TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 7-4954-S

Project 7-4954: Use of Recycled Portland Cement Concrete Fines in TxDOT Applications

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PROJECT SUMMARY REPORT

Highway Uses of Crushed Concrete Materials

The production of crushed portland cement concrete (CPCC) continues to grow year by year. Currently, in excess of 100 million tons of crushed concrete are generated annually in the United States. In conjunction with the increase of this waste product, recycling of CPCC has been suggested as an attractive alternative to disposal. Consequently, many researchers and engineers have investigated the reuse of crushed concrete materials.

Although CPCC contains particles of various sizes from inches to microns, most previous studies focused on the use of particles larger than the No. 4 sieve size relative to the use as coarse aggregates in new concrete. Since CPCC fines passing the No. 4 sieve tend to be highly absorptive and angular in nature, difficulties have been experienced in processing and using them in concrete mixtures.

The Texas Department of Transportation (TxDOT) has successfully used the coarse particles of CPCC in new concrete for various purposes. However, increased concrete crushing has resulted in growing stockpiles of CPCC fines (Figure 1). It is imperative that effective and full use of crushed concrete materials including fines be found. Therefore, this research project explored potential ways of using CPCC fines associated with TxDOT applications.

Figure 1. Stockpiled CPCC fines.

What We Did ...

The research approach for exploring potential TxDOT applications was divided into two areas: paving and non-paving. Under the framework of a joint research project, the Texas Transportation Institute (TTI) and the Center for Transportation Research (CTR) addressed paving and non-paving applications, respectively. Based on the literature review and discussions with TxDOT personnel, the research team identified the following potential items for use of CPCC fines:

- paving applications: flexible base, cement treated base, and HMA bond breaker;
- non-paving applications: portland cement concrete, flowable fill, backfill, and embankment.

Much of the research effort was devoted to a laboratory test program for material characterization. The test program focused on the identification of aggregate and mixture properties related to the current TxDOT specifications for the selected items. Properties related to constructibility, durability, and environmental issues were also addressed.

CPCC Fines

The research team characterized aggregate properties of CPCC fines including size distribution, specific gravity and absorption, unit weight and voids, plasticity index, methylene blue value, pH measurements, and chemical analysis. The methylene blue test was conducted in accordance with the modified ASTM C 837 method developed in NCHRP Project 4-19 for aggregate tests. This test is an effective way to evaluate the presence of potentially harmful materials in the fraction of an aggregate finer than the No. 200 sieve. The research team included pH measurements and chemical analysis for a comparative investigation of environmental issues. The research team collected bulk crushed concrete materials from four crushers around the state of Texas. Aggregate properties of coarse particles of crushed concrete were separately identified when they were required in conjunction with the studies of specific applications.

Use of CPCC Fines

The research team examined the feasibility of using crushed concrete materials in paving and non-paving applications. Items investigated included flexible base, cement treated base (CTB), and HMA bond breaker for paving applications, and flowable fill, portland cement concrete, backfill, and embankment for non-paving applications.

Flexible base is currently covered under TxDOT Item 247. Properties of crushed concrete mixtures were compared to those of conventional limestone base mixtures. Two different mixture gradations were determined so as to produce test mixtures containing 42 and 22 percent of materials passing the No. 40 sieve. All test mixtures were compacted at the optimum moisture content (OMC). CTB mixtures consisting of 100 percent crushed concrete materials as well as conventional limestone base materials were characterized and compared. The test program relative to CTB applications, covered under Item 276, focused on the properties related to shrinkage cracking behavior and moisture susceptibility of mixtures. The test program included compressive strength (ASTM C 39; D 1633), modulus of elasticity (ASTM C 469), free shrinkage measurements (ASTM C 157), stress relaxation test, restrained shrinkage ring test, and tube suction test. The research team determined eight test mix factorials for each aggregate source by two-level, three-variable experimental design with the variables of coarse and fine aggregate proportions and cement content.

All test mixtures were also compacted at OMC. HMA bond breaker mixtures containing CPCC fines were evaluated for hot mix design properties (Tex-204-F) and moisture susceptibility (Tex-531-C), and compared to the conventional mixture properties. The research team determined three mix designs, Design A, B, and C, with three different aggregate sources, conventional aggregates, CPCC fines, and manufactured sand (washed and regraded CPCC fines). Design A was the control mix consisting of conventional materials. Designs B and C included the two types of CPCC fines at 40 percent substituting the fine aggregates in the control mix. The inclusions of CPCC fines were determined in accordance with Item 3116 Type B, which is covered under Item 345.

