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Waste Recycled Glass Powder as a Pozzolanic Additive for Cementing Oil Well

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Abstract

Fly ash is often used as a filler material during oil well cementing applications because it easily sets with hydraulic cement. However, the use of fly ash is constrained because of the limited supply of suitable quality ash. Therefore, finding suitable alternatives for fly ash that are cost effective and plentifully available with consistent quality can be beneficial.

This paper discusses three different types of finely ground waste glass powder used as a pozzolanic alternative. Pozzolan participates in a cementitious reaction with calcium hydroxide (i.e., lime) and other alkalis. The use of recycled glass offers two primary benefits. It reduces the burden on landfills, where it is dumped as waste material and it also works as an excellent additive to cement. Three different types of glass powders, primarily borosilicate, soda-lime-silicate, and mixed glass powder, were used.

Physical and mechanical properties of different cement samples containing glass powder were investigated. A 10 to 20% increase in pozzolanic activity was observed with the waste glass powder as a pozzolanic material compared to fly ash. The waste recycled glass powder also helped improve other cement properties, such as compressive strength and strength retrogression at higher temperatures

Introduction

Currently, the cement industry uses pozzolanic materials, which are byproducts of other industries or naturally occurring materials, such as fly ash waste from thermal power plants, silica fume waste from silicon industries, agricultural residues (e.g., rice husks and calcined clays), pulverized fly ash, and volcanic ash. Because of the increasing demands for consistent quality, the search for alternative pozzolanic materials is an active area of research. Waste glass powder is a non-recyclable solid waste and can be problematic in terms of landfill disposal because of its nonbiodegradable nature. However, this waste glass is fortunately a good pozzolanic alternative because of its amorphous silica and alumina content. These materials exhibit the pozzolanic activity by hardening similar to cement when reacting with lime in the presence of water. The construction sector has already exploited this idea in relation to cement technology. Apart from alleviating the environmental burden by means of energy conservation, this approach improves the overall performance of the cement. Most of this nonrecyclable mixed-color broken glass originates from the bottling industry.

The concrete industry has made efforts to use waste glass as partial or complete replacements for cement.[1-5] However, because of the strong reaction between the alkali in cement and the reactive silica in glass (alkali-silica reaction [ASR]), studies on glass usage in concrete were not always satisfactory because of strength reduction and excessive expansion.[6-11] Recent studies also show that the particle size of glass is a crucial factor for ASR reaction to occur. Coarse glass aggregates (12 to 4.75 mm) and fine glass aggregates (4.75 to 0.15 mm) are especially not suitable for concrete applications because they tend to cause excessive expansion. However, finely ground glass powder exhibits pozzolanic behavior and suppresses ASR reaction to a significant extent. It is also well-known that typical pozzolanic materials have high silica content, an amorphous structure, and a large surface area.

Considering all of these factors, this paper presents an evaluation of the usage of waste glass powder as a pozzolanic alternative for oil well cementing applications. Three types of glass powders (borosilicate, soda-lime, and mixed waste glass powder) have been used as fillers or binders in the cement system. They help improve long-term strength development and help prevent strength retrogression.

Materials and Methods

During the current study, three different types of recycled waste glass powders (RGPs), namely soda-lime glass, mixed glass, and borosilicate glass, were used as pozzolanic material. They are denoted as RGP-1, RGP-2, and RGP-3, respectively. Class G cement was used to mix all the slurries with densities of 15.8 lb/gal. For comparison purposes, 15.8-lb/gal neat cement slurry and slurry containing fly ash with 30 and 50% bwoc were also mixed. Slurries were mixed per the guidelines provided in API RP 10B-2.

The rheology of slurries was measured using a Fann 35 viscometer at different shear rates. Nondestructive compressive strength was measured using ultrasonic cement analyzer, Fann model 370. The diffraction patterns of glass powders were obtained using X-ray diffractometer X'PERT PRO within the 2θ range of 4 to 80º.

Results and Discussion

Fig. 1 illustrates the X-ray diffraction (XRD) pattern of the RGP-3 sample (borosilicate glass). The X-ray pattern clearly indicates the amorphous nature of borosilicate glass. The broad peak centered at a 2θ value of approximately 22°

represents amorphous silica. The presence of a large amount of silica has been confirmed by a XRF/ICP analysis. **Table 1** represents the elemental analysis (reported as the oxide) of the glass powder sample. In all three samples, the SiO_2 content was determined to be more than 75%. Borosilicate glass (RGP-3) exhibited a very small amount of CaO, and therefore, was determined to be more suitable as a replacement for fly ash in certain applications.

