Better Cement. **Better Concrete**

Technology Briefing

V.2b.14

FIREROK's™ High Temperature Concrete Offers Superior Thermal Properties, Providing Greater Concrete Durability

Exposure to high temperatures and elevated thermal cycling, is well known for creating deterioration in portland cement concretes (PCC). PCC suffers a near complete loss of mechanical properties and physical integrity at temperatures of 930°F (500°C) due to the decomposition of calcium hydroxide. However, short of the full loss of mechanical and physical integrity, the deterioration of PCC begins at much lower temperatures, driven by both chemical and physical limitations.

Much has been written on heat related failures of concretes due to chemical breakdown (dehydration of hydrates), yet often overlooked is the mechanical stress experienced within concrete during thermal cycling. It has been noted, the internal stress induced by thermal cycling contributes to material deterioration and failure at temperatures as low as 150°F (65°C). Additional deterioration takes place just beyond 212°F (100°C) when heat exceeds the boiling point and moisture is driven out of the concrete leading to pop-outs and spalling. In these conditions, the Calcium Silicate Hydrate (CSH) gel suffers loss of water and contracts, damaging the integrity of the matrix. Furthermore, field conditions provide a variety of service exposures (fluids, etc.), that aggravate the deterioration of PCC subjected to thermal cycling and high heat exposure (e.g., concrete blistering, pop-outs, significant micro fractures, and spalling). For these reasons, PCC is not recommended for use in environments where temperatures exceed 200°F (93°C) without careful mix design considerations and laboratory validation. Even with carefully engineered and validated mix designs, PCC is not recommended for environments where temperatures will exceed 400°F (204°C).

A growing number of industrial firms have turned to CeraTech USA's FIREROK™ cement concrete as a solution to in-service deterioration of portland cement concretes. CeraTech USA's FIREROK™ is an ASTM C1157 hydraulic cement system utilizing 95% fly ash and 5% liquid additives. The reaction products of activated fly ash cements decompose at higher temperatures than those of portland cement, making them able to withstand such conditions. Additionally, because the overall thermal properties of concrete also depend on the characteristics of the aggregate being used, it is important to understand how heat travels into, and through, the material. The higher density of the FIREROK™ cement system generates two important changes in the thermal properties of concrete: higher heat capacity and thermal conductivity both of which mitigate internal thermal stress. These two critical factors, greater chemical and mechanical stability, provide a much more durable concrete when exposed to high temperatures and high rates of thermal cycling.

In July 2012, CeraTech Inc., initiated an independent test procedure capturing thermal properties of mortars made with portland cement and FIREROK™ cement, evaluating their respective thermal performance, and obtaining values for subsequent finite element analysis.

TEST PROGRAM

The ability of concrete to maintain its integrity when exposed to elevated temperatures and thermal cycling is affected by both the cement system (portland, calcium aluminate, FIREROK™, etc.) and the aggregate. There are a number of studies available regarding the thermal capacity of aggregates in concrete. For the purpose of this analysis, the study concentrated on the cement systems, therefore the aggregates were removed.

Mortar specimens were prepared with the same proportions of cement and sand, varying only water to adjust for equal flow. The specimens were then provided to Dynalene Laboratory, an independent testing laboratory, to determine the thermal conductivity (K), and specific heat capacity (Cp). (Thermal conductivity (K) refers to the ability of a material to conduct heat while the specific heat capacity (Cp) refers to the energy required to change the temperature per unit mass of the material.) The results are presented in *Figure 1*.

TEST RESULTS

Results show FIREROK™ mortar demonstrates a much higher K and Cp than portland cement mortar. The higher Cp means that FIREROK™ requires more energy to increase in temperature. This significantly higher thermal conductivity ensures the increased heat is more broadly and uniformly dissipated throughout the material. **FIREROK™ cement concrete takes longer to absorb heat, more evenly disperses heat, and experiences much lower thermal stress than PCC**.

