Construction and Building Materials 186 (2018) 114–122

Contents lists available at ScienceDirect

Construction and Building Materials

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

Utilization of alkali-activated slag based composite in deepwater oil well cementing

Du Jiapei, Bu Yuhuan *, Cao Xuechao, Shen Zhonghou, Sun Baojiang

College of Petroleum Engineering, China University of Petroleum, 66 Changjiang West Road, Qingdao, China

HIGHLIGHTS

- SCA enhances early term compressive strength of AAS based composites.
- The dosage of resin affects the reaction degree.
- SCA can generate a thin membrane on the surface of slag particles.
- Resin and SCA influence the microstructure of reaction products of slag.

ARTICLE INFO

Article history:
Received 5 April 2018
Received in revised form 10 July 2018
Accepted 11 July 2018

Keywords:
Slag
Epoxy resin
Well cementing
Low temperature
Compressive strength
Setting time

ABSTRACT

The compressive strength and setting time of alkali-activated slag (AAS) based composites under deepwater condition of curing is investigated. Test results show that the AAS based composites obtain high early term strength and proper setting property for practical operations. Resin weakened the compressive strength decreasing phenomenon while the doping of coupling agent significantly enhanced the early term compressive strength of AAS based composites. The excessive resin could cover the surface of slag particles and affect both reaction rate and reaction degree of slags. The setting time of AAS based composites extended effectively after the addition of silane coupling agent. The silane coupling agent generated a thin membrane on the surface of slag particles and reduced the reaction rate of AAS. The X-ray diffraction, scanning electron microscopy and energy dispersive X-ray spectroscopy analysis show that resin and coupling agent cannot affect the chemical properties of alkali-activated slag, but they influence the microstructure of reaction products of slag. Low dosage of resin (5%) provided a well bond and uncracked structure of the matrix. When the AAS incorporated high dosage of resin, large aggregates formed. The connection between these aggregates and AAS is very weak. The coupling agent can act as a compatibilizing agent to enhance the connection among different phases.

1. Introduction

Portland cement is the most widely utilized cementitious material for sealing the annular between the formations and casing strings. It provides zonal isolation which ensures that groundwater and freshwater aquifers are effectively isolated. Additionally, when the life of the oil wells end and there is no intention to re-enter, permanent abandonment action should be taken by plugging part of the well or the whole well with Portland cement. In regard to the abandonment and plug operations, plugging materials are preferable to satisfy the typically regulatory requirements, such as long-term sealing integrity, low permeability, resistance to corrosive chemicals, high bonding strength to steel and ability to withstand mechanical loads [1].

In most conditions to cementing a well, Portland cement meets the important criteria of an effective isolation as it durability and low permeability. Nevertheless, in the case of deepwater ocean areas, the slow development of compressive strength at low temperature is the most critical challenge. Normally, the temperature of deepwater seafloor is less than 4 °C. Due to the heat transfer among seawater, riser and the inversion of thermal gradient, the temperature in surface cementing is about 15 °C [2]. Low temperature slows down the hydration rate of cement and leads to long setting time. Thus, the strength of cement sheath is insufficient to support the casing strings in a short period. This phenomenon

* Corresponding author at: College of Petroleum Engineering for Oil Well Cement Research and Testing, Economic and Technological Development Zone, Changjiang West Road 66, 266580 Qingdao, China.

E-mail address: buyuhuan@163.com (B. Yuhuan).

https://doi.org/10.1016/j.conbuildmat.2018.07.068
0950-0618/

persuades the oil and gas industry to invent strength accelerators [3–6] or look for alternative materials [7–9]. The strength accelerators are typically uneconomic which increase the well construction cost. In the case of low international oil price, an economic alternative material with good early-term strength is required.

Among various alternative materials of Portland cement, alkali-activated slag (AAS) cement is an economic material produced by utilizing an alkali-activated cementitious material rather than pozzolanic cementitious materials [10,11]. AAS has many advantages such as low carbon emissions, corrosion resistance, especially high early-term strength. Therefore, cementing materials made by AAS have been commonly used in civil engineering applications to take the place of ordinary Portland cement [12,13].

The properties of AAS have been widely investigated. Long et al. [14] studied the dynamic mechanical properties of AAS concrete under temperature-loads coupling condition. They found that the standard cured AAS achieved higher compressive strength than the natural cured samples when concrete heated from −45 °C to 250 °C. Sanjayan and Collins [15,16] investigated the mechanical properties of AAS and indicated that AAS showed higher compressive strength than Portland cement when prepared in similar mixing dosage. Bakharev et al. [17,18] investigated the acid resistance and carbonation resistance of AAS. They indicated that AAS presented higher acid resistance but lower carbonation resistance than Portland cement. However, in the field of oil well cementing, slags are usually used as a partial replacement of oil well cement to enhance the mechanical properties [19–21]. The AAS based materials are barely utilized in oil well cementing due to AAS showed lower durability in terms of compressive strength than Portland cement [22–24].

