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Principal Investigator: Nancy M. Whiting, Purdue University, whiting@purdue.edu, 765.463.2000
Program Office: jtrp@purdue.edu, 765.494.6508, www.purdue.edu/jtrp
Sponsor: Indiana Department of Transportation, 765.463.1521

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Hydraulic Fracture Test to Determine Aggregate Freeze-Thaw Durability

Introduction

Carbonate rocks are the primary sources used as coarse aggregate for concrete paving in Indiana. The freeze-thaw durability of carbonates can vary greatly from durable to highly susceptible to freeze-thaw distress. Using nondurable aggregates in concrete exposed to moisture and freeze-thaw cycles can lead to serious distress and greatly decrease a pavement's service life. The testing needed to identify freeze-thaw durable aggregates can take 90 days or more to complete. The main objective of this study was to develop a reliable, quick test method for determining the freeze-thaw resistance of carbonate aggregates quarried in Indiana using the 8-day Hydraulic Fracture Test (HFT).

The underlying theory behind this accelerated test method suggests that the HFT simulates the state of stresses that develop in concrete aggregates exposed to freezing and thawing environments by inducing hydraulic pressure in aggregate particles. Oven-dry aggregates are placed in a test chamber; the chamber is then flooded with water and pressurized using a compressed nitrogen gas to force water into the pores of the aggregate. When the applied pressure is released rapidly, compressed air trapped within the aggregate pores expands, expelling water from pores and creating internal stresses in the aggregate particles, which is believed to be similar to the pressures that can develop in aggregate particles as water in the pores freezes and expands. The degree of fracturing that develops is believed to be an indication of potential freeze-thaw durability of the aggregate. Aggregate fracturing is measured as a shift in mass over several different sieves after 50 pressurization-depressurization cycles.

Aggregate samples were identified and collected from 18 quarried carbonate sources in Indiana that represent a range of freeze-thaw performance: durable (Group A), nondurable (Group B), and of variable or unknown performance (Group C). Samples of aggregate from all 18 sources were subjected to basic characterization tests (e.g., specific gravity and absorption capacity) and HFT testing using both the small MnDOT HFT chamber and newly developed Indiana Department of Transportation (INDOT) HFT chamber. Aggregates from the same sources were also used to produce concrete beams that were subjected to the INDOT modified AASHTO T161-B freeze-thaw test, ITM210 *Class AP Coarse Aggregate,* to evaluate the dilation of beams exposed to freeze-thaw cycles.

Findings

The dilation and the durability factor (DF) measurements of the ITM210 concrete beams correlated well after 350 cycles of freezing and thawing ($R^2 = 0.91$) (as shown in Figure 5.4 in the report). As expected, all aggregate sources in Group A passed the freeze-thaw test while all sources in Group B tested as nondurable based on INDOT's acceptance criteria of less than 0.060% expansion.

The experimental data was analyzed statistically, and linear regression models were developed to predict the average percent dilation and the durability factor (DF) of freeze-thaw test beams using parameters obtained from HFT results. The percent dilation predicted by the model developed using the MnDOT HFT equipment results showed a good correlation with the measured dilations, resulting in an R^2 value of 0.836 and an adjusted R^2 value of 0.71. The DF models showed poor correlation between predicted and measured DF. The MnDOT HFT equipment with the dilation model developed is considered a good screening tool.

The model developed to predict percent dilation using INDOT HFT equipment results provided an excellent correlation between the measured dilation and predicted dilation with an $R^2 = 0.892$ and an adjusted R^2 value of 0.853, indicating the model has a high degree of certainty. This model correctly predicted the durability of 14 out of 18 sources. Of the four sources incorrectly identified, one was a durable source, A3, but had a predicted dilation of 0.1068%, clearly above the INDOT 0.060% acceptance criterion (as shown in Figure 1). Three sources (B3, B6 and C7) tested as nondurable, with measured dilations ranging from 0.081% to 0.085%, but were predicted to be marginally durable with dilations ranging from

0.055% to 0.0597%, just within the acceptance criterion (as seen in Figure 1). This dilation model appears to lose some sensitivity in predicting the performance of sources in the mid-range values that failed with measured dilations at or below 0.085%.

The model developed to predict ITM210 DF using INDOT HFT results also had a very good correlation between the measured and predicted durability factor with R^2 = 0.875, and adjusted R^2 = 0.812. INDOT has not developed acceptance criteria based on DF; therefore, the model's accuracy to predict durability could not be evaluated. This DF model is recommended for further development.

Implementation

The refined INDOT HFT equipment, procedures and analysis appear to provide a quick method to evaluate the freeze-thaw resistance of carbonate aggregates quarried in Indiana predicting the 90-day AASHTO T161/ASTM C666 FT test results in 8 days. At this time it is recommended that the INDOT HFT equipment and the developed regression model to predict dilation be used as a screening test employing the following criteria:

- If the HFT results in a predicted dilation lower than 0.050%, then the aggregate is expected to be durable.
- If the HFT results in a predicted dilation greater than 0.060%, then the aggregate is likely nondurable. Actual freeze-thaw durability testing (ITM210) can be performed to confirm.
- If HFT results in a predicted dilation between 0.050% and 0.060%, then freeze-thaw durability testing (ITM210) is required to determine the aggregate durability.

Of the 18 aggregate sources tested, if the above pass/fail criteria for HFT are used, the developed model correctly identified all nondurable aggregates and all but one durable aggregate. Continued testing of additional sources according to both ITM210 and the HFT is recommended. Refining the HFT model should be revisited once additional test data are available before the HFT can be used as a specified acceptance standard.

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Figure 1. *A comparison of measured and predicted dilation values*