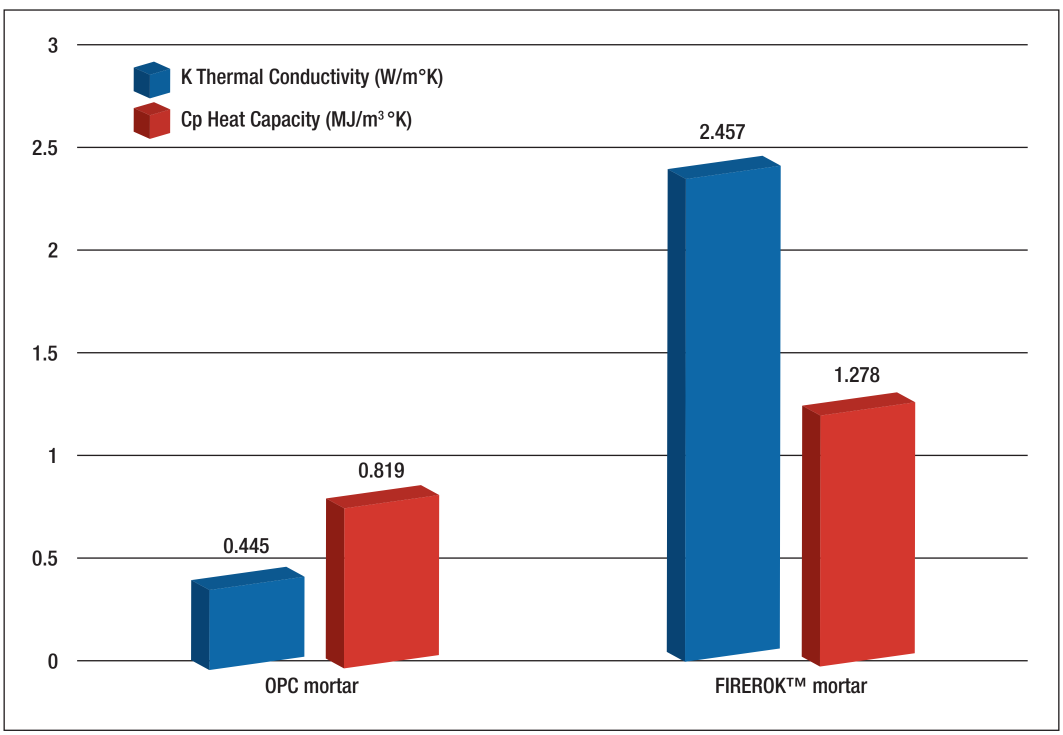

FIGURE 1: Thermal Properties of FIREROK™ vs. OPC

In comparison, the portland cement sample required less energy to increase in temperature, and has lower thermal conductivity. PCC heats up more rapidly, the heat remains concentrated in a specific location for a longer period of time resulting in much higher thermal stress within the material. **The higher thermal stress within the PCC is directly related to material deterioration and ultimate failure experienced in field conditions**.

The results show FIREROK™ provides a much higher thermal conductivity and heat capacity than PCC. Higher Thermal Conductivity (K) and Heat Capacity (Cp) translate into greater concrete durability.

The higher density of FIREROK™ cement produces a concrete that possesses a higher heat capacity and superior thermal conductivity than portland cement concrete. Although low thermal conductivity is one of the most sought-after features in most construction materials, it is not desirable in more brittle (and thus thermal stress-susceptible) materials like concrete. FIREROK™ absorbs heat more slowly, and dissipates heat more rapidly than portland cement concrete, dramatically reducing thermal stresses to the material. In addition FIREROK™ cement concrete's dense material matrix reduces the temperature gradient between the top and bottom of the slab, minimizing the potential for curling and cracking caused by daily temperature fluctuations.

DEVELOPING A FINITE ELEMENT MODEL

A finite element model was developed illustrating the differences between the two materials. The model consisted of a 6 ft. x 6 ft. x 1 ft. slab. In the simulation, the slab was subjected to cycles of 10 hours of heating at 400°F, followed by 10 hours of cooling at 72°F. The heat was applied in the top surface of the slab by convection, i.e., hot and cold air with a film coefficient of 15 W/m°K. The results are presented in *Figure 2* and *Figure 3*.

