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Role of Coarse Aggregate Porosity on Chloride Intrusion in HPC Bridge Decks

tech transfer summary

The pore properties of the coarse aggregates used in high-performance concrete (HPC) play a key role in the concrete's permeability and resistance to aggressive ion intrusion.

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RESEARCH PROJECT TITLE
Role of Coarse Aggregate Porosity on Chloride Intrusion in HPC Bridge Decks

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The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

Goal and Objectives

The goal of this research was to identify an effective test method to reduce uncertainty concerning the use of certain Iowa aggregate sources for manufacturing HPC for bridge decks. The specific objectives were as follows:

- Identify the properties (such as porosity and pore throat diameter) that describe the main features of the aggregate pore structure
- Evaluate test methods for quantifying the key pore system properties of coarse aggregates
- Examine the relationship between the coarse aggregate pore system properties and concrete permeability/chloride ingress measured using both electrical and non-electrical test methods
- Provide recommendations for evaluating Iowa coarse aggregates and HPC permeability

Background

Permeability is a key parameter controling concrete durability. In reinforced concrete structures such as bridge decks, the ingress of chloride ions from deicing chemicals can corrode the reinforcing steel, leading to concrete expansion, cracking, and disruption.

High-performance concrete (HPC) has been used for years in Iowa to reduce the permeability of bridge decks. Because HPC paste permeability has been substantially reduced over the years, the permeability of the concrete's coarse aggregate has become a critical component of the bulk concrete permeability. Meanwhile, many of Iowa's high-quality carbonate aggregates have a relatively high absorption (greater than 3%).

In recent years, the Iowa Department of Transportation (DOT) has found that electrical test methods such as AASHTO T 277 or AASHTO T 538 indicate that the chloride permeability values of some HPC applications are not as low as expected.

Additionally, HPC for which rapid electrical methods indicate high permeability has been associated with highly absorptive coarse aggregate. It is not clear whether a non-electrical test method such as AASHTO T 259 would indicate the same trend.

Problem Statement

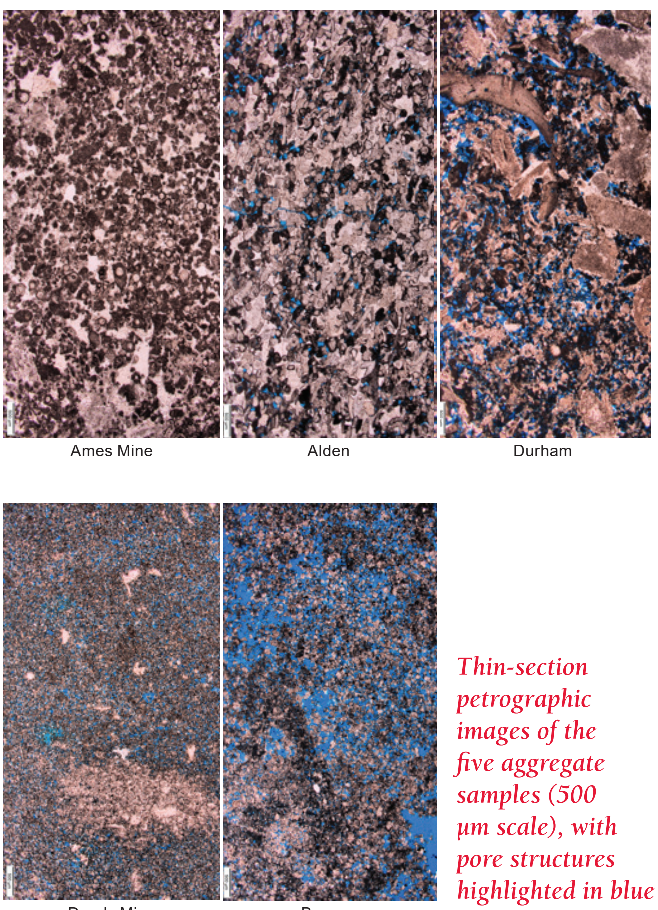
The pore structure of a concrete's coarse aggregate has become a key factor in concrete chloride permeability. It is therefore critical to investigate how coarse aggregate pore structure affects chloride permeability in HPC bridge decks and to identify test methods that effectively indicate these effects.

