Construction and Building Materials 84 (2015) 444–453

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Properties of self-compacting lightweight concrete containing recycled plastic particles

Shutong Yang [a,b,*], Xiaoqiang Yue [a], Xiaosong Liu [c], Yao Tong [a]

[a] Department of Civil Engineering in College of Engineering, Ocean University of China, Qingdao 266100, PR China
[b] Collaborative Innovation Center of Engineering Construction and Safety in Blue Economic Zone, Qingdao 266033, PR China
[c] Qingdao Shundafeng Industry and Trade Co., Ltd., Qingdao 266000, PR China

## HIGHLIGHTS

- Recycled plastic particles are used in self-compacting lightweight concrete (SCLC).
- Workability of SCLC is improved by replacing sand by plastic particles.
- Strength of SCLC is increased by replacing sand by plastic particles.
- Denser plastic-paste interfacial zone is got with relatively low plastic content.

## ARTICLE INFO

*Article history:*
Received 15 December 2014
Received in revised form 16 February 2015
Accepted 4 March 2015
Available online 28 March 2015

*Keywords:*
Recycled plastic
Self-compacting lightweight concrete
Workability
Mechanical properties
Plastic-paste interface

## ABSTRACT

This work is aimed to study the effect of incorporating recycled modified polypropylene (PP) plastic particles on the workability and mechanical behavior of self-compacting lightweight concrete (SCLC). Four replacement levels (10%, 15%, 20% and 30%) of sand by plastic by volume were introduced. The slump flow value is improved with an increase in the sand substitution. The viscosity of fresh SCLC is reduced and the passing ability is improved with the replacement level up to 15%. Both the dry bulk density and elastic modulus of SCLC decrease with an increase in sand replacement. The compressive strength, splitting tensile strength and flexural tensile strength are increased with the replacement level up to 15%. A microscopic study on the plastic-paste interface was performed.



## 1. Introduction

As one of the greatest inventions in 20th century, plastic has brought huge benefit in human life. Numerous plastic products are being consumed with the development of society. However, large amounts of plastic waste give much pressure on the environment due to the very low biodegradability of plastic. It is necessary to develop a rational approach for the waste disposal indicating both the economy and environmental protection.

Recycling plastic waste in cementitious materials is one of the best ways. The kinds of recycled plastic often include polyethylene terephthalate (PET), polypropylene (PP), polyethylene, melamine, polyvinyl chloride (PVC), polyurethane foam, polycarbonate (PC), glass fiber reinforced plastic (GFRP), etc. PET plastic waste can be used to produce unsaturated polyester resin for polymer concrete or mortar [1–8] which has better performance than the concrete or mortar made of Portland cement. The use of recycled PET in resin can reduce the cost of polymer concrete or mortar, alleviate an environmental problem and save energy [1,2]. Although the polymer concrete may experience a loss in strength at high temperature, it is still stronger than Portland cement concrete [3]. Jo et al. [5] concluded that the polymer concrete is more durable. Rebeiz et al. studied flexural properties [9,10] and shear behavior [11] of steel reinforced polymer concrete made with recycled plastic waste to ensure the structural use in practice. Moreover, the recycled plastic can be used to produce fibers to improve the ductility of concrete. The tensile strength and flexural tensile strength of the fiber-reinforced concrete based on plastic waste are increased [12–14], and the permeability and shrinkage are reduced [13,15].

Another economic and effective way of disposal is grinding plastic waste into small particles to replace fine or coarse aggregates in concrete mixing. As the content of aggregate replacement

* Corresponding author at: College of Engineering in Ocean University of China, 238 Songling Road in Qingdao, PR China. Tel.: +86 532 66781548; fax: +86 532 66781550.

*E-mail address:* shutongyang2013@163.com (S. Yang).

http://dx.doi.org/10.1016/j.conbuildmat.2015.03.038
0950-0618/

**Table 1**
The physical properties of cement.

| $SO_3$ (%) | MgO (%) | Loss in ignition (%) | Chloride ion content (%) | Alkali content (%) | Initial setting time (min) | Final setting time (min) | 3-Day compressive strength (MPa) | 28-Day compressive strength (MPa) |
|---|---|---|---|---|---|---|---|---|
| 2.01 | 1.80 | 2.15 | 0.019 | 0.56 | 185 | 295 | ⩾10 | ⩾32.5 |

increases, the density and elastic modulus of concrete or mortar are apparently reduced [16–23]. As for the mechanical properties, the compressive strength, splitting tensile strength and flexural tensile strength decrease with an increase in plastic content [16–26] mainly due to the mismatch properties between plastic particles and cement paste [19]. For plastic with non-absorption properties, internal bleeding water would accumulate and surround the plastic particles resulting in a relatively weak bond between the particles and cement paste [22]. Moreover, elongated or flaky particles can provide a bridging action in concrete subjected to bending and then the toughness behavior is improved [17,21,23,27]. The workability of fresh concrete also depends on the shape of plastic particles. If the particles have sharp edges, the slump value is reduced [26,28]. The fluidity becomes better with the introduction of particles which have spherical edges [26]. The durability is found to be much related to the kind of plastic. The resistance of chloride ion penetrability is improved for concrete containing PVC particles due to the impervious properties of PVC [19]. However, the chloride diffusivity coefficient of the concrete containing pre-wetted polyurethane aggregate is apparently higher than that of the conventional concrete [29].