Investigations have presented that AAS goes through drying shrinkage, which can lead to loss of durability. The drying shrinkage of AAS was evaluated to be up to six times higher than Portland cement [25,26]. Several varieties of admixtures, such as glass fibers, carbon fibers and organic resins, are mixed with alkali-activated materials to achieve better durability and mechanical properties [27]. Among these admixtures, epoxy resin reinforced alkali-activated material show a good and homogeneous dispersion [28,29]. Zhang et al. [30] mixed different dosage of resin with AAS/metakaolin based composites. The long-term compressive strength was improved significantly by doping resin. However, reference [8] indicated that low dosage of resin cannot form effective connection with inorganic phases at low temperatures. Thus, to form a firm and sound bonding with AAS, it is necessary to create an inorganic-organic covalent bond. Silane coupling agents (SCA) are additives which can promote the interface bonding from electrostatic adsorption and mechanical bonding to covalent bond [31]. Otherwise, the alcohols produced by SCA will act as retarder to adjust the setting time of AAS based composites [32].

In this paper, the utilization and performance of AAS based composites in oil well operations have been considered under low temperature of curing. The novel recommended method is based on the blending of epoxy resin to an AAS suspension. By using this new method, the resin reinforced AAS composites have been prepared and characterized by compressive strength, reaction degree, setting time, XRD (X-ray diffraction), SEM (scanning electron microscopy) and EDS (energy dispersive X-ray spectroscopy) analysis. In order to prolong setting time and improve the connection between the resin and AAS matrix, SCA was used. In presence of SCA, the setting time and early-term strength of AAS based composited could satisfy the demand for deepwater oil well sealing.

2. Experimental procedures

2.1. Materials

The superfine GGBS (ground-granulated blast furnace slag) was supplied by Jiaozuo Yukun Mining Corporation, China. About 99% of the GGBS particles are finer than 10 μm. The particle size distribution is shown in Table 1. The chemical composition and physical properties of GGBS is shown in Table 2. The NaOH with 99% purity and KH560 saline coupling agent was supplied by Sinopharm Chemical Reagent Co., Ltd. Epoxy resin (ER) and curing agent (CA) was supplied by Shanghai coating corporation, China. Normally, without curing agent, epoxy resin cannot solidify. Therefore, curing agent was used to cure epoxy resin. The chemical structure and molar mass of epoxy resin and curing agent are shown in Fig. 1. API Class G cement (ACG) was utilized for compressive strength behavior comparison between AAS-based composites and Class G cement. The Class G cement obtained from Jiahua cement corporation, China.

2.2. Specimen preparation

In order to make an alkali-activated binder with high mechanical properties, the preparation procedure should be taken seriously. Firstly, the activator was prepared by mixing water and NaOH powder for 60 s. After that, the solution was cooled to experimental temperatures (7 °C, 10 °C and 15 °C), due to the dissolution of NaOH releases a large amount of heat which affects the alkali activation. The strong alkalinity of NaOH solution reduces the setting time which influences pumpability of the composite slurry. Therefore, a NaOH dosage of 6% by weight of GGBS was selected. The weight ratio of NaOH and GGBS was kept constant in all of the formulas. The mix design parameters and their designation are shown in Table 3. Then, GGBS was added to the NaOH solution and mixed for 1 min. Normally, consistency is utilized to evaluate the pumpability of slurry in oil well cementing [33]. When the initial consistency is less than 30 Bc, the oil fields consider the slurry can be used. Due to the high specific surface area of GGBS, the liquid/solid ratio less than 0.8 makes the consistency higher than 30 Bc. Thus, the water/GGBS ratio of 0.8 by weight was used in this investigation to guarantee the slurry can pump into the downhole successfully. The water/cement ratio of 0.44 by weight was

Table 1
Particle size distribution of GGBS.

Particle size distribution/μm	<3	3–5	5–8	8–10	>10
GGBS	44.61	40.66	13.66	0.88	0.19

Table 2
Chemical composition and physical properties of GGBS.

Oxides	GGBS (Wt%)
CaO	36.57
SiO_2	28.30
Fe_2O_3	0.83
Al_2O_3	13.16
SO_3	1.65
MgO	7.58
Na_2O	0.49
K_2O	0.50
Loss on ignition	9.65
Density (g/cm^3)	3.01
Specific surface area (m^2/kg)	420.00