

Fire damaged concrete from a PETROGRAPHER'S perspective

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INTRODUCTION

Portland cement concrete is the most commonly used construction material and is also one of the most cost-effective fireproofing materials. Due to low thermal conductivity, portland cement concrete can delay the fire damage to reinforcing steel and delay or reduce the ultimate damage to concrete structures, reducing the potential loss of life and property. Depending on the temperature reached and duration of fire, concrete may eventually sustain damage and even lose its structural integrity. Fire damage to concrete structures can range from cosmetic, which requires little or no repair, to catastrophic failure. Fire damage to concrete, when occurring, is typically limited to a depth of a few centimeters from the surface exposed to fire, although deep cracking and spalling may also occur.

Generally speaking, the compressive strength of portland cement concrete may decrease up to 25% when the concrete is exposed to approximately 120 °C. As temperature increases beyond this point, the compressive strength of the concrete may recover slightly and then experience significant decrease. A 55% reduction of compressive strength may occur when the temperature exposed to the concrete reaches 650° C. However, the correlation between the temperature exposed and the compressive strength reduction of the concrete depends largely on the composition and mix proportions of the concrete, such as aggregate composition, water-to-cementitious materials ratio (w/cm), cement and supplementary cementitious materials content, and other properties. For example, at a given temperature, concrete containing calcareous aggregate and concrete with lower w/cm may experience less compressive strength reduction than concrete containing siliceous aggregate and concrete with higher w/cm .

Another concern for fire damage to reinforced concrete structures is the effect of heat exposure on the yield strength and ultimate strength of reinforcing steel. The yield strength of embedded steel will decrease as temperatures exposed increase. The yield strength typically starts to decrease when concrete temperatures reach approximately 250° C. Up to 50% of the yield strength and the ultimate strength of rebar could be reduced when the concrete temperatures reach 500° C. Therefore, determination of temperatures exposed to concrete structures is highly important in assessing fire damage to concrete structures. Knowledge of maximum temperature exposed and the corresponding depth of exposure or isotherms for given temperatures in fire damaged concrete is typically the basis for engineers and property owners to develop repair strategies. While many tools and methods are available to assess fire damage to concrete structures, such as visual observation, mechanical sounding, physical testing,

