



Rapid-hardening controlled low strength materials made of recycled fine aggregate from construction and demolition waste

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HIGHLIGHTS

- Recycled fine aggregate, from urban red brick based C&D waste, is used in CLSM.
- The effect of accelerator on the rapid-hardening properties of CLSM is investigated.
- Evaluate the workability and the mechanical properties of CLSM.
- The strength of CLSM is predicted by using three mix-designed parameters.

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ABSTRACT

Rapid-hardening controlled low strength material (CLSM) containing recycled fine aggregate from construction and demolition (C&D) waste was prepared with the sprayed concrete accelerator. Eleven mixtures were made with different accelerator-to-binder (A/B), water-to-solid (W/S) and binder-to-recycled fine aggregate (B/R) ratios. The workability (flowability and bleeding rate) of fresh mixture and the mechanical properties (early strength, long-term strength and dynamic elastic modulus) of hardened material were tested. The results show that adding (20 ~ 50%) accelerator reduces the bleeding rate of CLSM by 48.8 ~ 84.6%, with no significant effect on the flowability. Improved flowability of CLSM can be achieved by increasing the W/S or B/R ratio, with increased or reduced bleeding rate, respectively. The optimal A/B ratio for best early strength development is 40%, with the early hour strength (2 ~ 4 h) up to 0.41 ~ 0.79 MPa. When A/B ratio is held constant, the early strength of CLSM is affected by the amount of cementitious materials and the actual content of free water. An accurate predictive model for the long-term strength of CLSM was established through regression analysis, in which three control parameters are considered. A power function relationship between the compressive strength and the dynamic elastic modulus is also established. Dynamic elastic modulus can thus serve as an indicator for evaluation of the mechanical properties of CLSM.

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1. Introduction

Construction and demolition (C&D) waste is generated in the process of construction and demolition of buildings and other infrastructures. It mainly contains waste concrete, waste mortar, waste brick and construction broke bits, etc. Up to 40 million tons of it was produced annually in the Beijing municipal area alone for the past decade, with a stockpile hitting more than 300 million tons due to lack of proper treatment [1]. Meanwhile, new construc-

tion projects consume massive natural resources. Researchers have used C&D waste to make recycled asphalt mixtures, recycled concrete, cement stabilized macadam, as well as paving stone, curb and concrete pipes [2–7], etc. While most high quality aggregate in C&D waste are being recycled in multiple ways at present, the fine materials with particle size below 5 mm, which are estimated to account for 20 ~ 50% of the total C&D waste, are only occasionally used for recycled brick or block, as reported in a few literature [8–10]. The percentage of fine aggregate recycled with these methods is insignificant.

As defined by American Concrete Institute (ACI) committee 229, controlled low strength material (CLSM), also known as flowable fill, flowable mortar, soil-cement slurry, etc., is a kind of self-compacting and self-leveling cement-based material with

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adjustable strength that could replace the conventional compacted fill [11]. CLSM has a specified strength of 8.3 MPa or less at the curing age of 28 days; but it usually does not exceed 2.1 MPa in practical application for the ease of future excavation [12]. CLSM is widely used in transportation infrastructure, such as pipe trench, abutment back, retaining wall and road subgrade for its easy preparation and casting, as well as small settlement [12,13]. The typical components of the CLSM are cement, fly ash, fine aggregate and water, in which fly ash is the mineral mixture used to improve flowability and to reduce bleeding [14]. Large amounts of alternative materials such as clay, quarry dust, dewatered sludge, waste glass, on site surplus soil, industrial waste incineration bottom and rubber particles can all be utilized in CLSM as fine aggregate [12–18]. For material cost reduction, some scholars considered the slag, cement kiln dust, rice husk ash, stainless steel reducing slag and other active powder for cement substitute in the production of CLSM [13,16,18,19]. In addition, water reducing agent, air entraining agent, foam particles and other additives can also be added in to improve the workability of fresh CLSM [20–23]. At present, however, few studies on the preparation of rapid hardening CLSM containing recycled fine aggregate from C&D waste are available for its large scale application.

In this paper, the use of recycled fine aggregate of C&D waste in CLSM is investigated for potential applications in C&D waste treatment and new building materials for rapid backfill engineering with environmental, economic and social implications.

