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Investigation of using hybrid recycled powder from demolished concrete solids and clay bricks as a pozzolanic supplement for cement

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HIGHLIGHTS

- The pozzolanic property of hybrid recycled powder is systematically studied.
- The unique microstructure morphology of hybrid recycled powder is captured.
- Quantitative chemical analysis is carried out for hybrid recycled powder.
- Hybrid recycled powder changes the microstructure characteristics of cement paste.
- Hybrid recycled powder shows potential of being used as a supplement for cement.

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ABSTRACT

During recycling construction and demolition wastes containing both concrete solids and clay bricks, a large amount of hybrid fine powder is generated. Finding a "green" way to dispose this hybrid recycled powder not only promotes sustainable construction, but also benefits the current effort to reduce the human-produced aerosol, which triggers air pollution. To investigate the use of hybrid recycled powder as a supplementary cementing material, the pozzolanic property of hybrid powder is comprehensively studied here by utilizing advanced tools including SEM, AFM, LPS and XRD. Recycled powder of different concrete–clay brick ratios is first studied with a focus on its fineness, loss on ignition, strength activity index and water requirement. Then, the microstructure characteristics and chemical composition of the hybrid recycled powder, obtained directly from a dust collection system, are qualitatively and quantitatively probed. To develop a deeper understanding of the activity mechanism of hybrid powder, nano-scale characterization is employed to scan and analyze the microstructure of cement paste supplemented with hybrid recycled powder. It is found that the activity mechanism of hybrid powder is strongly correlated with its unique microstructure morphology and chemical composition. The results show that if the proportion of clay brick as well as the replacement percentage is well designed, hybrid powder from dust collection systems has potentials of being used as a cement supplement for concrete.

1. Introduction

The construction and demolition wastes (C&D wastes) generally consist of materials used in civil construction, which typically include concrete, clay brick, mortar, wood, plastic and steel. As more and more civil structures are approaching the end of their expected lifespan, finding economical and environment-friendly strategies to manage the disposal of C&D wastes is an essential aspect of the current progress towards a sustainable built environment.

A promising practice to meet this goal is to utilize C&D wastes to generate recycled materials and then use them again to produce "green" construction materials. After metals and organic materials are removed, C&D wastes can be crushed into recycled aggregates, which are then reused in construction based on their mechanical and chemical properties. This practice, which significantly reduces the environmental and economic footprints of civil structures, has been widely adopted around the world and many international and national specifications and standards [1–5] are developed to guide and improve its implementations in practice.

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During the recycling process, a large amount of dust, as a byproduct, is generated. The dust obtained from collection systems is usually called recycled micro-powder and how to reuse it is a challenge attracting increasing interests in recent years. Similar to many other countries, a significant portion of C&D wastes is sintered clay brick in China, especially for those collected in towns and villages. Due to the financial burden resulting from the high demands for labor and time, there are usually no screening procedures implemented to separate concrete solids and clay bricks from C&D wastes in the current recycling practice. Consequently, the recycled powder obtained in collection systems is a hybrid of concrete and clay brick. A recent report shows that the percentage of clay brick can be up to more than 50% in C&D wastes collected in Chinese cities [6,7]. This unique composition of C&D wastes leads to more dust obtained in collection systems, because sintered clay brick has lower strength compared to concrete and thus is easier to be pulverized during recycling [8,9].

This hybrid recycled powder of a large number of fine particles, if not correctly collected and disposed, can spread and suspend in air to increase the level of human-produced aerosol, which triggers air pollution causing respiratory system diseases and other disorders, e.g., asthmas and lung cancer. In many developing countries, the particulate-induced air pollution imposes a severe threat to public health, which is exemplified by the increasing air quality warnings issued in Chinese cities. Therefore, finding a "green" way to dispose the waste dust generated in the recycling of C&D wastes is of great importance for reducing the fine particulates suspended in air, and thus contributes to both public health and environmental sustainability.

An environment-friendly way is to reuse it like fly ash to produce "green" construction materials. It is widely reported that sintered clay brick, after comminuted, can be used as a pozzolanic supplement like fly ash because of the rich pozzolanic ingredients in its mineral composition [10,11]. Thus, it can be added to concrete to replace part of cement, as well as to suppress the expansion induced by the possible alkali–silica reaction [12]. In a recent research [13], different types of clay bricks from different European countries were collected and then ground into powder to replace the cement. Chemical tests for pozzolanic activity confirmed that all the brick types investigated displayed good pozzolanic activity and this conclusion was further supported by strength development data based on the mortar bars [14].

