Project Summary

Texas Department of Transportation

0-5820: Using Cement Paste Rheology to Predict Concrete Mix Design Problems

Background

Abnormal chemical interaction between C_3A contents in cement, sulfate contents in pore solution, and certain chemical and mineral admixtures at certain temperatures sometimes causes abnormalities in workability, setting time (e.g., early stiffening or excessive retardation) and strength gain, which is generally defined as cement-admixtures incompatibilities in concrete. Cement paste rheology measurement instead of traditional concrete workability tests (e.g., slump) was considered a technically sound concept in identifying those incompatibilities before concrete is placed.

The overall goal of this research project was to develop an easy-to-use, relatively inexpensive field laboratory test and equipment to predict potential concrete mixture incompatibilities through the direct measurement of cement paste rheology. The specific objectives were:

- to develop an easy-to-use instrument based on the Superpave Dynamic Shear Rheometer (DSR) that could measure cement paste rheology with permissible repeatability and sensitivity, and
- to investigate whether potential cement-mineral/chemical admixture incompatibilities can clearly be identified through direct measurement of cement paste rheology in the laboratory.

What the Researchers Did

The suitable areas of modification/upgrade for the DSR were identified based on an extensive literature search and recommendations provided by the manufacturer. The DSR was then upgraded by adopting these recommended modifications (e.g., covering both upper and lower plates by 240 size grit paper to avoid slippage, installing closed-water circulation for temperature control, and developing a sealing cap for total evaporation control) to make it suitable for measuring cement paste rheology.

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Preliminary investigation used the modified DSR to optimize test conditions (e.g., 1 mm as optimum plate gap, 0-200/s as optimum shear rate, and longer test duration) and develop a DSR-based rheology test procedure. A special temperature-controlled, high-shear (up to 6000 rpm) cement paste mixing procedure simulated shearing effects that cement paste experiences in concrete. Both mixing and rheology measurement were conducted under controlled temperature conditions to investigate temperature effect more accurately. Another advanced rheometer device (AR 2000) along with conventional heat of hydration (HOH) and setting time tests were used as supporting tools to validate the applicability of DSR.

An extensive laboratory investigation used the modified and optimized DSR-based rheology test procedure with varieties of cements, supplementary cementitious materials, and different types and dosages of commonly used chemical admixtures under different temperature conditions.

The HOH and setting time tests were also performed for all the studied mixtures as supporting tools. A procedure to formulate rheology-based acceptance criteria was developed based on the test results generated in the main laboratory investigation. A field demonstration program was conducted to show repeatability and sensitivity of the DSR-based rheology test method. The feasibility of a cement paste mini-slump test as an alternative or supporting tool for the rheology test was also investigated.

What They Found

In the preliminary investigation, both the DSR and AR 2000 rheometers support each other as well as being fully supported by HOH and setting time results in measuring cement paste rheology with permissible reproducibility and sensitivity and identifying incompatible mixtures. This validated the applicability of DSR to measure cement paste rheology.

In the main test program, absolute values of plastic viscosity (PV) and yield stress (YS) were determined corresponding to five time intervals for all the selected mixture combinations. The rate of change of PV and YS was then calculated using their absolute values at different time intervals. Almost all the incompatible mixtures identified by HOH and setting time criteria are characterized by abnormal ranges of PV/YS rate of change. Therefore, the rheology-based test results were strongly supported by the HOH and setting time results. The rate of change of PV and YS was found to be the most sensitive parameter to identify the studied incompatible mixtures and used to develop acceptance criteria.

In the field demonstration program, permissible reproducibility of the rheological parameters based on limited mixture combinations was evident.

In the mini-slump cone test, pat area at 5 minutes seems to be a relatively better criterion than the pat area rate of change. However, cases of both false positive and negative were observed with this criterion and therefore it did not come up as an effective criterion.

What This Means

The test results showed that DSR in the modified form is capable of measuring cement paste rheology with permissible reproducibility and sensitivity and of distinguishing between normal and incompatible mixtures.

However, the number of tests conducted in the present research was not adequate to assign threshold numbers for establishing acceptance criteria. Further refinement of acceptance criteria based on detailed work covering different types of incompatibilities and field laboratory-based validation programs are warranted in order to come up with an easy-to-use, relatively inexpensive field laboratory test and equipment for cement paste rheology measurement. This future testing will ultimately help material suppliers, concrete producers, and other users detect problematic combinations of concrete ingredients during the mixture design process and thereby avoid concrete cracking and other durability issues resulting from incompatibilities.

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