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Hydrophobic Lightweight Cement with Thermal Shock Resistance and Thermal Insulating Properties for Energy-Storage Geothermal Well Systems

Toshifumi Sugama and Tatiana Pyatina *

Brookhaven National Laboratory, Upton, NY 11973-5000, USA; sugama@bnl.gov
* Correspondence: tpyatina@bnl.gov

Abstract: This study assessed the possibility of using polymethylhydrosiloxane (PMHS)-treated fly ash cenospheres (FCS) for formulating a thermally insulating and thermal shock (TS)-resistant cementitious blend with calcium aluminate cement. To prevent FCS degradation in an alkaline cement environment at high temperatures, the cenospheres were pre-treated with sodium metasilicate to form silanol and aluminol groups on their surface. These groups participated in a dehydrogenation reaction with the functional ≡Si–H groups within PMHS with the formation of siloxane oxygen-linked M-FCS (M: Al or Si). At high hydrothermal temperatures of 175 and 250 °C, some Si–O–Si and $SiCH_3$ bonds ruptured, causing depolymerization of the polymer at the FCS surface and hydroxylation of the raptured sites with the formation of silanol groups. Repolymerization through self-condensation between the silanol groups followed, resulting in the transformation of siloxane to low crosslinked silicon-like polymer as a repolymerization-induced product (RIP) without carbon. The RIP provided adequate protection of FCS from pozzolanic reactions (PR), which was confirmed by the decline in zeolites as the products of PR of FCS. Cements with PMHS-treated FCS withstood both hydrothermal and thermal temperature of 250 °C in TS tests, and they also showed improved compressive strength, toughness, and water repellency as well as decreased thermal conductivity. The lubricating properties of PMHS increased the fluidity of lightweight slurries.

Keywords: lightweight cement; thermally insulating cement; energy storage wells; geothermal cement; thermal-shock-resistant cement; hydrophobic cement

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1. Introduction

The use of generating or storage geothermal systems for stabilizing the electric grid, increasing its flexibility, and providing energy on demand presents a possibility of flexible and renewable energy generation and storage. The geothermal environments of storage reservoirs can range from rock and sand formations to hot confined aquifers over the bedrock heated by magma. For a robust long-term performance, the geothermal reservoir must be able to withstand repeated thermal stresses during the injection and production of heated fluids. Since the most economical heat-recovery systems require high-temperature carrier fluids, the thermal shocks may be significant. For example, in case of hybrid solar–geothermal energy production and storage, the steam temperature may exceed 300 °C. Cement is used for well construction as a sheath between metallic pipes (will be referred to as "casing" in the paper) and underground formation zones to provide zonal isolation, prevent casing corrosion, and support the well structure. Cement sheath failure to fulfill any of its tasks may result in catastrophic events where the well would be abandoned, and a new well would have to be constructed. Although generally, it is difficult to attribute the failure of a well to a single factor, cement failure was concluded to cause the failure in several geothermal fields [1,2]. Oil field well integrity solutions cannot be easily adopted for geothermal wells because of the high operating temperatures, aggressive environments, and repeated thermal shock (TS) conditions.