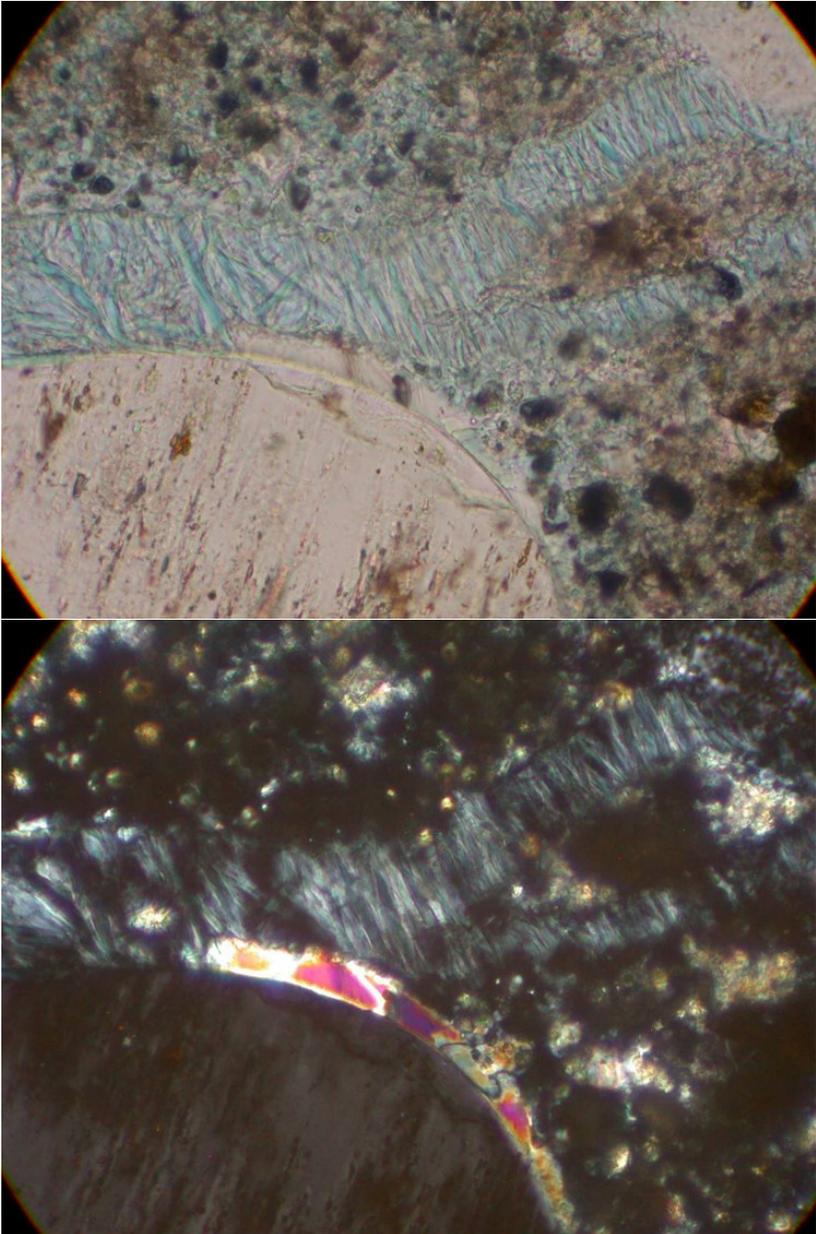


Figure 1. Abundant secondary ettringite formation in microcracks in surface region of a fire damaged concrete. The ettringite was formed as a results of dehydration due to the fire and reprecipitating in cracks after the fire.

scanning electron microscopy, X-ray diffraction, ultrasonic, and other non-destructive evaluation methods, concrete petrography has been proven to be a unique and indispensable tool in assessing fire damaged concrete. By evaluating geothermometers in concrete, a concrete petrographer can establish isotherms or thermal gradients in fire damaged concrete structures.

Concrete is a heterogeneous material consisting of aggregate and cement paste. Certain minerals in aggregate and portland cement paste are known geothermometers exhibiting phase transition or decomposition at specific temperatures. By identifying the phases of these geothermometers, the minimum temperature that has been exposed to the concrete containing these minerals may be established. For example, ettringite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 32\text{H}_2\text{O}$) in cement paste dehydrates below 114°C (Figure 1). Calcium hydroxide ($\text{Ca}(\text{OH})_2$) from cement hydration dehydrates and converts into lime (CaO) around 450 to 500°C . Quartz (SiO_2) undergoes a phase transition at 573°C from α quartz to β quartz, with an associated volume expansion. Calcite (CaCO_3) calcines at 900°C and converts into lime (Figure 2). Lime is not a chemically stable mineral and will hydrate back into calcium hydroxide upon exposure to moisture, with a significant volume increase, which may cause further damage to concrete (Figure 3 and Figure 4). As temperatures continue to increase, some silicate minerals may become melted (Figure 5). It should be pointed out, however, that temperatures associated with these phase transitions or decompositions were measured at laboratory atmosphere, which is different than concrete structures exposed to fire. The cement paste and some aggregates contain free water or structural hydroxyl groups, which may be released due to rapid temperature increase caused by fire exposure. The water vapor pressure will thus build up within the pore system of the concrete, creating an internal autoclave condition with elevated temperature as well as elevated pressure. The geothermometers discussed above would behave slightly differently in autoclave conditions than at atmospheric pressure. The exact temperatures at which phase transitions and decompositions of geothermometers take place should also be slightly different, depending on the composition of the concrete and the exposure conditions to the fire. Nevertheless, evaluation of these geothermometers in concrete would provide invaluable information regarding the maximum temperature to which the concrete was exposed.

