Summary of Testing of Recycled Crushed Concrete

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ABSTRACT

To investigate the performance of recycled concrete aggregates (RCA), physical test data from 1977 through 1982 are summarized in order to present typical characteristics of the RCA material. In situ deflection test results on various projects since 1974 are summarized. Deflection testing was performed on pavements constructed with crushed stone, asphaltic concrete, and recycled crushed concrete base courses. Analysis of the data indicates that the pavements constructed with recycled crushed concrete bases have strengths equal to or higher than stone or asphalt base pavements. The results of both laboratory work and test pavement experiments on the use of RCA in asphaltic concrete mixtures are also presented. In both cases it was found that the RCA-asphalt mixtures have 1.5 to 2.0 times the stability and are 15 percent lighter than a standard crushed stone-natural sand mix. In addition, the RCA mixture requires 0.5 to 1.0 percent more asphalt cement to have equal air voids and filled criteria. Finally, data from the Texas State Department of Highways and Public Transportation's long-term experience with the use of RCA-asphalt mixes are presented.

In 1977 a recycling corporation located in Hicksville, New York, began producing recycled concrete aggregates (RCA). Since the inception of the company more than 1.0 million cubic yards of material have been produced and sold for use as a granular dense-graded base course on various residential roads and parking fields throughout Nassau and Suffolk counties.

The original plant equipment consisted of a 22 x 50-in. Telsmith jaw crusher, a 48-in.-diameter Telsmith cone crusher, a 5 x 16-ft double-deck vibrating screen, and miscellaneous chutes and conveyors. This equipment was used to crush and screen the recycled materials.

In 1982 additional equipment was added to the plant, which consisted of a 45-in.-diameter fine cone crusher and a 5 x 16-ft triple-deck vibrating screen.

All concrete used for recycling was obtained from various locations throughout Nassau and Suffolk counties and consisted of concrete from sidewalks, driveways, curbs, and a limited amount of pavement.

The purpose of this paper is to summarize the results of quality assurance testing performed by consulting engineering firms, private laboratories, and county and town engineering departments. The testing was performed on material supplied to road reconstruction projects throughout Nassau County. In addition, experience relating to the use of RCA in asphaltic concrete mixes is summarized.

TESTS AND EVALUATION OF RECYCLED CRUSHED CONCRETE

During the 1977-1982 construction seasons a substantial amount of testing was performed because of the large volume of material used. The results of this testing are summarized in order to present typical physical characteristics of the RCA material.

Specifications required that samples be obtained from the supplier's stockpile and from the field after the material was placed, graded, and rolled. The field sampling was supervised by representatives of Nassau County and the consulting engineer on the particular project. The frequency of the testing was as follows:

1. Stockpile samples were taken each day of production and a washed gradation analysis (ASTM D422) was performed.
2. Every 2 weeks a stockpile sample was obtained and the following tests were performed: Los Angeles abrasion test (ASTM C131), magnesium soundness test (ASTM C88), plasticity index (ASTM D424), California bearing ratio (CBR) test (ASTM D1883), and moisture density test (ASTM D1557).
3. Field samples were obtained each week from Nassau County and town of Hempstead betterment projects, and the following tests were performed: washed gradation analysis (ASTM D422), Los Angeles abrasion test (ASTM C131), magnesium soundness test (ASTM C88), plasticity index (ASTM D424), CBR test (ASTM D1883), and moisture density test (ASTM D1557).

Testing Results from 1977 Through 1982

A summary and comparison of the test results for the years 1977 through 1982 are given in Figures 1 and 2. A study of Figure 1 indicates that the average gradation curve falls within a relatively narrow limit. Figure 2 shows a comparison of physical properties of RCA from 1977 through 1982. The values of Los Angeles abrasion, magnesium soundness, and maximum dry density are all extremely consistent from year to year. The CBR test results are relatively uniform from 1978 through 1981. There was a dramatic increase in CBR values in 1982. This increase is consistent with the addition of a third crusher to the plant operation; the increase in the quantity of crushed particles would explain the increase in stability.

A statistical analysis of the data indicates that from 1977 through 1982 the Los Angeles abrasion mean value was 36.5 percent and the standard deviation was 3.6 percent. The magnesium soundness results showed a similar consistency, with a mean value of 3.75 percent and a standard deviation of 1.3 percent. This was based on 112 Los Angeles abrasion tests and 107 soundness tests.