Research Description

Five coarse aggregates and corresponding rock samples were obtained from five different sources. The aggregates are typically available in Iowa and included three limestone (Ames Mine, Alden, Durham) and two dolostone (Douds Mine, Bowser) aggregates.

The aggregates were tested to determine their specific gravity and water absorption values and aggregate correction factor.

Cores taken from the rock samples were tested to characterize the aggregate pore properties. The tests included helium pycnometry (porosimetry); mercury intrusion porosimetry (MIP); thin-section petrographic methods, including scanning electron microscope (SEM) petrography; surface resistivity; and water sorptivity.

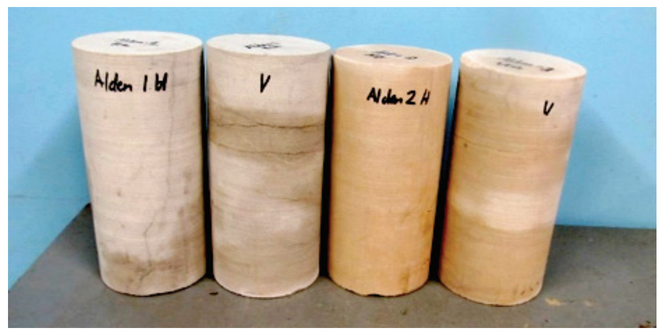


Thin-section petrographic images of the five aggregate samples (500 μm scale), with pore structures highlighted in blue

The five coarse aggregates were used to create five different HPC mixes with a given HPC mix proportion but with different coarse aggregates. A corresponding mortar mix was sieved from one of the concrete mixtures to eliminate the coarse aggregate. Concrete specimens, including cylinders and ponding slabs, were prepared from the six mixes.

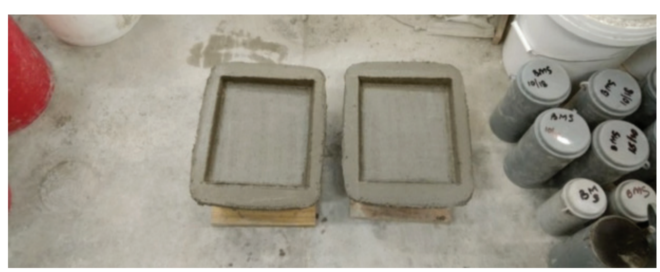
Tests were conducted on the fresh concrete mixes for quality control, and electrical and non-electrical tests were performed on the hardened concrete specimens to measure permeability/chloride penetration. The electrical tests included surface resistivity and rapid migration (Nord test), and the non-electrical tests included water sorptivity and salt ponding.

The relationships between the aggregate properties, especially regarding pore structure, and the chloride penetration resistance of concrete were examined.



Four-inch by eight-inch rock cores taken from blockstones for testing the surface resistivity of the aggregate samples

One-inch core plugs taken from the hardened concrete samples for use in mercury intrusion porosimetry tests



Slabs made from the concrete mixes for use in salt ponding tests

Key Findings

Different trends were observed for the electrical and non-electrical test methods:

- The electrical tests on the concrete specimens showed that concrete surface resistivity decreased as aggregate absorption increased, which is consistent with the Iowa DOT's findings. However, the Nord test values increased as aggregate absorption increased.
- The non-electrical tests on the concrete specimens indicated that the water sorptivity and salt ponding tests both followed the same trends. The initial sorptivity and chloride concentration increased with limestone aggregate absorption but decreased with dolostone aggregate absorption.

