates perform well in structures and have many advantages, including high strength, good tensile strain, and a low thermal conductivity coefficient. The material also has sound-dampening and heat-insulation properties arising from voids within the lightweight aggregate [9–11]. Because the weight of the structural seismic body is directly proportional, lightweight aggregates are commonly used in structures to reduce the weight of structures and to reduce the impact of earthquakes on structures [12,13]. Thus, lightweight concrete is preferred in the construction of tall buildings [14], bridges, and external house walls.

In a recent effort to reduce energy consumption and carbon emissions, countries throughout the world have made efforts to study the effect of wastes added to concrete on engineering properties. Such wastes include the fly ash made by the Tai-Power Thermal Power Plant and the water-quenched slag powder made by the China Steel Corp. The results of these studies have shown that the addition of an appropriate amount of industrial waste, such as water-quenched slag powder or fly ash to replace part of the cement or sand in concrete, yields better engineering properties than adding cement alone and is more profitable [15,16].

According to Executive Yuan of the Environmental Protection Administration, in the 2008 bulletin of the Industrial Waste Exchange Information Center, waste tires are a general waste product to be recycled or reused. Its code is R-0302, and 1326 MT is recycled per year [17]. The disposal of waste tires is a critical environmental issue in many countries due to their large size and fixed shape, their large storage volume, and the low propensity for breaking down. The disposal of waste tires in a landfill will shorten the life of the landfill and is not cost effective. Over the long term, waste tires often damage the surface of the leak-proof coating layer of landfills [18].

Among Taiwan's optoelectronic industries, TFT-LCD manufacturing occupies the greatest share of output, and Taiwan's TFT-LCD output is among the highest in the world. Without proper treatment, these LCD products would slowly pollute Taiwan's environment and disrupt its ecology. Because it is difficult to melt waste glass into ash after incineration, its value will be greatly undermined unless it is recycled and reused [19–25]. Some countries have adopted policies to mandate the use of a certain amount of waste tires in construction. In 1991, the United States forced state governments to use a certain amount of waste rubber in asphalt paving, despite the underdeveloped technology. As a result, the requirement was not implemented, but the states remained in compliance due to the terms and conditions of the law. Arizona has used rubber waste tires in road construction with very good results, and they advocate leapfrogging with an open-graded friction layer rather than a densely graded friction layer. Despite the high cost of rubber-containing asphalt, its service life is much longer than that of ordinary asphalt, making it economically efficient [26]. The random disposal of waste tires also allows them to serve as breeding grounds for malaria-bearing mosquitoes and other pests that are harmful to both the environment and to human health. Furthermore, the dioxin in tires can lead to harmful combustion or fires in landfills. All of these factors make waste-tire disposal a significant environmental risk [27,28].

Waste tires can be shattered, and the resulting rubber powder can be added to concrete for asphalt concrete paving [29,30] to enhance road surface elasticity, friction and service life [31]. The excellent expansibility of rubber-containing concrete makes it useful for the seismic protection of structures. The lightweight, sound-dampening, and vibration-absorption properties of rubber concrete enable it to be applied in railway and highway projects [32]. Some recent studies have explored adding rubber powder to concrete to replace fine aggregates. These results showed that, because rubber has a lower unit weight than common normal-weight aggregates, adding rubber powder to concrete decreases concrete slump, workability, compressive strength and splitting tensile strength; these parameters decrease with an increasing replacement amount [33,34]. Because rubber is nonabsorbent, adding rubber powder to concrete decreases waters absorption and the effective impedance of chloride ion penetration. Rubber powder also improves freeze–thaw resistance [35–37]. Eldi and Senouci added broken waste rubber tire to concrete and found that both the compressive strength and tensile strength decreased, while the toughness and flexural capability were significantly enhanced [38].

This study produces lightweight aggregate concrete using four kinds of recycled green building materials, namely, fly ash, slag powder, rubber powder and glass sand. The engineering properties of these materials are then compared with those of normal-weight concrete, and the materials are analyzed with fresh mix, hardened, and durability tests. Then, these results were used to evaluate the applicability of green building materials in concrete and their contribution to improving the environmental sustainability of the construction industry.

2. Experimental programming

2.1. Experimental material and mixture ratio

This study tests general cement made by the Taiwan Cement Corp., which is Type I Portland cement according to ASTM C150. The cement was sealed with impervious plastic to ensure quality. F-class fly ash was acquired from Tai-Power Hsin-Ta Thermal Power Plant and was to CNS 3036 standard. Water-quenched slag powder was produced by China Steel Corp. and was ground into a fine powder by China Hi-Ment Corporation. Waste LCD glass sand was crushed and passed through a No. #4 sieve to obtain a particle size close to that of natural fine aggregates. Table 1 shows the physical and chemical properties, particle-size distribution and chemical analysis of glass sand. Waste tire rubber powder with #30 fineness was obtained from Taiwan Water-jet Technical Co.; its physical and chemical properties are shown in Table 2. Taiwan Shi-men Reservoir silt was dehydrated pelletized and sintered to obtain lightweight aggregate particles. Sieve analysis was conducted as per ASTM C33 to filter off some overly large and small particles and to decrease the influence of particle size on water absorption. The lightweight aggregates were then pre-dipped in water for more than 24 h to reduce the water absorption capacity and to decrease the influence of the water-to-binder ratio. Table 3 shows the basic properties of lightweight aggregates, and Table 4 presents the mixture-ratios. Figure 1. C is concrete, G5 for waste glass substitution 5%, R10 for waste rubber substitution 10%.

2.2. Experimental variables

This study applied recycled green building materials to lightweight aggregate concrete and general normal-weight concrete and studied their differences. Using a constant water-to-binder ratio (W/B = 0.4), we replaced standard sand with recycled green building materials (0%, 5%, 10%), mixed these materials to form lightweight aggregate concrete and general normal-weight concrete. We then studied the fresh-mix properties, hardened properties, durability and microstructure.

2.3. Experimental methods

A slump test was performed on all fresh-mix concrete samples. Engineering properties, such as compressive strength and ultrasonic-pulse velocity were tested at 7, 28, and 56 days. The Fresh concrete slump test was conducted as per CNS 1176; the unit weight test was conducted as per CNS 11151; the compressive