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Comparative study of carbonized peach shell and carbonized apricot shell to improve the performance of lightweight concrete

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HIGHLIGHTS

- The carbonized peach shell and carbonized apricot shell is lightweight and can be used as lightweight aggregate in concrete.
- The mechanical and creep properties of carbonized peach shell concrete and carbonized apricot shell concrete was studied.
- The carbonized peach shell and apricot shell significantly improve the mechanical properties of concrete.
- The carbonized peach shell and apricot shell significantly decrease the creep deformation and creep rate of concrete.

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ABSTRACT

To improve the performance of peach shell concrete (PSC) and apricot shell concrete (ASC), the effect of carbonized peach shell (CPS) and carbonized apricot shell (CAS) instead of peach shell (PS) and apricot shell (AS), respectively, on physical, mechanical and triaxial creep properties of lightweight aggregate concrete (LWAC) was investigated. Results showed that the replacement of raw aggregates (PS and AS) with carbonized aggregates (CPS and CAS) reduced the density, water absorption and open porosity, and increased the efficiency factor, total porosity of LWAC. Moreover, the mechanical properties were significantly enhanced, and the CAS mixture obtained the highest compressive strength, splitting tensile strength, flexural strength and modulus of elasticity, which were 38.8 MPa, 3.54 MPa, 5.49 MPa, and 15.1 GPa, respectively, an increase of 44.2%, 55.3%, 54.6%, and 42.5%, respectively, compared to the AS mixture. Triaxial creep results showed that under coupled water pressure and axial pressure condition, the use of carbonized aggregates instead of raw aggregates significantly decreased creep strain of LWAC and the concentrations of K^+, Ca^{2+}, Na^+, Mg^{2+} and Sr^{2+} in the leaching solution. Therefore, use of CPS and CAS as lightweight aggregate in concrete can significantly improve the performance of LWAC.

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1. Introduction

Concrete is one of the most widely used building materials [1], more than 10 billion tons of concrete are produced each year in the world [2]. Typically, conventional concrete consists of 12% cement and 80% aggregate by weight. For the production of concrete, about 10 billion tons of sand, gravel and crushed rock is consuming every year in the world [3]. More seriously, the exploitation of a large amount of raw materials has severely damaged the surface vegetation and polluted the local environment [4]. For sustainable development of concrete industry, a variety of industrial and agricultural wastes have been used as a substitute for natural aggregate to produce environmentally friendly concrete [5], including miscanthus giganteus, expanded waste glass, oil palm shell, palm oil clinker, wood, mussel shell and coconut shell. The advantage of using these wastes in concrete is to reduce the consumption of natural aggregate and dispose waste [6].

Peach (*Prunuspersica (L.) Batsch.*) and apricot (*Prunusarmeniaca L.*) are widely cultivated in most provinces of China. The output of peach and apricot in China is approximately 13.1 million tons [7] and 3.1 million tons [8], respectively. Most of them are used to produce a variety of deep-processed products, including drinks,

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candied fruit, canned food, etc. Therefore, more than 800 thousand tons of peach shell (PS) and apricot shell (AS) are produced during deep processing, and they are considered as an agricultural solid waste [7].

PS and AS have the same biomass components as other agricultural wastes, such as wood, peanut shell and hazelnut shell etc., and their ingredients are carbohydrates (approximately 46% cellulose and 14% hemicellulose) and 33% lignin, a small amounts of 7% extractives and ash [9]. Atimtay and Kaynak [10] reported the contents of C, O, H, N and S element in the AS were 52.38%, 38.78%, 6.57%, 1.07%, and 0.15% by weight, respectively. The contents of C, H, N, O and S in the PS were very similar to those of AS, which were 51.95%, 5.76%, 0.79%, 40.7% and <0.01%, respectively [11].

At present, recycling methods of PS and AS waste are mainly used as raw materials for soil amendment, biomass fuel and activated carbon. Hosseinabady et al. [12] reported the use of AS as a soil amendment to adsorb heavy metals from contaminated soil. Arvelakis et al. [11] reported that PS could be used as gasification feedstock due to its low ash content and high heating value. Kaynak et al. [12] reported the combustion characteristics of PS and AS with coal, and suggested PS and AS could be used as a potential source of energy. Dilek et al.[13] reported the use of PS to produce activated carbon by single step steam activation at 800 ◦C. Sabermahani et al. [14] reported the low-cost activated carbon made from AS and modified with rhodamine B could be used to remove toxic thallium (I).