In addition to the geothermometers discussed above, color changes of both cement paste and certain aggregates in concrete are also indicative of concrete temperatures exposed. These changes are mostly due to dehydration of the paste and/or oxidation of iron containing phases in both the paste and aggregate. Due to the significant variability in composition and texture of both cement paste and aggregate, observation regarding color change is empirical, approximate, and is associated with broad ranges of temperature. Generally speaking, concrete color is normal to temperatures below 300°C . From 300°C to 600°C , the color gradually changes from pink to red. From 600°C to 950°C , the color changes to different tones of gray. Above 950°C , the color becomes buff (Figure 6). The color change may be subtle for the paste and is typically

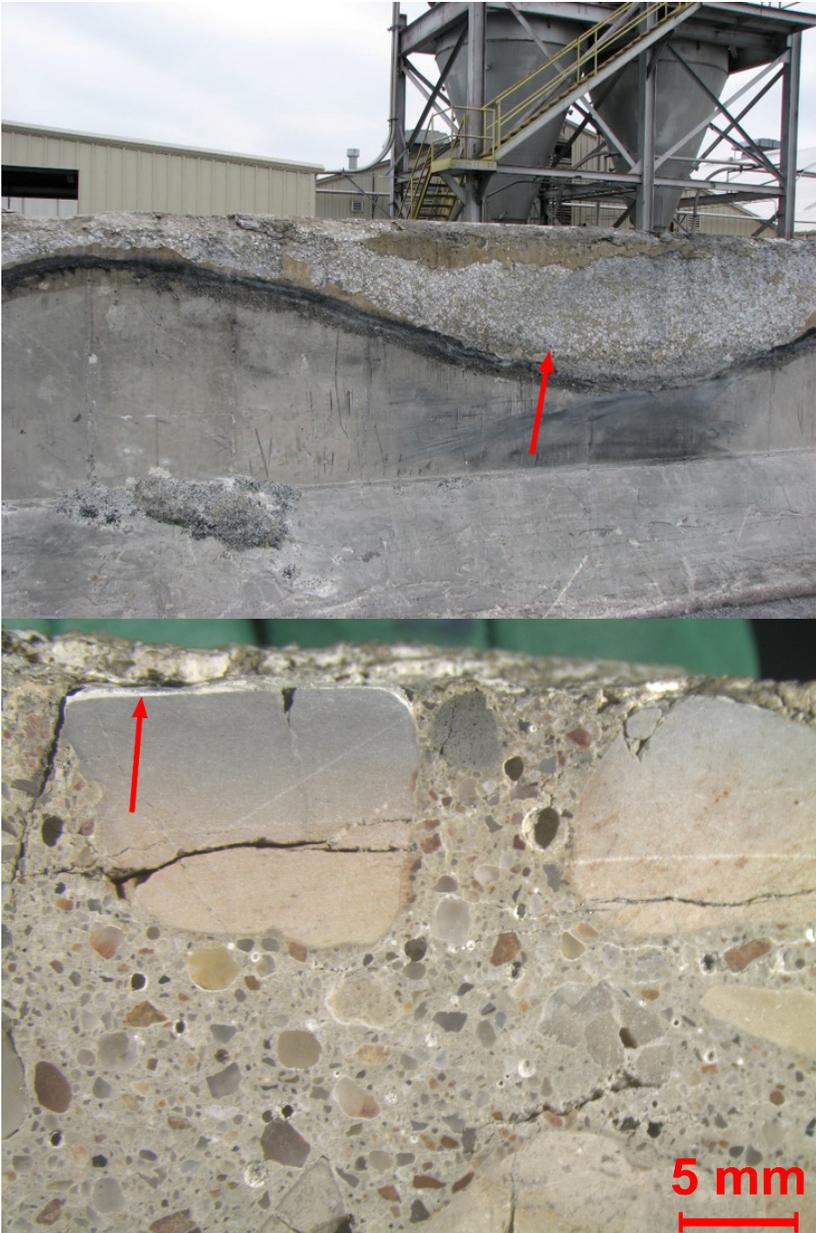


Figure 2. Calcination of limestone coarse aggregate. The white material was carbonated calcium hydroxide crystals.

