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Petrographic and Petrophysical Analysis of Decades-Old Iowa Portland Cement Concretes

tech transfer summary

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RESEARCH PROJECT TITLE
CT Analysis of Ancient Concretes

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Analysis of portland cement concrete in Iowa shows strong correlation between decreasing porosity and increasing age. This is apparently due to reduced pore space in the paste having more impact on total connected porosity than increased porosity due to coarse and fine aggregate deterioration.

Problem Statement

It has remained uncertain which properties have allowed certain portland cement concrete (PCC) pavements predating Iowa's air entrainment requirements to last so long—and whether these properties can be used to increase the durability or reduce the cost of modern pavement designs.

Background

In cold climates, the modern method for making durable PCC pavement has been to entrain air in the paste. This enables formation of an air void network that accommodates pressure increases during freezing conditions.

The Iowa Department of Transportation (DOT) has required air entrainment since 1952, and yet some Iowa pavements constructed before this time show little to no deterioration and have remained in service decades beyond their originally designed service life.

Objectives

- Study the evolution of pore networks in pre-1950 and post-1950 Iowa PCC pavements
- Interpret the deterioration of pavement aggregates

Research Methodology

To characterize PCC pavement air void networks from both before and after air entrainment became common practice in Iowa, the research team performed an integrated petrographic and petrophysical analysis on samples from 10 pavements using nondestructive and destructive evaluation methods as follows:

- Helium pycnometry to examine the total connected porosity of the air void network
- Computed tomography (CT) scanning to cross-validate the helium pycnometry results as well as to calculate pore and aggregate size distributions
- Mercury porosimetry to identify pore-throat size distributions and cross-validate CT-measured values

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- Thin sectioning to characterize the physical state of coarse aggregate particles, determine their lithology, and identify their modes of deterioration

Furthermore, a MATLAB script was developed to provide similar metrics to the RapidAir 457 Air Void Analyzer but for CT and thin section images (e.g., porosity, pore size distribution, grain size distribution).

Key Findings and Discussion

The initial hypothesis motivating this study was that pores forming around and inside deteriorating coarse aggregate particles in some unusually durable pre-air-entrainment PCC pavements are connected through pores in the paste that serve to create effective air void networks.

It was instead found through this study that the porosity of pavements showed strong correlation between decreasing porosity and increasing age. These results indicate that PCC porosity (i.e., the total percentage of air voids in a pavement) can be predicted from pavement age, at least in Iowa.

Petrographic data suggest that this phenomenon is due to a reduction of pore space in the paste, with the reduction in paste porosity having more impact than the increase in porosity due to coarse and fine aggregate deterioration.

The trend of porosity decreasing with age can be explained by the post-1950 samples' multiscale air void networks connected through three pore types:

- Micropores and fractures in the paste
- Pores formed due to coarse aggregate dissolution
- Intraparticle micropores formed due to fine aggregate dissolution

Thin section imaging and mercury porosimetry also indicated that the post-1950 pavements have smaller pore throats than the older samples.

The trend of porosity decreasing with age can likely also be explained by the pre-1950 samples' mineral growth visible in pores and reaction rims in the paste due to dissolution, which may reduce the connectivity of these older samples, decreasing their total connected porosity. Thin section imaging and mercury porosimetry indicate that pores in the older samples are mostly connected through fractures and microporosity in the paste.

While the pre-1950 and post-1950 samples have similar pore types, the deterioration mechanisms for the two groups are different. The pre-1950 samples have complete deterioration of the coarse aggregate, resulting in the formation of large pores that allow water drain through the pavement. Overall, the post-1950 samples have an interconnected air void network through deteriorating aggregate and fractures in the paste, and mineral precipitation may have reduced the connectivity of this pore network even further.

CT and helium analyses had good agreement with the RapidAir 457 Air Void Analyzer (ASTM C457) image analysis on total connected porosity. Unfortunately, although the MATLAB script used to extract PCC samples' three main phases (coarse aggregate, paste, and pores) from their respective CT images was tested with the thin section images in order to customize the segmentation algorithms to these particular Iowa DOT samples, it remained challenging to identify clear boundaries between each phase.

The main issue was the presence of voxel values that could belong to more than one phase (e.g., fine aggregate can have the same voxel value as paste as indicated by the same grayscale value and the same color in the CT images, making it difficult to differentiate the fine aggregate from the paste).

Nevertheless, the CT images did show a clear trend across grain size and pore size distributions, where the coarse aggregate size distribution coincides with the pore size distribution for all samples. Specifically, the most abundant pore sizes were formed due to the dissolution of fine aggregate and therefore their dominant sizes are similar to that of the fine aggregate grains.

CT and thin section images also showed that pores in the older pavements that are due to the deterioration of fine aggregate and smaller coarse aggregate are largely similar in size, even if somewhat more irregularly shaped, compared to pores created in more modern pavements through the use of air-entraining agents. In addition, it was observed that open pores similar in size and shape to modern air entrainment pores were visible even in PCC manufactured pre-1950 (in addition to the larger pores observed to derive from the deterioration of coarse aggregate).

This suggests that either air-entraining agents were being used before they were widely acknowledged (a "secret sauce") or that the fine aggregate has deteriorated to the extent that the resulting pores mimic the function of pores introduced via air-entraining agents.

Implementation Readiness and Benefits

This study found that some coarse aggregate pebbles are currently undergoing dissolution or have completely dissolved away, which suggests another way of creating an air void network in concrete: the inclusion of dissolvable materials. The solubility of these materials could be tailored to specific design goals.

In addition, this study suggests that—at least in Iowa—pavement age can be used as a strong predictor of PCC porosity.

Recommendations for Future Research

Future work should involve scanning-electron microscopy and geochemical analyses in order to identify the mineralogy of the dissolution rims in pores and paste to track how they can change over time in ways that are not related to fracturing.

Also, if the pore networks of PCC pavements mature over time, the researchers propose that it is necessary to monitor this evolution by regular sampling and petrographic analysis of pavements. By better understanding the evolution of the air void network and coarse aggregates in PCC, pavement engineers and materials geologists will be able to make more informed decisions when designing pavements to ensure maximum longevity and durability and thus reduce the life-cycle costs of pavements to Iowa taxpayers.