2. Objectives and research significance

The objectives of this research are:

- (1) to explore the feasibility of using recycled fine aggregate from C&D waste to produce CLSM;
- (2) to explore the micro structure and macro properties of C&D waste and the characteristics of CLSM;
- (3) to investigate the influence of sprayed concrete accelerator on the early strength of CLSM;
- (4) to evaluate the workability of fresh mixture and the mechanical properties of hardened material;
- (5) to predict CLSM strength by using mix-designed parameters.

3. Experimental program

3.1. Materials

Recycled fine aggregate from C&D waste was obtained from a construction waste disposal plant in Beijing, China (Fig. 1). The most prominent feature of C&D waste from Beijing is the large amount of red brick, as compared with those from other areas such as Hong Kong, the United States and Turkey [5,24,25]. It also contains much mortar and concrete, as well as a small amount of wood, rubber, plastic and other organic ingredients.

As shown in Fig. 2, the particle-size distribution of recycled fine aggregate used for this study does not comply with GB/T 25176-2010 [26] and ASTM C33/C33M-13 [27] in that the finer powders are too much in the former. This is, however, advantageous in the case of CLSM as it improves the workability of fresh CLSM [20]. For a better understanding of the micro performances of recycled fine aggregate, X-ray Diffraction (XRD) and Scanning Electron Microscope (SEM) analysis were executed. The dried recycled fine aggregates were sieved, and the XRD analysis was conducted on the powder with the particle size less than 0.075 mm. The samples of 3 g powder were laid down on the glass sheet and gently pressed to form a sample plane of 10 mm × 10 mm. The XRD-7000 X-ray diffractometer (made by the Shimadzu Corporation, Japan) was



Fig. 1. Recycled fine aggregate from construction and demolition waste.

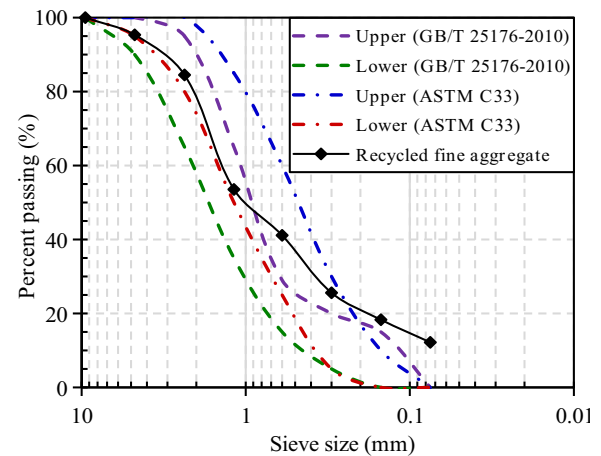


Fig. 2. Sieve analysis of recycled fine aggregate from construction and demolition waste.

used in this study. The mortar and brick particles with the particle size of 4.75 mm were subjected to the SEM analysis, in which the mortar and brick particles were cleaned and dried by ultrasonic wave and then fixed on the sample table with conductive adhesive. The JEOL JMS 6500F field emission scanning electron microscope made by Japan Electronics Co., Ltd. was used. In Fig. 3, XRD result of recycled fine aggregate shows that it mainly contains Quartz (SiO_2), Calcite (CaCO_3) and Anorthite sodian ($(\text{Ca,Na})(\text{Al,Si})_2\text{Si}_2\text{O}_8$). SEM images of red brick and mortar with high content of recycled fine aggregate from C&D waste are shown in Fig. 4. The rough surface and many pores of the red brick and mortar particles are related to the low density and high water absorption of C&D waste.

Ordinary Portland cement (P.O, strength grade 42.5) was sourced from Yanxin Building Materials Co., Ltd. in Hebei Province, China, with physical properties in line with the technical requirements of GB 175-2007 [28]. The accelerator for sprayed concrete, which is based on sulphoaluminate cement clinker and can be regarded as a kind of rapid hardening cement, was produced by Tangshan Polar Bear Building Materials Co., Ltd. in Hebei Province, China, with specific surface area 550 m^2/kg . X-ray fluorescence (XRF) spectroscopy is a non-destructive analysis used commonly

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