The CBR and maximum dry density test results were analyzed during two periods: from 1977 through 1981 and for 1982. The plant crushing operation was changed in 1982 and the additional crushing would effect the CBR and density results more than the abrasion and soundness values. The analysis indicated that before 1982 the CBR mean and standard deviation results, based on 133 tests, were 143.8 and 28.7 percent, respectively. In 1982 the values, based on 24 tests, were 168.7 and 27.2 percent. The maximum density results before 1982 had a mean value, based on 119 tests, of 128.5 pounds per cubic foot (pcf) with a standard deviation of 2.6 pcf. In 1982, 24 tests were reported and the results showed

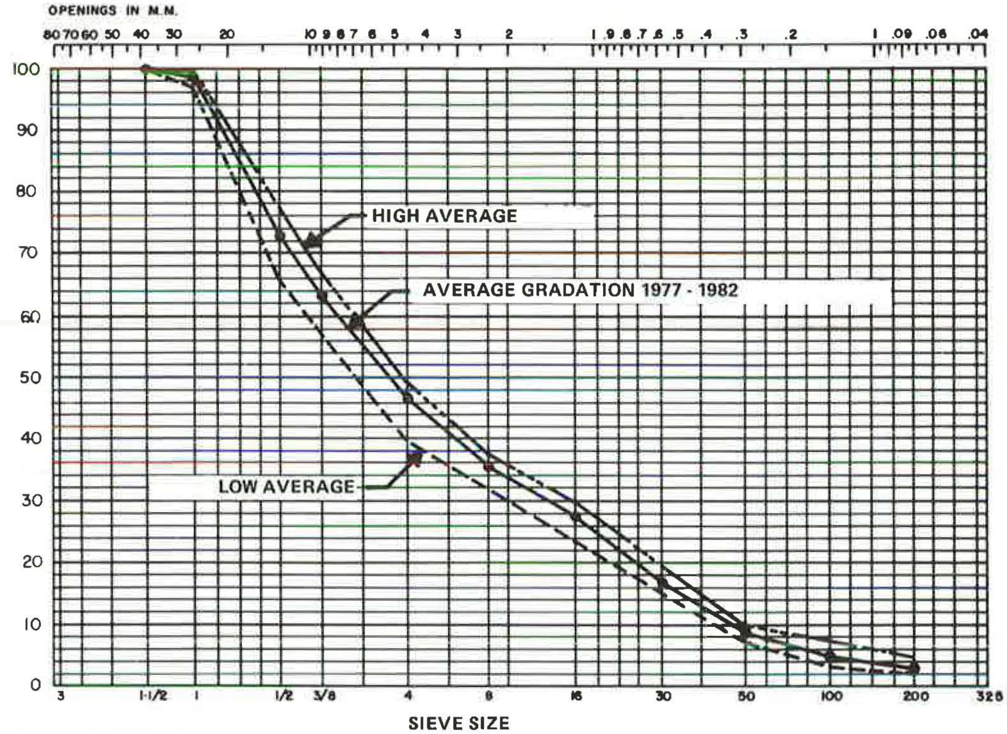


FIGURE 1 Yearly comparison of gradation testing.

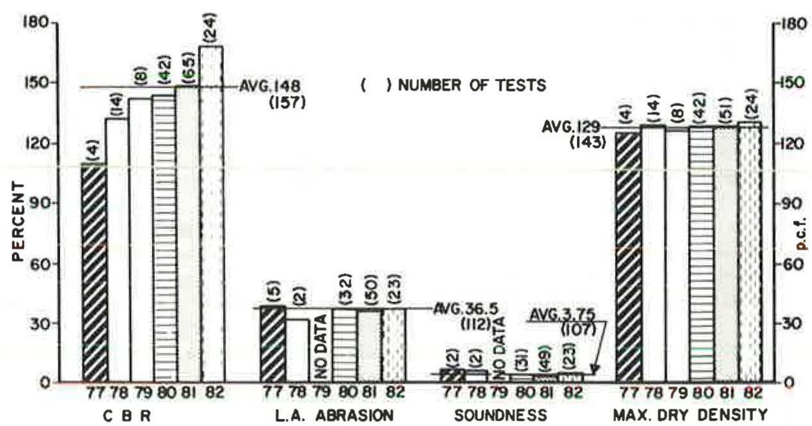


FIGURE 2 Yearly comparison of physical tests (1977-1982).

an increase in mean maximum dry density to 130.0 pcf with a standard deviation of 1.6 pcf. The crushing and screening operation at a recycling plant apparently can have a considerable effect on the stability of RCA granular base material.

One other physical test was performed consistently since 1977--the plasticity index. A total of 106 tests were performed and the plasticity index was zero (nonplastic) for all tests.

Evaluation of Recycled Concrete Dense-Graded Aggregate Base

An enormous quantity of testing indicates that recycled crushed concrete consistently complies with all the parameters required for excellent long-term performance. The material is well graded, it is nonfrost susceptible, the fines are nonplastic, and the material is crushed and has cubical shaped, rough textured particles.

The RCA material exhibits high strength and stability (average CBR of 148). The magnesium soundness and Los Angeles abrasions are consistent with mean values of 3.75 and 36.5 percent, respectively. All test results are well above the minimum specification requirements for dense-graded aggregate bases and subbases.

