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Properties of recycled PVC aggregate concrete under different curing conditions

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HIGHLIGHTS

- Lower mechanical properties were achieved by the incorporation of RPVC aggregate.
- Curing condition significantly affected the properties of both normal and RPVC concrete.
- RPVC aggregate in concrete made it more sensitive to continuous air curing.
- Initial water curing of 7 and 14 days reduced the strength of concrete up to 9.8% and 7.3%, respectively.
- PVC concrete under different curing conditions classified as “good” concrete quality.

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ABSTRACT

This paper presents the properties of concrete prepared by replacing 20%, 30%, 40% and 50% of natural sand with recycled PVC (RPVC) aggregate under different curing conditions. Six different curing regimes were applied including continuous water curing, continuous open air curing, continuous laboratory curing and in the remaining three regimes, concrete specimens were exposed to initial water curing periods of 3, 7 and 14 days. The effects of each curing techniques on the compressive strength, splitting tensile strength, elastic modulus, initial and final absorption were determined.

Results showed that irrespective of the curing condition, RPVC incorporation generally reduces the mechanical properties of concrete measured in terms of compressive strength, splitting tensile strength and modulus of elasticity. However, curing condition affects the strength of both normal and RPVC aggregate concrete, the RPVC aggregate concrete is more sensitive to air storage curing. Moreover, CEB-FIP model code is found to provide an adequate prediction of splitting tensile strength of RPVC aggregate concrete at different curing conditions. A low absorption can be achieved for RPVC aggregate concrete exposed to different curing conditions classified as “good” concrete quality. In general, continuous water curing is the most suitable curing condition for concrete; however, initial water curing for 14 and 7 days decrease the strength of RPVC concrete only up to 7.3% and 9.8%, respectively.

1. Introduction

Excellent versatility, availability, satisfactory compressive strength and durability are the main features which caused concrete to be known as the most widely used construction material in the world. Concrete is gained acceptance for use in a variety of applications including bridges, high-rise buildings, highways, dams and others. It has been expected that the demand for concrete is grow to approximately 18 billion tons a year by 2050 [1]. Nonetheless, concrete cannot be considered as an environmentally-friendly material [2]. Approximately, three-quarters of the volume of concrete is occupied by aggregate [3] which is usually derived by the depletion of the natural resources. This consumes a large amount of natural resources which can restrict the invaluable role of concrete in promoting society’s development. Hence, the need for using alternative materials is becoming absolutely essential. Scientific research proved that recycled aggregate (RA), resulting from construction and demolition (C&D) activities could be successfully employed in the production of concrete [4–7]. Producing RA concrete not only could reserve the natural resources but also prevent the environmental pollution. C&D waste aggregates are composed of various types of materials such as brick, tiles, metal,

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concrete, and glass. Polyvinyl chloride (PVC) waste is also expected to be derived from C&D activities.

PVC is one of the most used thermoplastic materials [8]. It has been estimated that the worldwide consumption of PVC is at 39.3 million tons in 2013 [9]. Global demand for PVC is expected to rise by about 3.2% per year until 2021 [9]. Due to the rapid growth of the PVC products, the disposal of PVC waste has been a major concern in the public discussions. In this respect, the utilization of waste PVC in the concrete production can be pointed out as an innovative option with environmental [4,10] and economic benefits. In this respect, Kou et al. [4] studied properties of lightweight concrete prepared with PVC granules. Recently, Senhadji et al. [10] evaluated the effect of PVC waste aggregate usage on the physical, mechanical, and chloride ion penetration of concrete. Since the properties of concrete under field condition can differ significantly from that in the standard moist condition; a detailed investigation needs to be conducted to understand the characteristics of recycled PVC (RPVC) concrete exposed to different curing conditions before its usage in the jobsite. This research was designed to assess the influence of recycled PVC aggregate on the properties of concrete under different curing conditions.