The following effects of coarse aggregate absorption on concrete chloride content were observed:

- The mortar mix concrete had a higher chloride content than any of the concrete specimens made with the five coarse aggregates. This indicates that fluids and chemicals penetrate concrete through the mortar and into the aggregate.
- The concrete made with higher absorption limestone aggregate had a higher chloride content after the salt ponding tests.
- The chloride content of the concrete made with dolostone aggregate decreased as aggregate absorption increased. Therefore, aggregate absorption values cannot simply be used to estimate a concrete's chloride intrusion resistance.

The following effects of the coarse aggregate pore system on concrete permeability and chloride intrusion were observed:

- Concrete surface resistivity decreased nonlinearly while the Nord test's chloride migration coefficient increased nonlinearly with the critical and threshold pore sizes of the concrete's coarse aggregates.
- For concrete made with limestone aggregate, the initial sorptivity and chloride content (measured by the salt ponding tests) increased nonlinearly with the critical and threshold pore sizes of the concrete's coarse aggregates. However, the critical and threshold pore sizes had a very small effect on concrete chloride content.
- In contrast to the concrete with limestone aggregates, the concrete with dolostone aggregates showed a decreasing trend in initial sorptivity and chloride content as the critical and threshold pore sizes of the coarse aggregates increased.

Additional important relationships between the tested parameters were observed:

- The surface resistivity of concrete made with limestone aggregate increased linearly while the surface resistivity of concrete made with dolostone aggregate decreased with the surface resistivity of the corresponding aggregate.
- For concrete made from both aggregate types, concrete chloride content (measured by the salt ponding tests) decreased as concrete surface resistivity increased, and concrete chloride content increased with concrete initial sorptivity.
- Close relationships were observed between aggregate absorption and specific gravity and between aggregate absorption and helium porosity, and a strong linear relationship was observed between aggregate helium porosity and MIP.

Recommendations for Testing

- The effects of aggregate absorption on concrete sorptivity and chloride intrusion depend upon aggregate type. Therefore, aggregate absorption should not be used as a sole criterion for concrete durability control.
- The critical and threshold pore sizes of aggregate obtained from MIP tests can be used to provide quantitative information on the pore connectivity of aggregate, mortar, and concrete.
- Thin-section tests can provide detailed information on aggregate quality, e.g., grain size and pore characteristics.
- While concrete surface resistivity is related to concrete initial sorptivity and chloride content, the concretes made with limestone or dolostone aggregate showed opposite trends in this relationship. Therefore, when the surface resistivity test is used, the type of coarse aggregate in the concrete should be known.
- For concretes made from both aggregate types, concrete chloride content measured by the salt ponding tests always increased with concrete initial sorptivity. A 6-hour initial sorptivity test can substitute for a 90-day salt ponding test for a quick evaluation of concrete chloride intrusion.

Recommendations for Future Study

- The present study examined only three limestone and two dolostone aggregates. More Iowa aggregates should be studied to verify the observed trends.
- Because fluids and chemicals can penetrate into the aggregate through the mortar, future studies should include concrete mixes with a lower water/binder ratio (w/b). Mortar that is thus less permeable may seal the permeable aggregate particles and improve concrete chloride resistance.
- The opposite trends exhibited by the limestone and dolostone aggregate concretes are probably due to a potential cement reaction at the surface of the dolostone aggregate and the internal curing provided by the stored water in the more porous aggregates. High-porosity dolostone aggregates should be further studied to explore this issue.
- A comparison study involving the construction of two field HPC overlays, one made with a low-absorption and low-sorptivity aggregate and the other made with a high-absorption and especially high-sorptivity aggregate, can be used to verify the findings from the present study.

Implementation Readiness and Benefits

Because the pore properties of the coarse aggregates used in HPC mixes are a key component of bulk concrete permeability, characterizing the coarse aggregate's pore properties is crucial for creating low-permeability concrete that can resist aggressive ion intrusion.

The recommendations provided by the present study can help improve aggregate characterization, better understand the effects of aggregate pore properties on concrete performance, and more quickly measure concrete chloride intrusion.

Additional aggregate types and samples, additional types of concrete mixes, and field HPC overlays should be studied to extend and verify the findings of the present study.