Considering the huge demand for concrete, some scholars have tried to produce lightweight aggregate concrete (LWAC) by using PS and AS as aggregates. Yildiz et al. [15] investigated the normal weight aggregate was replaced with 40% AS by volume, the density and compressive strength of apricot shell concrete (ASC) were kg/m^3 and 14.92 MPa, respectively. Wu et al. [16] reported the effect of different fiber and content on peach shell concrete (PSC). However, although PS and AS can be used as lightweight aggregate for the production of concrete, its physical, mechanical and durability properties are inferior to the other lightweight aggregate (expanded clay, expanded shale and pumice, etc.). Similar to other bio-based aggregates (wood, coconut shell and oil palm shell etc.), the presence of organic matter in PS and AS leads to a weak bond between the aggregate and the mortar interface, which is a major factor affects the physical and mechanical properties of concrete [15,16]. In particular, decay characteristics of such biomass waste in long-term humid environments are an important limiting factor for the application of the concrete in actual building structures. Therefore, in order to eliminate or reduce the organic matter content of raw aggregates (PS and AS) and improve their resistance to decay, they should be treated before using.

For bio-based aggregates, the most common pretreatment method currently used is to soak it with a chemical solution or heat treatment. Kupaei et al. [17] studied the effect of pretreatment oil palm shell by using different alkali solution on concrete. Yew et al. [18] reported that heat-treated oil palm shell at 60 °C for 0.5 h improved the physical and mechanical properties of concrete. However, chemical solutions may be leached out from the aggregate during the rainy season, and be carried by rainwater into the river and soil, and eventually causes environmental pollution [19]. Kim et al. [20] reported the minimum temperature for the decomposition of cellulose crystals was greater than 300 °C. Therefore, although the low-temperature pretreatment may temporarily improve physical properties of the bio-based aggregates, it cannot decompose the organic matter.

Carbonization is an inexpensive and reliable pyrolysis technology that causes thermal decomposition and cracking of organic matter (cellulose, hemicellulose and lignin) [21]. Meanwhile, it also can significantly reduce the swelling-shrinkage and improve the dimensional stability, biological resistance and surface quality of wood [22]. The reasons why carbonization can increase dimensional stability and rot resistance are as follows: Firstly, the carbonization can pyrolysis the hydroxyl groups, resulting in a decrease in water absorption of bio-based materials, and subsequently a reduction of internal stress [23]. In addition, carbonization can also degrade the hydrophilic hydroxyl groups of bio-based materials, increase the hydrophobic groups, and thus the dimensional stability of bio-based materials is significantly improved. Moreover, carbonization at high temperatures significantly reduces microbial nutrients in the bio-based materials, which eliminates microbial population and the conditions for fungal growth, and eventually achieves the performance of resistance to biodegradability [24]. Therefore, the pretreatment of PS and AS by carbonization may be an effective method to improve the performance of peach shell concrete (PSC) and apricot shell concrete (ASC).

Generally, the carbonization process of wood runs in three steps [25,26]: 1) Preheating and drying of wood (<200 °C), its main purpose is to evaporate the moisture in the wood biomass; 2) Precarbonization (200–280 °C.), it is an endothermic process, which mainly focused on the devolatilization of volatile; 3) Carbonization (300–500 °C), it concerns the final combustion of biomass and the emission of exhaust gases (CO, CO_2, H_2 and CH_4 etc.). For the production of artificial aggregates (expanded clay), it usually needs to be sintered at a temperature of 1000–1250 °C [27], and it consumes 80–100 kg of coal to produce per cubic meter of expanded clay [28]. However, the temperature required for carbonization is much lower than that of artificial aggregate, so carbonization is relatively energy-saving due to its lower carbonization temperature and less greenhouse gas emissions [29]. Ding et al. [30] reported the generated pyrolysis gas (tar vapor, CH_4, H_2 and CO etc.) from low-temperature carbonization (200–220 °C) could provide an energy sources for high-temperature carbonization (400–500 °C) by self-heating. Pereira et al. [31] investigated the emissions can be mitigated by incineration of the gas, and the energy generated by the incineration of the gas can also be used in the drying of the raw materials to be carbonized. Benavente et al. [32] reported that carbonization technology could reach energy saving more than 50% by using hydrothermal carbonization instead of dry thermal treatments. Therefore, the energy consumption of the carbonization process can be reduced by some new equipment and new methods [33], which can be a sustainable and energy-saving method for the pretreatment of the organic aggregate.

In this study, the effect of carbonized aggregates (CPS and CAS) used as lightweight aggregate to replace raw aggregates (PS and AS) on physical, mechanical and triaxial creep properties of lightweight aggregate concrete (LWAC) was investigated. PS and AS were replaced by the same volume of CPS and CAS, respectively, and the other parameters were kept constant. The properties of the investigation include physical properties (density, efficiency factor, water absorption and porosity), mechanical properties (compressive strength, splitting tensile strength, flexural strength and modulus of elasticity) and triaxial creep characteristics under the combination of water pressure and axial pressure condition.

2. Materials and methods

2.1. Materials

2.1.1. Cement

Type I 42.5 grade Ordinary Portland Cement was used as the binder and obtained from a local cement company. The physical and chemical properties of the cement are shown in Table 1.

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