



# Office of Innovation, Partnerships & Energy

## Innovation, Research & Implementation Section

# Executive Summary Report

## **Forensic Investigation of AC and PCC Pavements with Extended Service Life: Volume 3: Petrographic Examination of Blast Furnace Slag Aggregate Concrete Cores taken from PCC Pavements in Cuyahoga County, Ohio**

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### **Problem**

Air-cooled blast furnace slag has been used as a coarse aggregate in portland cement-based pavement concretes since at least the early 1900's. Many of these concretes have performed satisfactorily. In recent times a number of PCC slag aggregate pavements constructed in Michigan in the early 1990's have shown extensive cracking and joint deterioration after only ten years or so of service. The nature of this pavement distress is described as being unique to the slag aggregate concretes. This situation prompted a number of field and laboratory studies, which are cited in the present report. Currently there is an on-going FHWA study of this distress issue.

Four slag aggregate concrete pavements in District 12 (Cleveland) of the ODOT system currently show evidence of the same type of unique distress. Cores taken from these pavements were petrographically examined in Phase 3 of the present Forensic Investigation. The findings are of direct value to ODOT and provide additional input and insights for the FHWA study.

### **Objectives**

In the work conducted to date by other researchers, at least three potential sources of distress have been cited to explain the unique distress observed in the Michigan pavements. These potential distress mechanisms include (1) alkali-silica reaction [ASR] activity, (2) internal sulfate attack, and (3) freeze/thaw damage. At the time our research study was initiated, there was no consensus as to which of these distress mechanisms was dominant.

The objectives of the current research on the Cuyahoga County cores are to (1) characterize the distress in the slag aggregate concrete cores, (2) identify the operative distress mechanisms, and (3) identify, if possible, which of the cited (or other) distress mechanisms is dominant.

### **Description**

Two full-depth, 4-in. (10 cm) diameter cores were taken from each of the four Cuyahoga County pavement sites. One core was taken in an area of the pavement slab currently showing distress in the wearing surface. A second companion core was taken nearby in an area of the slab that does not currently show the distress.

Petrographic examinations were conducted on the cores using both optical microscopy procedures and scanning electron microscope (SEM) procedures. The distress in the cores was characterized using crack-mapping procedures in the optical microscope examinations and using energy dispersive x-ray spectroscopy (EDS) procedures in the SEM work. The findings from this study led to an identification of the distress mechanisms, as well as to the identification of the dominant distress mechanism.

### **Conclusions & Recommendations**

Cores from three of the four slag aggregate pavement projects showed the unique form of distress reported by previous researchers. The age of these pavements is eleven and sixteen years. Cores from an eight year old pavement do not yet show this distress.

Internal sulfate attack and alkali-silica reactions (ASR) were both confirmed as operative distress mechanisms in the concretes from the aforementioned three projects. The distress is manifested as an extensive network of cracks, which are present primarily in the topmost 3 to 4 in (7.6 to 10.2 cm) portion of the cores. The fracture planes are roughly parallel to the

plane of the wearing surface of the cores. With few exceptions the cracks pass along the bond lines between the cement paste and the slag aggregate particles (rather than intersecting the particles).

The petrographic evidence supports a conclusion that internal sulfate attack is the dominant distress mechanism in the examined cores. The source of the internal sulfate is the slag coarse aggregate particles. Sulfides leached from the particles are carried into the cementitious matrix of the concrete via moisture migration. Both moisture and oxygen from the atmosphere are present in the topmost portion of the pavement slabs in service. Over time, in this region of the slab, the sulfides are converted through oxidation to sulfates. These “new” internal sources of sulfates react with pre-existing hydrated calcium aluminate phases and calcium sulfoaluminate phases to produce ettringite (another hydrated calcium sulfoaluminate mineral. These expansive reactions are the source of the distress in concretes that experience internal sulfate attack.

The question remains: “Why don’t all slag aggregate concretes show this unique form of distress”? A number of factors influence this situation, which include,

- The time of exposure of the pavements.
- Variability in the chemistry, mineralogy, microstructure, and physical properties of a given source of the slag.
- Variability in the source and type of Portland cement.
- The use of supplementary cementitious materials, such as fly ash.

Air cooled blast furnace slags are useful as aggregates in Portland cement concretes for a number of reasons. They are relatively inexpensive, they are hard and sound, and their

use provides an outlet for what otherwise would be a solid waste product requiring disposal space. Despite this, their continued use does require that the type of distress associated with some of these concretes in the field must be controlled.

Currently it is not known which material variables of the blast furnace slag aggregates control their involvement in potentially destructive materials-related distress in Portland cement concretes for pavement applications. Even if a correlation could be identified, it would not be practical or economical to cull out the undesirable product. Given this situation the issue must be addressed through other avenues. These can include (1) an informed choice of cementitious ingredients to limit the effects of internal sulfate attack and ASR, and (2) providing some restraints on the accessibility of moisture to the concrete pavements in the field.

### **Implementation Potential**

There are a number of sound reasons for continuing the use of blast furnace slag as a coarse aggregate source in ODOT PCC pavement concretes.

The potential for materials-related distress in these concretes can be reduced through the following steps.

1. Select Portland cements for these concretes that have a low tricalcium aluminate content. The choice here should be ASTM C 150 Type II or (if available) Type V.
2. Always use a supplementary cementitious material (SCM) with these concretes. The SCM that is chosen should have a proven record of improving the sulfate resistance and the resistance to ASR in Portland cement concretes. Class F fly ash and slag

cement are suitable candidates. Class C fly ash should be avoided.

3. The preferred mix design for these concretes is ODOT's Class C concrete, for which the cementitious material content is 550 to 660 lb/yd<sup>3</sup> (326 to 356 kg/m<sup>3</sup>). Avoid the use of concretes that have a cement content in excess of these amounts. The intent here is to limit the amount of tricalcium aluminate that is available for participation in the undesired reactions.
4. The unique materials-related distress associated with the slag aggregate concrete is dependent on the presence of water in the concrete. The distress typically begins and subsequently is most extensive in the concrete adjacent to joints (transverse and longitudinal) and to shoulders. Steps that are taken to (1) limit the downward movement of water into the joints, (2) improve drainage in the base material, and (3) provide a cementitious phase with a low permeability, should improve the chances of limiting or eliminating the undesirable reactions. For Items (1) and (2) this calls for improved joint sealing materials and systems, and free-draining bases. For Item (3) this calls for a low water to cementitious material ratio and an acceptably low entrained air void content.