Construction and Building Materials 157 (2017) 917–929

Contents lists available at ScienceDirect

Construction and Building Materials

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

Fresh and hardened properties of polymer incorporated self compacting concrete mixes for neutron radiation shielding

Santhosh M. Malkapur [a,*], L. Divakar [a], Mattur C. Narasimhan [b], Narayana B. Karkera [b], P. Goverdhan [c], V. Sathian [d], N.K. Prasad [e]

[a] Department of Civil Engineering, Ramaiah University of Applied Sciences, Bengaluru, 560094, India
[b] Department of Civil Engineering, NITK Surathkal, Mangalore, Karnataka 575025, India
[c] RPD. Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
[d] RSSD. Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
[e] MDPDD. Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India

HIGHLIGHTS

- Hydrogen content is critical in shielding neutron radiation.
- Pulverised high density polyethylene (HDPE) used as source of hydrogen to develop new concrete mixes.
- The HDPE material was incorporated as a partial replacement to river sand.
- These mixes are called **Polymer-Incorporated Self-Compacting Concrete (PISCC) mixes**.
- The PISCC mixes have satisfactory fresh and hardened properties and enhanced neutron radiation shielding properties.

ARTICLE INFO

Article history:
Received 29 October 2016
Received in revised form 8 August 2017
Accepted 21 September 2017

Keywords:
PISCC mixes
Polymeric material
Segregation resistance
Neutron radiation shielding

ABSTRACT

Several works in the past have reported that the hydrogen content in the hydrated concrete plays an important role in shielding the neutron radiation; higher the hydrogen content, better is the neutron radiation shielding. In this study, pulverised high density polyethylene (HDPE) material is used as an additional source of hydrogen within concrete to develop a novel class of **Polymer-Incorporated Self-Compacting Concrete (PISCC) mixes** for enhanced neutron radiation shielding. The HDPE material was incorporated as a partial replacement to river sand. It is found that the PISCC mixes have satisfactory fresh and hardened properties and enhanced neutron radiation shielding properties.

1. Introduction

Concrete is a good shielding material to both gamma and neutron radiations, as it can be designed to accommodate both the light and heavy nuclei within it [1]. The gamma radiation shielding can be provided for by means of high density ingredient materials [2,3]. Unlike a gamma radiation shield, an efficient neutron shield requires a balanced mixture of ingredient materials containing both light and heavy nuclei [4]. One major chemical constituent which can effectively contribute to neutron radiation shielding properties of a shielding material is the hydrogen content in it [5,6]. Hydrogen with a single nucleon, $_1H^1$, is the best candidate for neutron shielding since it can efficiently thermalize (slow down) the fast neutrons through elastic scattering. The resulting thermal neutrons with lower energies, have much greater affinity of absorption.

Several attempts have been made in the past to study the shielding properties of concrete mixes containing different rich-sources of hydrogen incorporated within them. They include liquid polymer (liquid form) based concretes such as polymer concrete mixes and polymer cement concrete mixes [5,7,8]. The polymer impregnation of Ordinary Portland Concrete mixes [9,10] has also been attempted.

Generally, the total aggregate content in the concrete mixes measures to about 60–75% by volume. Hence, in order to have more amounts of hydrogen within them, hydrogen-rich aggregates such as Serpentine ($(Mg, Fe)_3Si_2O_5(OH)_4$), Colemanite ($2CaO{\cdot}3B_2O_3{\cdot}5H_2O$), and Limonite ($FeO(OH){\cdot}nH_2O$) have been used as par-

* Corresponding author.
E-mail address: sm.malkapur@gmail.com (S.M. Malkapur).

https://doi.org/10.1016/j.conbuildmat.2017.09.127
0950-0618/

tial/full replacement to fine or/and coarse aggregate in the concrete mixes. These minerals contain good amount of water of crystallization in them and trigger the hydrogen contents in the concrete mixes produced using them [5,11].

All such works have reported shielding performances improved to different degrees, mainly attributed to the increased hydrogen contents in such mixes as compared to the ordinary conventional concrete mixes. However, most of the natural hydrogenous aggregate materials, as mentioned above, are not available locally at all the places. Again, the concrete mixes with epoxy or liquid polymeric materials are costlier and often involve special techniques for casting and hence production of such concrete mixes at large scales on site becomes difficult. Hence, in this work attempts are made to use pulverized polymeric material as an alternate source of hydrogen within the concrete mixes for enhancing their neutron shielding capabilities.

The use of solid plastic/polymeric materials in concrete mixes is not new and several works evaluating the properties of such concretes mixes with different percentages of polymer content, used as a partial replacement to either fine or coarse aggregates have been reported. The focus of these investigations was, in general, the evaluation of effect of incorporation of polymeric contents on the fresh and hardened properties of such concrete mixes. While the mixes have been developed with either enhanced or reduced workability characteristics, depending on the volume of replacement, type of polymer, form of polymers etc., [12–16], the results have indicated, in general, overall reduction in strength performance characteristics of these mixes. The reduction in compressive strength of concrete specimens varied from 5 to 72% for a change in replacement level of 10–50% (by vol.). Reductions are also reported in flexural strengths and split tensile strengths, varying between 0–45% and 0–60% respectively for a replacement level of varying between 0 and 50%. Moduli of elasticity were found to decrease up to 60% of the value for control concrete [13,16–21].