Curing is defined as a treatment intended to keep satisfactory moisture content and temperature in concrete during the period of time [11]. The importance of curing condition on the properties of concrete cannot be oversold. Proper curing is necessary for concrete to resolve problems associated with undesirable environmental actions. It is well documented that curing techniques and curing duration have significant effect on the strength and durability of concrete [11–15]. Gayarre et al. [12] found that the 28-days compressive strength of concrete with RAs was similar to that of natural aggregate concrete for standard curing environment, while the compressive strength of RAs concrete lost up to the 20% when cured under open-air condition. Incorporating 25–35% of fly ash and applying steam curing were reported by Kou et al. [13] as one of the practical ways to utilize a higher percentage of RAs in structural concrete. Buyle-Bodin and Hadjieva-Zaharieva [14] showed initial absorption, air permeability and carbonation depth of RA concrete cured in water is lower than to that achieved for air storage curing condition. Ferreira et al. [15] employed plastic waste aggregates resulted from shredding used waste PET bottles to investigate the influence of different curing conditions on the properties of waste aggregates concrete. The results showed that in most mixes, the highest modulus of elasticity was achieved for wet chamber curing followed by outdoor environment curing and finally laboratory conditions curing. A study by Fonseca et al. [16] revealed that the mechanical performance of recycled aggregate concrete is affected by curing conditions roughly in the same way as conventional concrete.

To the author's knowledge, the research concerning the characteristics of concrete with RPVC under different curing conditions is not considered. This has been subjected as the main objective of this study. For this purpose, six different curing regimes were applied to the concrete mixes incorporating 0%, 20%, 30%, 40%, 50% RPVC as replacement of natural sand. Curing regimes includes fully water curing, curing at room temperature, outdoor environment curing and initial water-curing for the first 3, 7, and 14 days in the remaining three regimes. The properties of concrete were evaluated by slump, compressive strength, splitting tensile strength, modulus of elasticity, initial and final absorptions.

2. Experimental plan

2.1. Materials

Type I ordinary Portland cement complying with the requirement of ASTM C 150 was used in the production of concrete specimens. The chemical composition of cement is given in Table 1. The natural aggregate consisted of river sand with fineness modulus of 2.83 and crushed gravel with maximum size of 12.5 mm and water absorption of 0.95%. In order to achieve a required size of RPVC aggregate as shown in Fig. 1, scraped PVC pipes were ground into small pieces with particle size of less than 5 mm. The aggregate grading details are presented in Table 2 and Fig. 2.

Table 1
Chemical composition of Portland cement type I.

	Cement
Chemical composition (%)	
SiO_2	21.46
Al_2O_3	5.55
Fe_2O_3	3.46
CaO	63.95
MgO	1.86
SO_3	1.42
K_2O	0.54
Na_2O	0.26

2.2. Mixture proportion

Five concrete mixtures containing RPVC aggregates were designed and produced at a constant water/cement ratio of 0.4 and cement content of 400 kg/m^3. The reference concrete which made with natural aggregate is denoted as RC. The coarse and fine aggregate contents in this mix were 1040 and 800 kg/m^3, respectively. In the other concrete mixtures called RPVC20, RPVC30, RPVC40 and RPVC50, RPVC aggregates was used as a replacement of sand at four replacement levels of 20%, 30%, 40% and 50%, respectively. This range of RPVC aggregate replacement has been selected on the historical data and preliminarily studies.

2.3. Curing conditions

After the completion of initial fresh concrete test, the fresh concrete was poured into the moulds. Specimens were de-moulded one day after casting and were immediately exposed to the following six curing conditions:

1. Continuous water curing (CWC): Specimens were immersed in 21 ± 1 °C water until the testing age.
2. Continuous room curing (CRC): Specimens were kept in a room with a controlled temperature and relative humidity until the testing age. The average temperature and relative humidity were 21 °C and 59%, respectively.
3. Outdoor environment curing (OEC): Specimens were cured at uncontrolled temperature and relative humidity in outdoor environment without any protection until the testing age.
4. Initial water cuing-3 (IWC3): Specimens were initially immersed in 21 ± 1 °C water for 3 days and after that kept in room condition until the testing age.
5. Initial water cuing-7 (IWC7): Specimens were initially immersed in 21 ± 1 °C water for first week after casting followed by exposure to the room curing till the date of testing.
6. Initial water cuing-14 (IWC14): Specimens were initially immersed in 21 ± 1 °C water for two weeks. Then, they were moved to the room curing condition until the testing age.

The details of each curing condition were illustrated in Table 3.

2.4. Test procedure

A slump test was conducted according to the ASTM C143 standards before the concrete was cast in moulds. Three 100 mm cube