The thermal stress generated in portland cement surpasses the ultimate tensile strength after approx. 7 hours of exposure at 400°F. At this point, the integrity of the specimen is compromised and cracking or spalling is expected to occur. Conversely, FIREROK™ resists the intermittent thermal loading at 400°F temperatures.

After the initial thermal loading, the OPC sample reaches a max temperature close to 240°F while the FIREROK™ sample (the one with the highest Cp) takes a longer time to absorb heat, reaching a lower maximum temperature of only 170°F. This behavior represents the differences in Cp of the two concretes; FIREROK™ has the highest heat capacity, therefore takes a longer time to absorb heat and reaches a lower maximum temperature in the same period of time. The OPC sample quickly absorbed the heat, since it had the lowest Cp.

The minimum temperature depends on the ability of concrete to transport heat to the inside of the structure; hence, it is dominated by K and not Cp. Since the OPC sample had the lowest K value, its minimum temperature increased at a slower rate, reaching the lowest minimum temperatures of the concretes. With K value approximately 5 times higher than that of OPC, FIREROK™ dispersed heat more uniformly, increasing it's minimum temperature at a higher rate, and reaching a higher minimum temperature.

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Simulation of FIREROK™ and PCC undergoing cycles of heating up to 400°F and cooling at 72°F

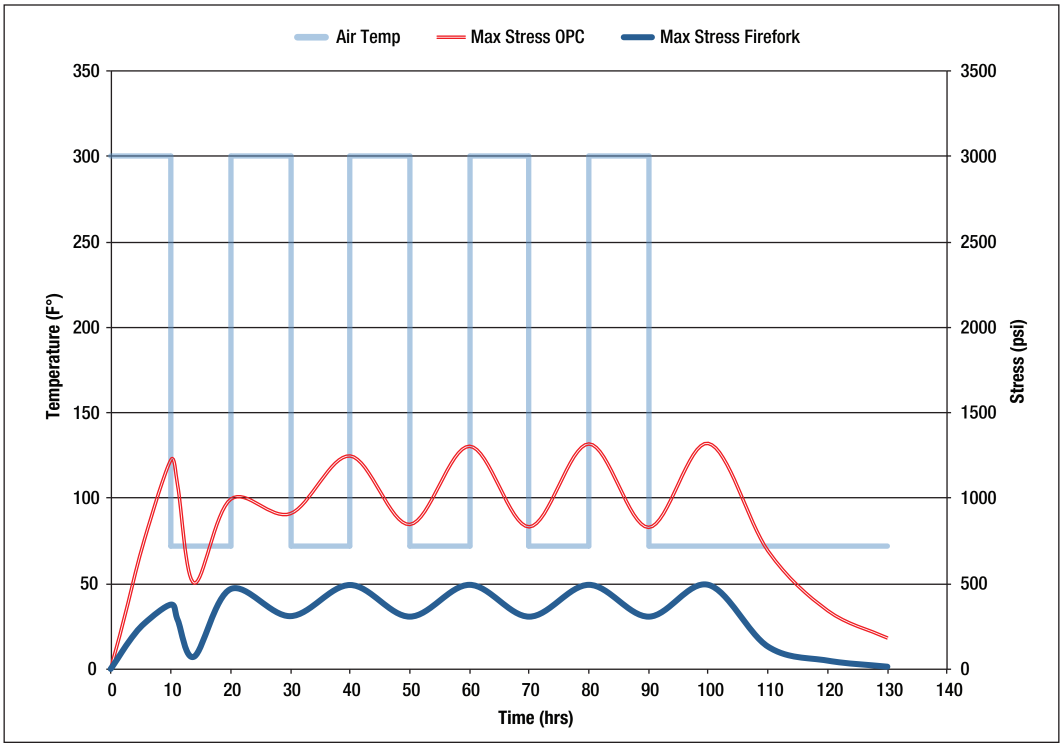