However, not many studies have been reported so far with the intent of use of polymers as a source of hydrogen to enhance the neutron radiation shielding performances of concrete mixes. The present work aims to load the concrete mixes with additional amounts of hydrogen, taken in the form of solid polymeric powder material used as a partial replacement to sand, and to evaluate the fresh and hardened properties of such concrete mixes.

2. Materials and methodology

2.1. Materials

Ordinary Portland Cement (OPC) conforming to the requirements for 43 grade OPC as per IS: 8112 [22] has been used for all the mixes in this investigation. The fly ash used was procured from M/s Raichur Thermal Power Station, Shakthinagar, Karnataka, India and it conforms to the specifications as laid out for silicious fly ash of IS: 3812 [23] (equivalent to Class F fly ash, ASTM: C618-2012a). Locally available crushed granite chips of 12.5 mm and down size, conforming to the requirements of IS: 383 [24], were used as coarse aggregates.

In the present study, natural river sand conforming to zone II of IS: 383 [24] and virgin HDPE polymeric powder (pulverized to the size of the sand) together were used as fine aggregate. Of the various grades and forms commercially available, High Density Poly Ethylene (HDPE) of blow mould grade, procured from M/s Indian Oil Corporation Limited (IOCL), Mumbai, available in the form of pellets, was used herein. This selection was based on the higher hydrogen content in this polymeric material (Hydrogen content of 14.5% by mass of polymer, as obtained from a standard CHNS test) and higher strength attainment of mortar cube specimens prepared using the same. The HDPE polymeric material was initially pulverized to the size of sand particles, using a roto-molding machine at a local plastic industry. The various ingredients used in the investigation are shown in Fig. 1. The Scanning Electron Microscope (SEM) images of pulverized polymeric particles are also presented in Fig. 2. Table 1 presents the physical properties of all the aggregates.

A poly-carboxylate ether based super-plasticizer, Glenium Ace 30, BASF-make. conforming to the requirements of IS: 9103 [25], was used in the study. It had a pH value of 6.5, a specific gravity of 1.07 at 20 °C and a solid content of 42%. Its chloride ion content was found to be less than 0.2%. A commercially available Viscosity Modifying Agent (VMA) (Auramix V200, Fosroc), compatible with the superplasticizer was also used in the development of the concrete mixes herein. It is an opaque liquid having specific gravity of 1.01 at 20 °C and is chloride free.

2.2. Blending of different fine aggregates

The particle size distributions of sand and polymeric material are presented in Fig. 3(a) and they conform to the zone II and III of IS: 383 [24] respectively. In this work, different blends of sand and polymeric material were used for producing different concrete mixes. The results of the sieve analysis for sand – polymer blends at three typical partial replacements at 30, 40 and 50% by volume of sand are shown in Fig. 3(b). These three blends conform to Zone II, III and III of IS: 383 [23] respectively.

2.3. Mix design and design of experiments

The polymeric material, taken in the form of powder, is lighter than water and other ingredients in the concrete mix, and tends to float on the surface of the concrete mass on compaction by vibration. Hence, proportioning these mixes as conventional concrete mixes, where external compaction effort has to be applied, leads to segregation of polymers. This necessitates proportioning of the polymer incorporated concrete mixes based on self-compacting concrete technology, where full compaction is achieved without the aid of any external vibration. It was observed from the initial trials that the higher binder contents are very essential to ensure SCC-like flowability with no segregation of incorporated polymeric particles and also to compensate for the decreased strength characteristics in PISCC mixes. Under the circumstances, use of any of the standard mix design methodologies used for proportioning the SCC mixes, as available in the literature, could not be employed for designing of PISCC mixes.

Therefore, the PISCC mixes herein are proportioned as per the general guidelines of IS: 10262 [26]. Each of the fine and coarse aggregate volumes are taken to be 50% of the total aggregate volume. This higher volume of fine aggregates is taken so as to increase the amount of polymer content and in turn hydrogen content in the mixes. A higher total binder content of 600–660 kg/m^3 has been used for proportioning the PISCC mixes. Cement along with 35% fly ash (by total weight of binder) was used as a binder in all the PISCC mixes. Even with higher binder contents, lower water/binder ratios are required to achieve desired strength levels, which necessitated use of a super-plasticizer, which again at higher dosages, say above 0.8%, often leads to bleeding characteristics in PISCC mixes. Hence, it was decided to use lower dosages of a high range super-plasticizer.

2.4. Static segregation test on PISCC mixes

The basic concern that arises while proportioning PISCC mixes with higher amounts of polymers, as a partial replacement to river