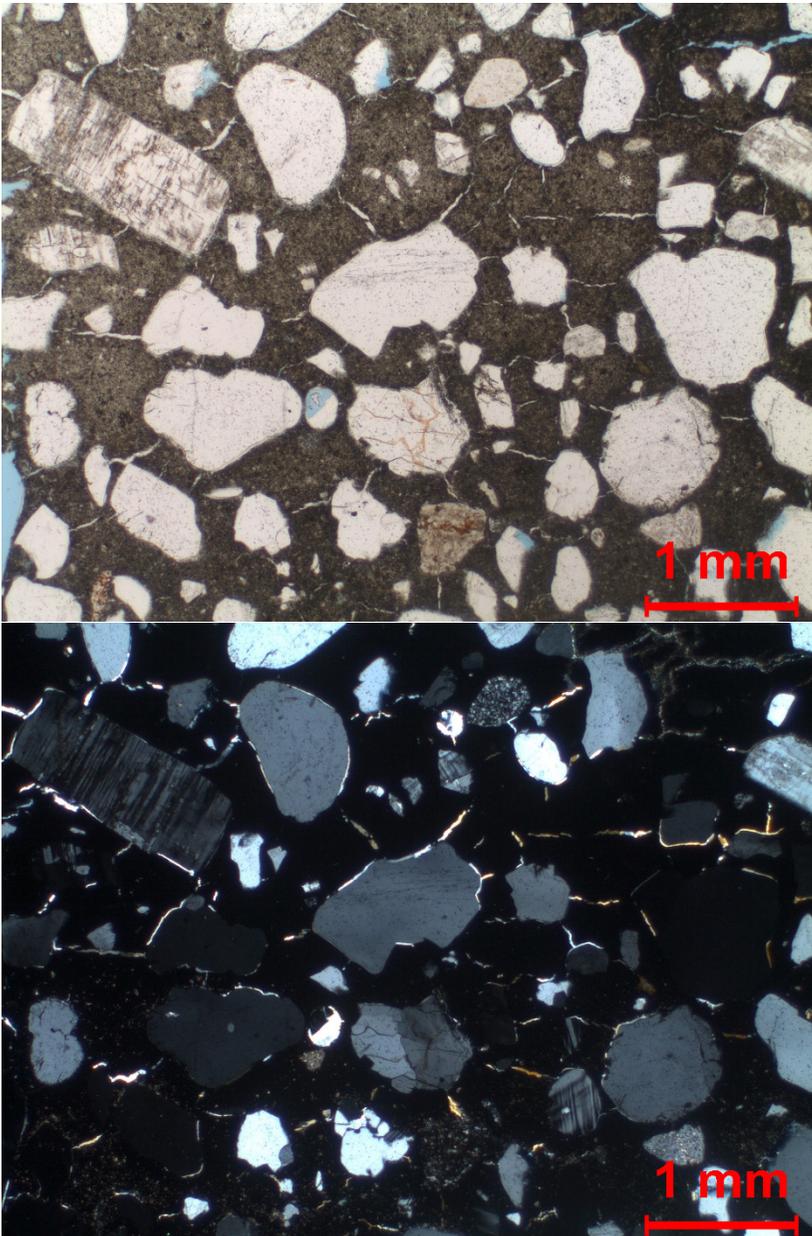


Figure 3. Map cracking in the paste due to rehydration of lime into calcium hydroxide. The lime was formed by dehydration of original calcium hydroxide due to a fire.