Nine mixtures of flowable fill, as covered under Item 4438, were mixed and evaluated based on both their fresh and hardened properties. Mixtures containing concrete sand, CPCC fines, and a blend of the two were evaluated. In addition, both air entrained and fly ash supplemented mixtures were cast and evaluated. Researchers investigated the feasibility for using CPCC fines as fine aggregates in TxDOT Class A concrete.

Four mixtures of concrete were evaluated based on their fresh and hardened properties. Three mixtures contained CPCC fines and one mixture contained a blend of CPCC fines and ASTM C 33 concrete sand. All mixtures were designed as 5-sack mixtures and used the maximum manufacturer's suggested dosage of mid-range water-reducing admixture. The standard requirements for materials used in backfill and embankment were compared to the properties of CPCC fines to evaluate the possibility of using CPCC fines in these applications. Backfill and embankment are currently covered under Item 400 and Item 132, respectively.

What We Found …

CPCC Fines

The aggregate characterization program showed that, in general, CPCC fines are non-plastic, highly absorptive, and highly variable in size distribution. CPCC fines also contained a substantial amount of materials finer than the No. 200 sieve. This fraction of the material contained both particles of hydrated cement and other contaminates, such as soil and clay. The methylene blue value was much higher than that of typical concrete sands. This test result indicates that difficulties may be encountered, especially with regard to water demand, when using CPCC fines as aggregates in concrete mixtures.

The pH measurements showed high alkalinity of CPCC fines. Removal of ultra fine materials passing the No. 200 sieve helped to reduce the high alkalinity of CPCC fines. The alkalinity does not necessarily imply any negative impact on the environment. For the environmental considerations, a more specific study is needed concerning contaminative leachate problems for applied mixtures. The tests for RCRA total contents showed that the CPCC fines contain higher levels of RCRA metals than typical virgin and manufactured sands. However, when two samples were tested to assess these metals' ability to leach, the levels detected in 15 of the 16 cases were below the detectability limits of the test.

These values are substantially lower than the present Environmental Protection Agency values for Toxicity Characteristic Leaching Procedure (TCLP). Similar values for the Synthetic Precipitation Leaching Procedure (SLPL) test were unavailable to the researchers. In the single case in which levels were detectable, they barely exceeded the detectability limits of the test. Thus, although measurable amounts of heavy metals may exist in CPCC fines, the leaching characteristics of these metals are more important than the presence of the metals in the sample.

Paving Applications

Flexible Base

1. The use of crushed concrete materials resulted in increased water demand to reach Optimum Moisture Content. Furthermore, an excessive capillary rise was observed for crushed concrete mixtures under a continued soaking condition, indicating possible moisture susceptibility of the mixture.
2. However, the strength test results indicated that crushed concrete mixtures are not so susceptible to moisture as suggested by the absorptive properties.
3. The strength of crushed concrete mixtures satisfied, for the most part, the minimum requirements of Item 247. Crushed concrete mixtures always showed higher strength than conventional mixtures.
4. Test results support the use of crushed concrete materials including CPCC fines in flexible base mixtures.

Cement Treated Base

1. Although the compressive strength of crushed concrete mixtures was generally lower than that of conventional CTB, crushed concrete mixtures were shown to satisfy the requirements of Item 276 when the cement content is properly selected.
2. A proportional relationship was observed between compressive strength and modulus of elasticity of CTB mixtures. Therefore, the modulus of crushed concrete mixtures was also lower than conventional.
3. Prediction models were established for the dependent compressive strength and modulus of elasticity of CTB. Agreement was observed between test data and estimations. The proposed models are expected to be useful for any CTB mixture.
4. The use of crushed concrete materials also resulted in greater tendencies of the mixture for drying shrinkage as well as stress relaxation.
5. As a combined effect of all relevant material properties, it was found that crushed concrete mixtures are not more vulnerable to shrinkage cracking compared to conventional CTB, although a crushed concrete mixture has

lower strength and higher tendency to shrinkage. Lower modulus of crushed concrete mixtures produces smaller stress under given strain, and the strong relaxation property seems to further reduce the stress to the level that could avoid cracking.

6. As in the flexible base application, the use of crushed concrete materials resulted in increased water demand to reach OMC. Unlike flexible base mixtures, however, all CTB mixtures showed stable dielectric values under continued soaking. Cement treatment seems to reduce capillary rise in the mixture and to subsequently eliminate moisture susceptibility.
7. As experienced by many TxDOT districts, crushed concrete materials including CPCC fines are highly recommended for use in CTB mixtures.