FIGURE 2: Thermal Stress (psi) of FIREROK™ vs OPC in Thermal Cycles

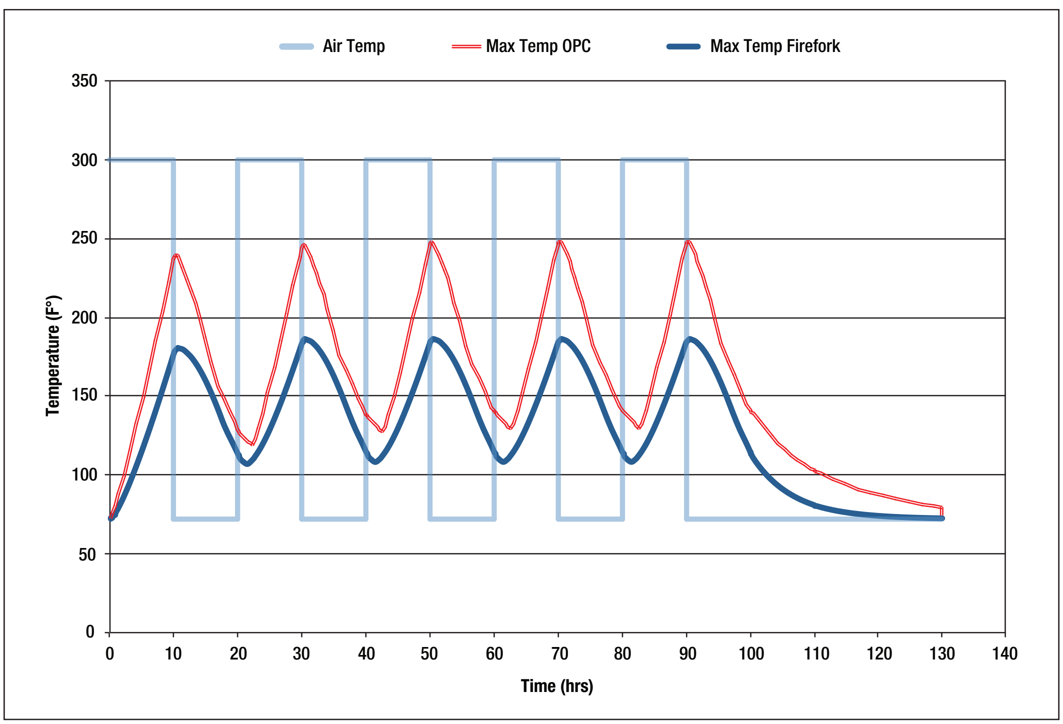

FIGURE 3: Max Temperature (°F) of FIREROK™ vs OPC in Thermal Cycles

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SUMMARY

The differences between portland cement concrete and CeraTech USA's FIREROK™ cement concrete are summarized below:

- FIREROK™ has higher thermal conductivity - 5 times higher than PCC.
- FIREROK™ has 50% higher heat capacity than PCC.
- When subjected to heat (in convection), concrete made with FIREROK™ will increase its temperature more uniformly, and therefore will experience a much lower thermal strain than with portland cement concrete.
- FIREROK™ has much greater durability than PCC in applications where concrete will be subjected to intermittent thermal loading.
- The degradation of concrete by heat depends on the thermal resistance of the binder (related to its internal structure), and its thermal properties (how it absorbs and transmits heat). In the case of thermal properties, FIREROK™ clearly outperforms PCC.
- FIREROK™'s lower (.18-.23) water-to-binder (W/B) ratio makes it much less prone to spalling than portland cement concrete.

FIREROK™ offers greater durability than PCC in environments with elevated temperatures and/or significant thermal cycling, while providing a green concrete alternative to high CO_2 from portland cement production. CeraTech USA's FIREROK™, KEMROK™ & ekkomaxx™ cement for concrete represent a commitment to Leadership in Concrete Durability & Sustainability.