Project Summary
Texas Department of Transportation

0-5111: Liquid Nitrogen Effects on Concrete

Background

Liquid nitrogen (LN) is quite possibly the most effective method of cooling fresh concrete, but it does not have a long or widespread history of use. Accordingly, there are very few records of its effects on short and long-term concrete properties. In spite of this, LN is being increasingly adopted in Texas and elsewhere to meet stringent concrete fresh temperature specifications in hot weather.

Concerns have arisen regarding possible interactions between LN and chemical admixtures that may affect workability or air content. Furthermore, it is possible that localized freezing may affect cement hydration, with consequences on property development and long-term durability. Additionally, there are unaddressed safety concerns with LN use and evidence that it can damage concrete mixing trucks. All of these issues merit thorough investigation before LN can be recommended for concrete cooling.

Liquid nitrogen also has potential uses beyond traditional cooling applications. While the common cooling methods of chilled water and ice have limited cooling capacity and can only be applied during initial mixing, LN can be used to cool concrete to very low temperatures and cooling can be done at any time during the mixing and transporting process. The consequences of and opportunities presented by flexible cooling have never been explored.

What the Researchers Did

Comprehensive laboratory and field investigations on the effects of LN on concrete were undertaken in this study. When cooling methods were tested, materials were heated to 100°F and the mixtures were cooled to 73°F on mixing; results were compared to uncooled control mixtures with fresh temperatures of 73°F and 100°F. A variety of chemical admixtures and supplementary cementing materials were tested. Initial experiments involved cement pastes and mortars cooled by chilled water, ice, or LN and tested for flow, setting time, drying shrinkage, and compressive strength development. Subsequent laboratory concrete mixtures were tested for slump, setting time, yield, compressive strength, splitting tensile strength, elastic modulus, chloride penetrability, air content, and air void distribution. In some tests, LN dosing time and fresh temperature were varied to investigate the consequences of delayed dosing and very low fresh temperatures. Field testing of ready-mix concrete involved measurement of slump, setting, and strength, as well as the effects of delayed dosing.

The effects of LN on cement hydration and hydration product development were examined using several techniques: isothermal calorimetry, x-ray diffraction, scanning electron microscopy of cement pastes, semi-adiabatic calorimetry on concrete, and inductively coupled plasma-optical emission spectroscopy of early-age pore solutions.

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A comprehensive survey was performed of the methods used in the field to apply LN cooling, including their safety implications. Additionally, the effects of LN on cracking of ready-mix truck drums was investigated through chemical analysis of the steel in the drums, visual examination of crack patterns and surfaces, and temperature measurement in the drums.

What They Found

Fortunately, LN cooling had no effect on most of the properties tested, with a few notable exceptions. In the laboratory, parameters that are related to the water-to-cement ratio such as slump, strength, and chloride penetrability changed slightly with LN cooling. This observation was linked to evaporation of water from the mixture during LN injection, an effect that is not seen in the field due to the smaller surface-to-volume ratio of concrete in a ready-mix truck drum compared to a laboratory mixer.

Interestingly, LN-cooled mixtures have slumps that are equivalent to those of 100°F uncooled mixtures rather than 73°F uncooled mixtures. It was concluded that the rapid reactions taking place during the first few minutes after mixing and before cooling determine the slump. This result has minimal implications in the field since concrete mixtures are already designed for the hot slump rather than the cooled slump.

The most remarkable results came from the flexible cooling tests. It was observed that concrete can be cooled at any time before initial set and still experience the setting time of a cold mixture rather than a hot mixture. Cooling to very low temperatures can delay setting significantly, and this can be done at any point prior to initial setting; for example, a 100°F mixture can be cooled to 40°F after an hour and set at the same time as a mixture whose initial temperature was 40°F. This means that concrete producers are not limited to cooling immediately upon batching, opening the door for many new uses of LN discussed in the next section.

Testing of ready mix drums suggests that cracking is related to the ductile-to-brittle transition that steel experiences on cooling. The cracking is not related to the age of the drum or the volume of concrete, but may be linked to position of the injection lance.

What This Means

LN cooling is recommended for widespread use because it does not significantly affect property development in concrete. Care should be taken during slump prediction to account for slump loss due to the high initial temperatures of the materials. Additionally, injection lances should be properly aligned in order to minimize drum damage related to low steel temperatures.

The possibility of delayed dosing opens up many opportunities in concrete construction. For one, since cooling need not be immediate upon batching, producers can minimize the cost of installing LN equipment by centralizing it on the job site or at one batch plant, cooling loads arriving from several batch plant locations. Additionally, LN cooling can be used as an impromptu retarding method. Concrete that is normally rejected because of an extended time in the truck due to traffic or construction delays can be cooled on site, extending the setting time. The results from this project demonstrate the likely success of such flexible cooling.

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