It is found if the proportion of the recycled clay brick powder in the concrete mix is well designed, the concrete strength is not significantly compromised. In an investigation by Kartini et al. [15], recycled clay brick powder is used to replace part of cement in concrete samples. The test results show corresponding to 10%, 20% and 30% replacement, the average strength of samples, when compared with the benchmark samples containing no recycled clay brick powder, is 4.4%, 8.4% and 14.9% lower, respectively. In another investigation, it is reported that no significant effect is found on the water demand and the setting time even the replacement is up to 25% [16].

The effect of recycled clay brick powder is also investigated in mortar. It is documented that when it replaces 10% of cement, the values of compressive and flexural strength at 90 days are similar to the companion samples, whose mix does not include any supplements [17]. Besides proportion, the grain size of brick powder shows a significant impact on the mortar strength. A recent test on mortar samples containing recycled clay brick powder graded by 4 different grain sizes, namely, 0.04, 0.06, 0.1 and 0.3 mm, shows that the grain size of 0.06 mm gives the highest strength among all the samples tested [18].

Similar to recycled clay brick powder, recycled concrete powder can also be used as a supplement in concrete because of its pozzolanic property. Both Chen et al. [19] and Sun et al. [20] studied the recycled micro-powder collected from the dust collection systems used for recycling demolished concrete solids. In their studies, the recycled micro-powder collected is mainly fine particles of hardened cement paste, mixed with a very small portion of stone powder from aggregate. By comparing the strength of samples containing recycled concrete powder with those containing none, they found that the recycled concrete powder showed about 70% pozzolanic activity.

The pozzolanic properties exhibited in both recycled clay brick powder and recycled concrete powder imply that it is possible to use the hybrid recycled powder obtained from dust collection systems as a cement supplement. Motivated by this, research to explore the use of the recycled powder from a hybrid of demolished concrete and clay brick attracts increasing interests. However, despite the progress has been made, information of the activity mechanisms of hybrid recycled powder and their correlation with concrete macro- and micro-properties is limited and further systematic study is much needed. To respond to this need, the objective of this study is to comprehensively investigate hybrid powder with a focus on microstructure characteristics and chemical compositions. A general study on hybrid powder of different concrete–clay brick ratios is first carried out to investigate the correlations of clay brick content with the properties of hybrid powder. Then, mortar samples supplemented with hybrid powder from a dust collection system are examined. The result found in this study provides qualitative and quantitative information to deepen the understanding of the activity mechanisms of hybrid recycled powder, and thus aids the current efforts to develop guidelines for its "green application" in practice.

2. Properties of hybrid powder of different concrete–clay brick ratios

As demonstrated by the measured bulk density of coarse solids (Table 1), clay brick is weaker than concrete because of its more porous meso-structure. This leads to lower strength for aggregates recycled from clay bricks. However, after ground into powder, clay brick shows an apparent density similar to concrete (Table 1). This implies the disadvantage related to the higher porosity in meso-structure is suppressed after clay brick is ground. Furthermore, after grinding, clay brick powder may show more active pozzolanic property because of the increase in surface area.

However, the similarity in porosity does not mean recycled clay brick powder is same as recycled concrete powder when used as a pozzolanic supplement to replace cement. This is due to their difference in mechanical property and mineral composition. To systematically characterize the properties of their mix, powder containing different weight proportions of concrete and clay brick is examined here. In addition to pure clay brick powder and pure concrete powder, hybrid powder with the percentage of clay brick increasing by a 10% interval is mixed. Thus, total 11 concrete–clay brick ratios are used for mixing the hybrid powder. Here the powder is collected by using a vacuum equipped with a proper sieve when the clay bricks and concrete solids are being ground in a lab ball mill.

Table 1
Density of recycled clay brick, recycled concrete and natural aggregate.

	Clay brick	Concrete	Natural aggregate
Bulk density (kg/m^3) of coarse solid	1920	2270	2610
Apparent density (kg/m^3) of fine powder	2521	2594	2645