It is observed that previous studies are mainly aimed at the properties of plastic waste as aggregate substitution in ordinary concrete. The work related to self-compacting concrete or mortar containing plastic particles is relatively few. Safi et al. [30] introduced waste PET particles as sand substitution in self-compacting mortar mixing. They stated that the slump value is significantly improved by incorporating the plastic particles but the compressive strength is apparently reduced with an increase in plastic content [30]. No literature is found about the effect of plastic waste on properties of self-compacting concrete. Moreover, self-compacting lightweight concrete (SCLC) has been gradually applied in practical engineering particularly in large-span bridge structures due to the light self-weight, ease of construction, lower on-site noise level, etc. Coarse aggregates used in SCLC often include expanded shale [31], expanded clay ceramsite [32], pumice [33], expanded polystyrene [34], etc. All the coarse aggregates are so light that they may float in the cement paste. High fluidity is demanded for SCLC, and hence the plasticity and viscosity of fresh paste should be reduced. Then the possibility of segregation is increased. It is crucial to design a rational mix proportion on SCLC. Shi and Wu [31] first provided a design procedure by combing the least void volume for a binary aggregate mixture, excessive paste theory, and ACI standard practice for selecting proportions for structural lightweight concrete. Glass powders and fly ash are added to increase the flowability and segregation resistance of the SCLC [31]. Workability is very important for SCLC [35]. Slump flow test and *V*-funnel test are usually performed to determine the fluidity of SCLC, and *L*-box test and *J*-ring test can be used to evaluate the ability of passing through steel bars [31–40]. Moreover, sieve segregation and settlement column tests are conducted to evaluate the segregation resistance of SCLC [36]. The binder content should be larger than that in ordinary concrete. An increase in binder content can improve the filling and passing abilities of SCLC [37].

Incorporation of plastic particles in SCLC as aggregate replacement can further reduce the material density. Therefore, the influence of plastic particles on the workability and mechanical properties of SCLC deserves to be studied. The intention of this paper is to study the effect of plastic particles as sand substitution in concrete mixing on the flowability, passing ability, uniformity of lightweight coarse aggregate distribution and mechanical properties of SCLC. Different from previous studies, the kind of plastic particles in this paper is modified polypropylene (PP) which is from waste industrial plastic floor boards or waste car bumpers. The mechanical performance of modified PP is improved and it may be beneficial to the strength of concrete containing this kind of plastic particles.

## 2. Experimental program

### 2.1. Materials used

Cement used in the experiment is No. 32.5 composite Portland cement (Chinese standard GB 175 [41]). The physical properties of cement are seen in Table 1. Ultra-fine fly ash was used to improve the flowability of SCLC with the physical properties in Table 2. Fine aggregates were river sands with fineness module of 2.75 and bulk density of 1360 kg/m$^3$. Expanded clay ceramsite was used as coarse aggregate as shown in Fig. 1. The bulk density of the coarse aggregate is 399 kg/m$^3$ and the water absorption is 16.2%. The particle size distributions of both sand and expanded clay ceramsite are shown in Fig. 2. Admixture was Sica 3301 polycarboxylate-based high-range water reducer (HRWR).

Plastic particles in the test are modified PP plastic which is recycled and provided by Qingdao Shundafeng Industry and Trade Co., Ltd. The recycled modified PP plastic was ground into small particles and rinsed. Then they were treated to

**Table 2**
The physical properties of fly ash.

| $SO_3$ (%) | Loss in ignition (%) | Percentage retained on 45 μm sieve (%) | Water requirement (%) | Water content (%) |
|---|---|---|---|---|
| 1.2 | 4.2 | 9 | 73 | 0.3 |

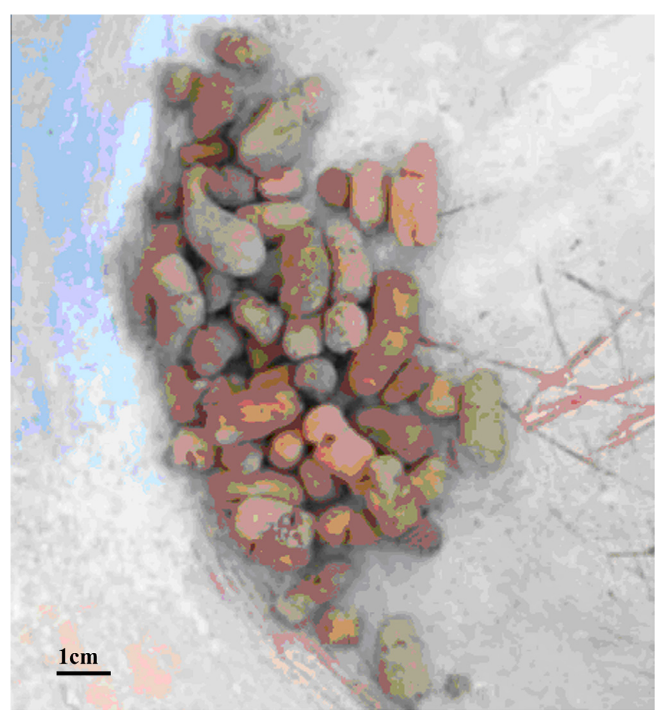


**Fig. 1.** Expanded clay ceramsite.