The Future of Concrete May be in its Past: The Natural Pozzolan Renaissance

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Abstract

The concrete industry is under increasing pressure to reduce greenhouse gas emissions and energy use in portland cement manufacturing. While there are several possible ways to address this challenge, an immediately available solution is to minimize the amount of portland cement used by substituting other materials to make concrete binders. We can learn a lot from the Romans, who made strong, durable concrete without any portland cement at all. We are entering a natural pozzolan renaissance, where the industry is searching far and wide for alternative cementitious materials, including those that mimic the Roman pozzolana. This paper addresses current research on such supplementary cementitious materials, specifically the performance of North American natural pozzolans.

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I. INTRODUCTION

One of the primary challenges for the cement industry in the coming decades will be to reduce greenhouse gas emissions, particularly carbon dioxide. In 2009, the International Energy Agency (IEA) and World Business Council for Sustainable Development (WBCSD) released a "Cement Technology Roadmap" [1], which outlines four strategies the cement industry can employ to reduce CO_2 emissions by 2050: 1) thermal and electric efficiency, 2) alternative fuels, 3) clinker substitution, and 4) carbon capture and storage (CCS). Kiln technology is rapidly reaching its efficiency limit [2], limiting further CO_2 reductions from this strategy. Alternative fuels and CCS technologies are largely still in the development stage, but favorable results are likely if widespread adoption of these technologies occurs. Clinker substitution is showing immediate results, effectively enabling some companies to already reduce CO_2 emissions by 25-30% [3]. However, if the clinker substitution strategy is taken to its maximum potential by partially substituting clinker with supplementary cementitious materials (SCMs), we will quickly run out of the most commonly used sources of SCMs. This supply-demand problem is driving research into finding and testing alternative sources of SCMs. As a result, natural pozzolans are currently experiencing a renaissance due to increasing demand for SCMs.

In the research presented here, natural pozzolans were investigated as substitutions for Class F fly ash, which is rapidly becoming a limited SCM in the US. This is especially concerning given the beneficial effect that Class F fly ash has on concrete durability, particularly resistance to alkali-silica reaction (ASR). While it is commonly known that natural pozzolans were used in ancient Rome, even in the US natural pozzolans cannot be called new, as they were widely used in the early 20th century before the low price of fly ash made it the SCM of choice. Returning to the past, by adopting more natural pozzolans in modern day concrete, may be a key part of the solution to reducing cement's environmental burden.

II. MATERIALS AND METHODS

Five natural pozzolans from the US were tested, as shown in [Table 1]. All passed the ASTM C 618 [4] criteria for Class N natural pozzolans. All were of similar particle sizes, with d_{50} values of 13-23 µm.

The SCMs were tested for their effects on compressive strength of mortars following ASTM C 109 [5]. The results were compared to a control mortar with Type I cement and no SCMs and also to a mortar with a Class F fly ash. SCMs were used as a 20% replacement of cement by weight, and the water-to-cementitious materials ratio (w/cm) was fixed at 0.5 for all mixtures.

The ability of SCMs to control expansion due to alkali silica reaction was tested following ASTM C 1567 [6] using a reactive sand. The replacement amount of cement with SCM was varied to determine the minimum amount of SCM necessary to control expansion.