Additional Studies

An independent study of RCA was performed by the Port Authority of New York and New Jersey (1). The initial scope of work was limited to the testing of RCA for use as an alternative material for a dense-graded aggregate base course, which is the highest quality unbound aggregate currently used by the Port Authority.

The RCA materials were evaluated for the following characteristics: resistance to wear, resistance to breakdown, resistance to weather, absorption of water and specific gravity, gradation, compaction, bearing capacity, chloride content, and composition of material. The materials tested by the Port Authority were sampled from five recycling plants located within New York City and Westchester County.

A comparison of the physical test properties for the material from the five plants in the Port Authority report and the Hicksville plant is given in Table 1.

TABLE 1 Comparison of Physical Properties from Various Recycling Plants

Test	Port Authority Report	Hicksville Plant Report
Los Angeles abrasion (%)	37.1	36.5
Magnesium soundness (%)	3.3	3.5
CBR[a] (%)	148.0	148.0
Maximum dry density (pcf)	128.0	128.8

[a]CBR corrected for reverse curvature.

The Port Authority testing was performed in 1982; the results given in Table 1 are the average of five tests, one for each of the producers. The Hicksville data are an average of all data since 1977 and represent approximately 150 tests. The physical properties show an amazing consistency. The Port Authority report studied the potential effect of compaction on the RCA in order to approximate the amount of breakdown (degradation) that would occur under field conditions. The test method used was developed by the New Jersey Inter-Agency Engineering Committee and uses the modified Proctor compaction test. The test was performed on RCA obtained from each of the five producers, as well as on dense-graded aggregate base material samples made from trap rock, gneiss, and dolomitic limestone. The RCA samples ranged from 4.4 to 14.5 percent loss with an average of 9.8 percent. The loss for trap rock, gneiss, and dolomitic limestone was 13, 14, and 24 percent, respectively.

The Port Authority also presented nondestructive testing data that were performed on a field installation of one supplier's RCA, which indicated that the in-place bearing of the specific supplier's RCA was equal to or greater than that of a control installation of typical quarry-processed dense-graded aggregate base course (DGABC) material.

The final report, issued in June 1983, made the following conclusions and recommendations.

1. The results of laboratory testing indicate that RCA has the potential to be used as an alternative for DGABC. However, because of the divergent sources of raw material and the resultant variability of RCA, a formal quality assurance system, in which the contractor is responsible for his quality control and the owner exercises a comprehensive acceptance testing plan, is required.
2. Current soil aggregate specifications for fill, filter material, and pipe bedding should be reviewed to include the use of RCA.
3. Any initial field installation of RCA should be monitored to evaluate its materials handling characteristics and the compactive effort required to obtain satisfactory density.
4. RCA is readily available in the New York area, as evidenced by the existence of eight producers of this material at this time. This should result in competitive pricing of this material and lower materials costs to the Port Authority.
5. If RCA is deemed an acceptable substitute for DGABC, the potential benefits include lower construction costs, reduced energy use, and effective use of a waste material.

IN SITU TESTING OF PAVEMENTS

During the past few years attempts have been made to measure the in situ strength of pavements constructed with recycled crushed concrete aggregate bases.

The method used in this determination was to measure pavement rebound deflections caused by a standard truck with an axle load of 18,000 lb. The equipment used for measuring the deflections was a Benkelman beam. Deflections have been used in evaluating pavements since the early 1950s. This experience has shown that long-term pavement serviceability with minimum maintenance will occur if the initial characteristic spring-time deflection of the pavement is less than or equal to 0.050 in. for secondary roads (2). (Note that characteristic deflection is the mean value plus 2 standard deviations.)

All deflection testing was performed by Sidney B. Bowne and Son, Consulting Engineers, Mineola, New York. All the work was in conjunction with road reconstruction projects within the town of Oyster Bay, New York. The procedure used by the consultant was to perform a deflection survey on the original pavement before reconstruction, and then a second survey on the finished reconstructed pavement. The town allows three pavement alternatives: a 3-in.-thick asphalt base, a 6-in. dense-graded crushed stone base, and a 6-in. dense-graded RCA base.

Each of the equivalent pavements were topped with a 1.5-in. binder course followed by a 1-in. wearing surface. A summary of all the deflection data since 1974 is given in Table 2.

TABLE 2 Summary of Pavement Strengths

	Stone Base	Asphalt Base	Crushed Concrete Base
Weighted average, final characteristic deflection (in.)	0.050	0.034	0.023
Weight reduction in deflection (%)	33.13	44.90	60.88
No. of projects	3	12	5
Total square yards of pavement tested	39,000	339,853	309,420

The data in Table 2 indicate that all the pavements are performing well. However, the pavements constructed with RCA bases are stiffer and stronger than the crushed stone and the full-depth asphalt base pavements.