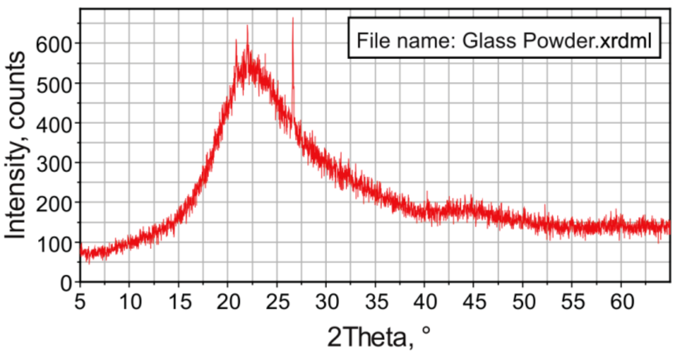

Fig. 1—XRD pattern of recycled glass powder.

Table 1—Quantitative Analysis of Glass Powders

Oxide	RGP-1 (Soda-lime Silicate) Conc., %	RGP-2 (Mixed-Silicate) Conc., %	RGP-3 (Borosilicate) Conc., %
Silica (SiO_2)	75.31	76.39	81.30
Alumina(Al_2O_3)	1.11	2.19	2.22
Calcium (CaO)	8.83	6.05	0.01
Magnesium (MgO)	2.80	1.18	—
Sodium (Na_2O)	10.77	8.86	0.55
Potassium (K_2O)	0.41	2.84	0.55
Boron (B_2O_3)	—	—	12.68

Fig. 2 indicates the rheological behavior as a function of shear rate for different slurries containing 30% bwoc RGPs, fly ash, and neat cement. Although the apparent viscosity of the cement system containing RGPs is higher than that of the neat and fly ash containing slurries at low shear rates, the values are not much different at higher shear rates. Also, it is observed in the laboratory that the slurries containing RGPs have good mixability and pourability.

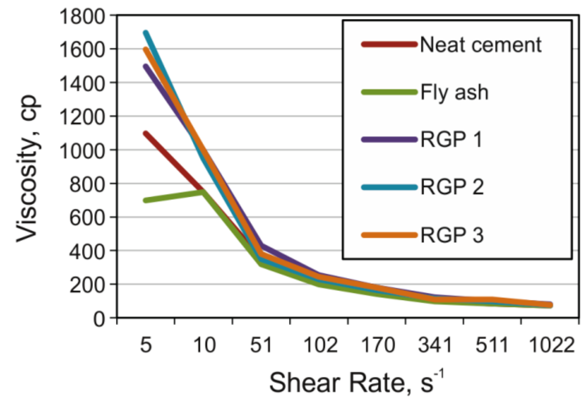

Fig. 2—Rheology of the slurries.

Fig. 3 illustrates the nondestructive compressive strength development of different cement systems containing RGP-1, RGP-2, and RGP-3. These systems were compared against neat cement and cement systems containing 30% bwoc fly ash. 30% bwoc recycled glass powder was added to the cement, and the strength was measured at different temperatures and 3,000 psi pressure. From Fig. 3, it can be observed that 24-hr UCA strength development was comparable to that of the fly ash at all of the three temperatures.

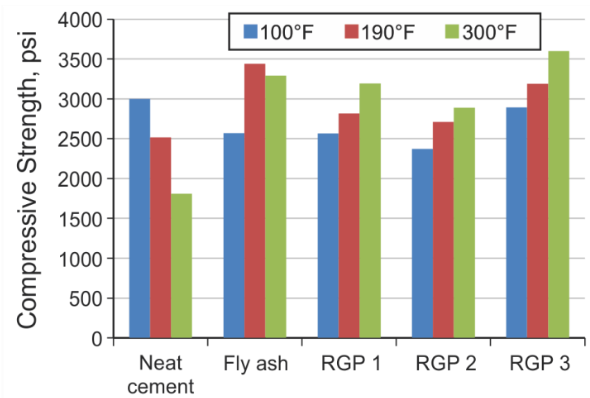

Fig. 3—UCA 24-hr compressive strength at different temperatures.

Fig. 4 presents the strength development of cement systems containing a higher amount of glass powder (50% bwoc of RGP-1 and RGP-3) at 190°F for 24 hr and 3,000-psipressure. Compared to neat cement and 50% bwoc fly ash, slurries containing higher amounts of RGP-1 and RGP-3 showed better compressive strength. It definitely indicates that glass powder acts not just as a filler, but takes part in the hydration reaction and exhibits pozzolanic behavior.

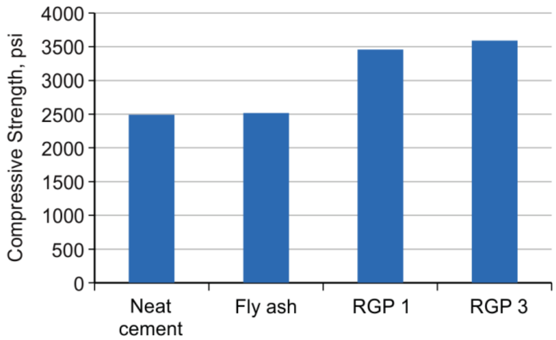

Fig. 4—UCA compressive strength development at 190°F with 50% bwoc fly ash and RGP.