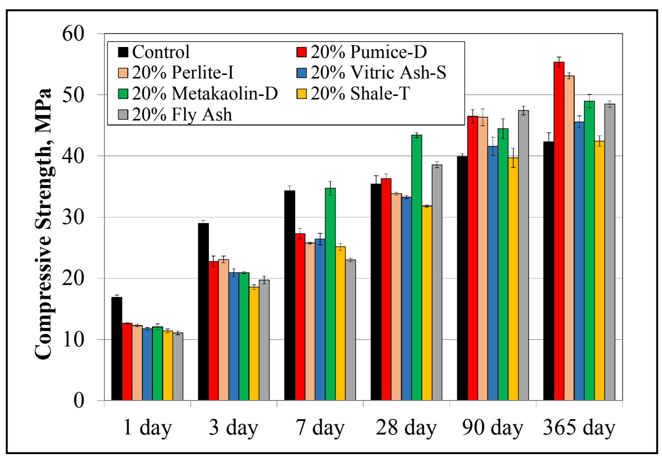
III. RESULTS AND DISCUSSION

Results from compressive strength testing of mortars are shown in [Fig. 1]. At one day, all SCM-containing mixtures, including fly ash, have lower strengths than the cement-only (control) mixture. By 7 days, the mixture containing Metakaolin-D has a strength equivalent to the control mixture. The other SCM-containing mixtures take longer to gain equivalent or higher strengths than the control, with the Shale-T taking the longest, at 90 days. That the strengths of all SCMs do eventually reach or overtake the strength of cement-only mortar confirms that all of these materials are pozzolanic, which has also been verified using other methods, including measurement of paste $Ca(OH)_2$ content [7]. All of these pozzolans compare well against the Class F fly ash in terms of compressive strength development, suggesting that they can be suitable SCMs by this measure.

Table 1. Natural pozzolans tested

Pozzolan	***Source***
Pumice-D	Idaho
Perlite-I	Idaho
Vitric Ash-S	Nevada
Metakaolin-D	Missouri/Indiana
Shale-T	Texas

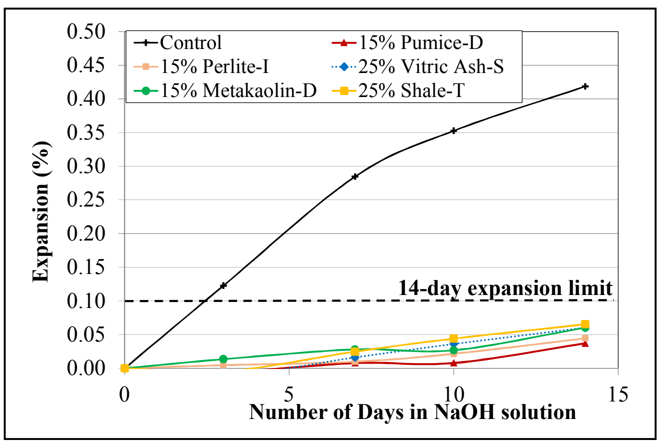
Fig. 1. Compressive strengths of mortar cubes containing 20% SCM with w/cm=0.5



The results of alkali-silica reaction testing are shown in [Fig. 2]. Aside from environmental motivations, a primary reason for using SCMs is to improve concrete durability. Class F fly ash is well known to reduce expansion due to ASR, so any substitutes for fly ash need to show equivalent performance in order to be adopted in areas where ASR is a problem. The data in [Fig. 2] demonstrate that all of the pozzolans tested reduced expansions due to ASR below the threshold prescribed by ASTM C 1567 [6]. The minimum amount of SCM needed to control expansion varied between 15% and 25%. These results suggest that all of the tested pozzolans can be considered to be adequate replacements for Class F fly ash with respect to controlling expansion from ASR.

Compressive strength and ASR are not the only performance criteria for adoption of SCMs. These are reported here because they are among the most important. Other performance testing has been done on these materials and is reported elsewhere [7]. All performance testing suggests that these materials can be suitable replacements for Class F fly ash, effectively expanding the portfolio of SCMs available for use in the US.

Fig. 2. Results of ASTM C1567 alkali silica reaction testing



IV. CONCLUSIONS

In the search for new and underutilized sources of SCMs to reduce clinker contents in cements or cement contents in concrete, natural pozzolans have a promising future. The pozzolans tested in the work presented here represent a wide range of minerals, from volcanic materials to calcined sedimentary materials. The results have shown that all are pozzolanic and have the potential to contribute to strength development and durability enhancement.

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