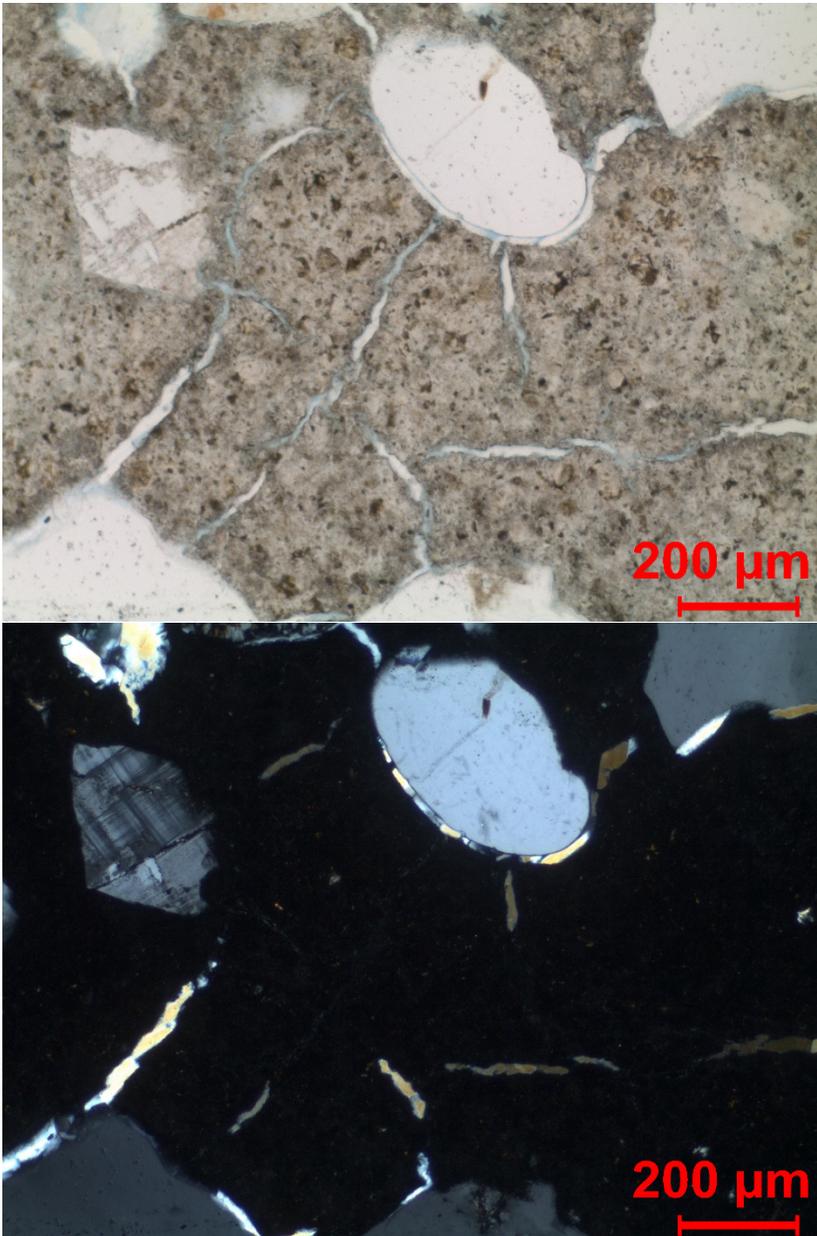


Figure 4. Map cracking in the paste due to rehydration of lime. Note that calcium hydroxide is only in the cracks but not in the paste in the fire damaged region. Deep in the concrete, abundant calcium hydroxide crystals are present in the paste.