Strength retrogression presents a major challenge to cementing high-temperature wells. Fig. 3 indicates that these glass powders can help prevent strength retrogression, particularly at temperatures higher than 230°F. To prove this point, all of the cement systems mentioned in Fig. 3 were evaluated for strength retrogression behavior at 300°F for 72 hr. Additionally, the higher amount of RGP-3 (50% bwoc) was also studied to understand the effect of the concentration of glass powders on strength retrogression behavior **(Fig. 5).** Moreover, the decrease in strength for neat cement clearly indicates that this system undergoes continuous strength retrogression over time. In contrast to this, all other four systems containing glass powder showed gradual increases to strength development with respect to time. This clearly underlines the fact that glass powder not only acts as pozzolan, but also helps prevent strength retrogression. From Fig. 5, it is evident that, for preventing strength retrogression, 30% quantity of RGP-3 is sufficient because both 30 and 50% glass powder containing cement systems depicts similar behavior at 300°F.

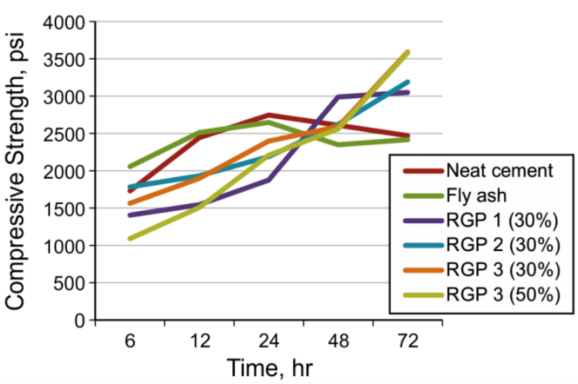

Fig. 5—Strength retrogression behavior of RGP's at 300ºF.

Because it has been demonstrated that 30% RGP is sufficient for preventing strength retrogression at 300°F, this system was evaluated at this temperature for a longer duration **(Fig. 6).** Fig. 6 illustrates 24 days of data for both fly ash and RGP-3 powder. An initial increase, followed by a decrease in strength that becomes less-pronounced with time, was observed for the cement system containing fly ash. On the contrary, the continuous increase in strength, followed by a plateau, is noticed for the RGP-3 system. Even after 24 days, the RGP-3 system exhibited 1,600-psi higher compressive strength compared to the fly ash system. This clearly proves that glass powder has several merits compared to fly ash in cementing applications.

These results illustrate that RGP-3 exhibits better performance than the other two glass powder samples. The strength retrogression behavior of RGP-3 can be explained based on the cement hydration reaction. Silicates are major constituents of cement composition. These silicates play an important role in developing early- and long-term compressive strength by the formation of C-S-H gel. The C-S-H products formed during hydration are thermodynamically stable up to 230ºF (110ºC). Above this temperature, they convert into crystalline α-C_2SH. This new phase has a lower bulk volume, which results in the high porosity and low compressive strength of set cement.[12] For preventing strength retrogression, silica flour or sand is commonly added to the cement slurry. This decreases the ratio of CaO to SiO_2 in the cement from 1.5:1 to 1:1. At this lower ratio, tobermorite ($C_6S_6H_5$), which is thermodynamically stable up to 300ºF (150 ºC), is created during the cement hydration and preserves high strength and low permeability. Because RGP contains more than 75% silica, it is possible that this theory of preventing the conversion of C-S-H to α-C_2SH holds for this work.

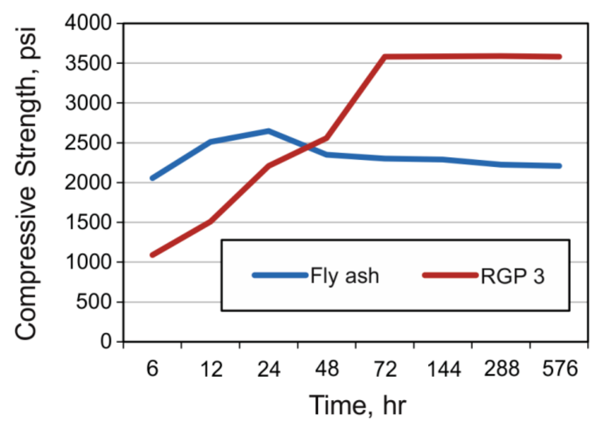

Fig. 6—Compressive strength developments for longer duration.

Conclusions

From the results presented in this paper, the following conclusions can be established.

Use of recycled glass powder provides multiple advantages because it (1) validates pozzolanic activity, (2) prevents cement strength retrogression behavior at high temperatures, and (3) reduces the water disposal burden on the environment. Among the three glass powders evaluated, borosilicate-recycled glass powder demonstrated better performance compared to the mixed and soda-lime recycled glass powders. Compared to fly ash, the use of borosilicate glass powder seems to be a viable option.

Acknowledgments

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