HMA Bond Breaker

1. According to the gradation requirements of Item 3116 Type B, the maximum substitutions of crushed concrete materials were determined at 40 percent of total aggregates for both manufactured sand and CPCC fines.
2. The use of crushed concrete materials resulted in a slight increase of the optimum asphalt content but higher strength and stability. In general, design properties of the mixtures satisfied the requirements of Item 345.
3. Crushed concrete mixtures were also shown to be more susceptible to moisture than conventional mixtures with regard to strength. When moisture sensitivity is a primary design criteria for a bond breaker material, limited amounts of lime could be used as a stabilizer.
4. Crushed concrete materials including CPCC fines are recommended for use in HMA bond breaker mixtures.

Non-paving Applications

Flowable Fill

1. Flowable fill can be produced using CPCC fines instead of conventional aggregates, such as ASTM C 33 concrete sand.
2. Due to the large amount of minus No. 200 material in the CPCC fines, it was difficult to entrain air into flowable fill mixtures containing this material. Therefore, trial mixing is recommended when air-entrainment is desired. Trial mixing will identify any potential problems with air-entrainment for a specific source of CPCC fines.
3. The high level of minus No. 200 material in the CPCC fines increased the water demand of flowable fill using CPCC fines.
4. For the same mixture proportions, flowable fill with CPCC fines was weaker than flowable fill using conventional aggregates.
5. Increasing the cement content of the mixtures compensated for the strength decrease due to the increased water demand.

Portland Cement Concrete

1. The use of CPCC fines in portland cement concrete caused increased water demand and severely diminished workability.
2. Even with large dosages of water-reducing admixtures, concrete using CPCC fines was extremely stiff and unworkable.
3. As a result of the increased water demand and low workability, CPCC fines should not be considered as potential aggregates for portland cement concrete.
4. An abundance of TxDOT applications capable of using unwashed and ungraded CPCC appear to exist. Therefore, the future production of the washed CPCC fines should be reevaluated to ensure the most efficient use of the entire crushed product.

Backfill and Embankment

1. Aggregate properties of both unwashed and washed CPCC fines meet current TxDOT standards for Items 400.5, Backfill, and 400.6, Cement Stabilized Backfill.
2. The properties of both unwashed and washed CPCC fines also meet current TxDOT standards for Type C embankment.
3. CPCC fines are recommended for use in these applications.

The Researchers Recommend …

The research team proposed revisions of TxDOT specifications, which allow the use of CPCC fines in the selected applications, except portland cement concrete application. The following considerations are suggested regarding field implementation as well as other areas of future study.

1. Efforts should be immediately undertaken to implement the use of CPCC fines in HMA bond breaker, flexible base, flowable fill, and backfill applications.
2. A better method to determine the specific gravity and absorption of high fines materials, such as CPCC fines, should be developed.
3. Continued efforts should be made to reduce the amount of CPCC fines produced and/or find additional uses for the material.
4. Although not a major concern, the presence of heavy metals and their ability to leach from CPCC fines should perhaps be further investigated. If significant levels of heavy metals are found in CPCC fines, an investigation to determine both the source of these contaminates and their ability to leach from the sample should be performed. An assessment of acceptable SPLP limits and procedures for accurately assessing the levels of heavy metals and their ability to leach from various samples may need to be developed.
5. Flexible base mixtures consisting of crushed concrete materials showed so-called bulking behavior when the test specimens were compacted. It is recommended that field studies address workability, especially related to compaction and finishing of the layer.
6. Material behavior under repeated loading and environmental cycling should be identified in the field as well as the laboratory. Specific interest is given to resilient modulus and permanent deformation for flexible base and fatigue behavior for CTB applications.
7. Flowable fill mixture proportions for mixtures incorporating CPCC fines should be investigated with the objective of reducing the amount of fly ash used in flowable fill using CPCC fines due to the high amount of minus No. 200 material in CPCC fines. This reduction in fly ash content could eliminate concerns of long-term strength gain and excavatability.

For More Details . . .

The research is documented in Report 4954-1, *Characterization of Crushed Concrete Materials for Paving and Non-Paving Applications.*

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TxDOT Implementation Status—January 2005

Some of the recommendations from this research are being implemented by the Houston District. A formal implementation project is not envisioned at this time.

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