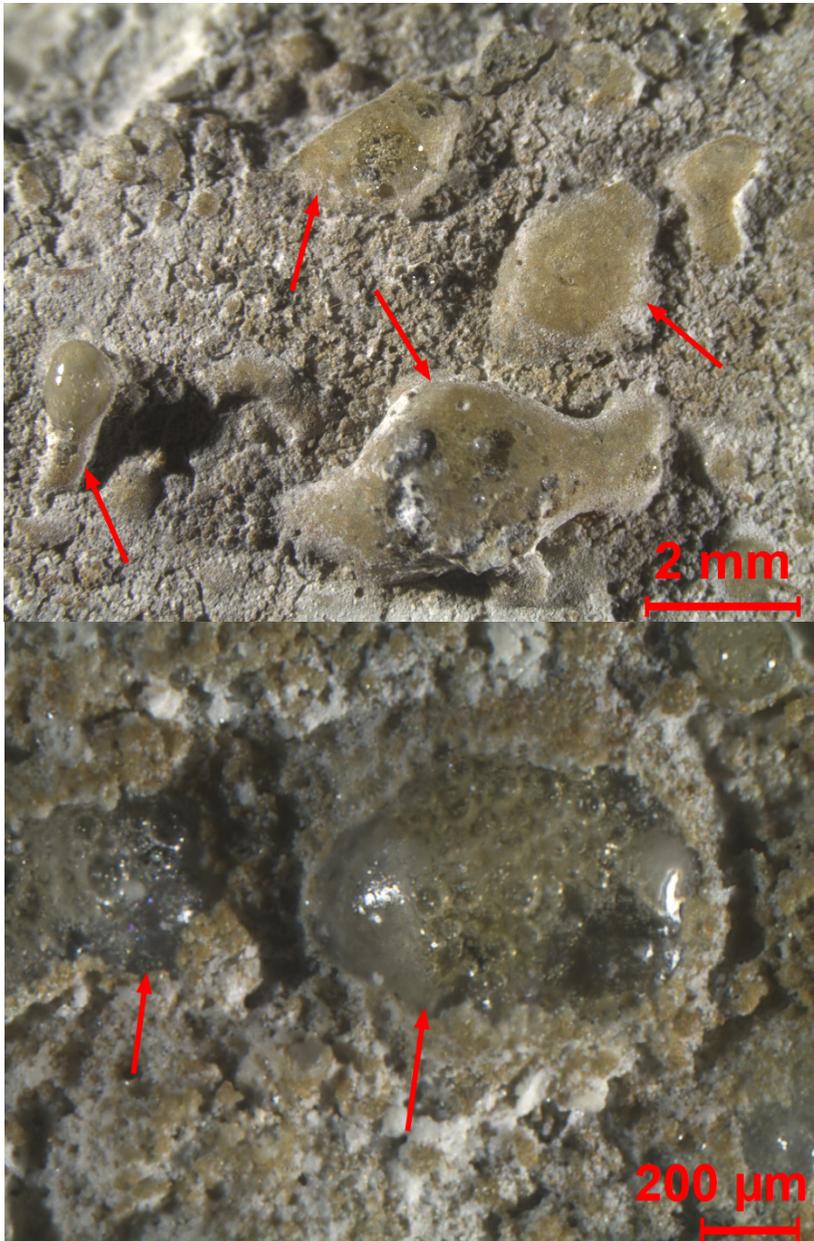


Figure 5. Glass beads formed from melted quartz sand on the surface of a fire damaged concrete.

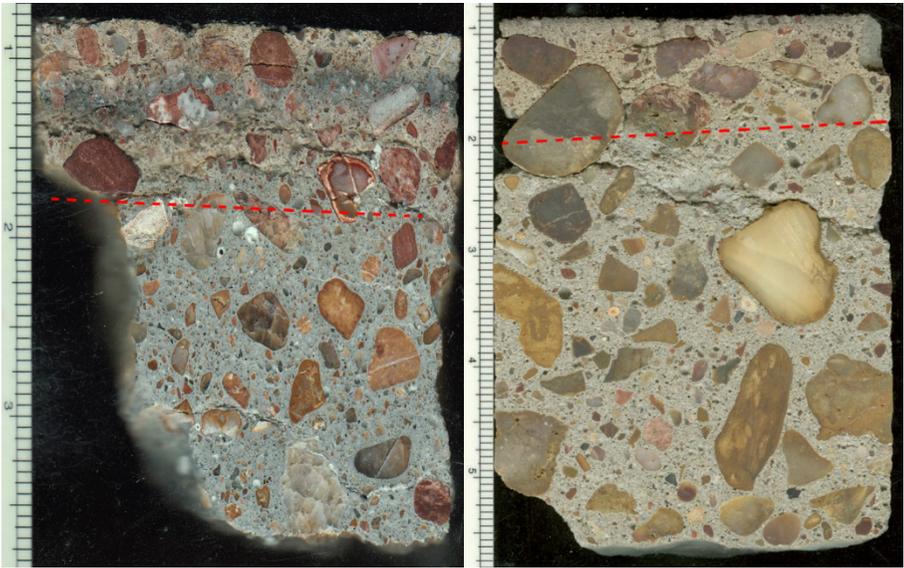


Figure 6. Color change of the surface region of concrete cores due to the effect of fire.

more obvious for some siliceous and calcareous sedimentary and metamorphic rocks. Other degradation of the concrete, such as surface crazing, popouts, spalling, cracking, and softening of the paste, may also occur in concrete due to the effect of fire.

Petrographic examination of fire damaged concrete samples should be performed on both lapped sections as well as thin sections. Visual examination of as-received cores or other specimens should be performed first to identify locations for further investigation. Since the most severe damage occurs on the exposed surface, it is often necessary to preserve the surface condition of the samples, such as by impregnation with epoxy. Color change of aggregate or paste is best observed on lapped or polished sections using a stereomicroscope. Assessment of geothermometers in the cement paste must be performed carefully on thin sections using a petrographic microscope. A thermal gradient of temperature change as a function of distance to the exposed surface can be established for each examined sample. An isotherm of a given temperature, such as 500° C, can be obtained for the entire structure based on petrographic examination of multiple samples selected at strategic locations.