RCA IN ASPHALTIC CONCRETE MIXES

Locally, within the past 3 years, there has been an effort to use RCA in asphaltic concrete mixes. This effort included a pavement test strip at Abbey Lane in the town of Hempstead in 1981, plus some additional unmonitored binder work in the town in 1982. During this time some laboratory mix designs were made to compare RCA-asphalt mixtures to asphaltic concrete made with standard virgin aggregates. In 1982 a second, more extensive, test strip was constructed in Hempstead at Blacksmith Lane in Levittown.

Laboratory Studies of RCA-Asphalt Mixes

Abbey Lane

On July 22 and July 23, 1981, a laboratory study was performed and a comparison of the Marshall test properties was made between a New York State (NYS) type 3 binder made with 100 percent RCA and an identical mix using 50 percent crushed stone and 50 percent natural sand. The aggregate gradations are given in Table 3.

TABLE 3 Abbey Lane Type 3 Binder Mix

Sieve Size	Job Mix (% passing)	Specification (% passing)
1.5 in.	100	100
1 in.	100	95-100
0.5 in.	74.4	70-90
0.25 in.	65.3	48-74
0.125 in.	55.1	32-62
No. 20	30.7	15-39
No. 40	18.3	8-27
No. 80	6.9	4-16
No. 200	2.5	2-8

Note: For asphalt concrete, the job mix had various percentages passing and the specifications called for 4.5 to 6.5 percent passing.

Three Marshall specimens (50 blows per side) were made at each asphalt cement content for each mix. The standard stone-natural sand mix was molded at 4.5, 5.0, and 5.5 percent asphalt contents. The RCA mix used 5.0, 5.5, and 6.0 percent. All mixes were compacted at a temperature of 255°F and the gradations of all specimens were identical. The test procedure conformed to ASTM C1559, and nine molds were made for each mix.

The optimum asphalt contents, based on stability alone, would be 5.00 percent (Marshall stability = 1,539 lb) for the standard stone-natural sand mix and 5.50 percent (Marshall stability = 2,550 lb) for the RCA mix (see Table 4).

TABLE 4 Summary of Marshall Test Results, Abbey Lane

Mix	Asphalt Content (%)	Stability (lb)	Flow	Density (pcf)
Standard stone-natural sand mix	4.50	1,428	10	146.5
	5.00	1,539	11	148.4
	5.50	1,418	13	149.6
RCA mix	5.00	2,285	10	123.8
	5.50	2,550	11	123.7
	6.00	2,383	14	125.4

A comparison of the tests results revealed some surprising facts. The RCA-asphalt mix had stability values approximately 60 percent higher than the crushed stone-natural sand mixes at all asphalt contents studied. The comparison also indicated that the RCA mix was approximately 16 percent lighter than the stone mix.

Based on the laboratory study, the RCA mixes had considerably higher stability and offered a potentially enormous economy because it would require approximately 16 percent fewer tons of mix to pave equivalent areas of equal thickness. With this information in hand, it was then decided to construct the Abbey Lane test strip.

Blacksmith Lane

The asphalt base mixes used on Blacksmith Lane were the same as those for Abbey Lane. The job mix formula from Abbey Lane was used for the type 3 RCA mix and the type 3 crushed stone mix. An additional job mix formula was developed by using HVEEM criteria for the emulsion base. The emulsion base was formulated to conform to the NYS type 3 binder specification. The emulsion mix design was performed by McConnaughay Asphalt Lab in Lafayette, Indiana.

A comparison of the RCA type 3 and the standard crushed stone-natural sand job mix formula showed results similar to the Abbey Lane project. At their optimum asphalt contents of 5.7 percent for the RCA mix and 5.0 percent for the standard mix, the Marshall stability and density of the RCA mix was 70 percent higher and 11.5 percent lower, respectively. It should be noted that the air voids at these optimum asphalt contents were 3.20 percent for the RCA mix and 4.23 percent for the standard mix. The 5.0 percent asphalt content should probably be increased by approximately 0.2 percent to equalize the voids. This would increase the density, and the difference in densities would be closer to the 16 percent difference noted on Abbey Lane. The mix design for the RCA type 3 mix is given in the following table:

Compactive Effort	Value
Blows per side	50
Optimum asphalt content (%)	5.7
Marshall stability (lb)	2,700
Flow	13.2
Air voids (%)	3.2
Voids filled (%)	77.0
Unit weight	135.0

Comparisons of Mix Designs

In 1981 and 1982 the Materials Testing Lab of Flushing, New York, made Marshall mix designs for two New York State Department of Transportation (NYSDOT) mixes consisting of a type 3 binder and a type 6 top. These mixes were tested with RCA and with crushed stone and natural sand. Comparisons of the mixes are shown in Figures 3 and 4.

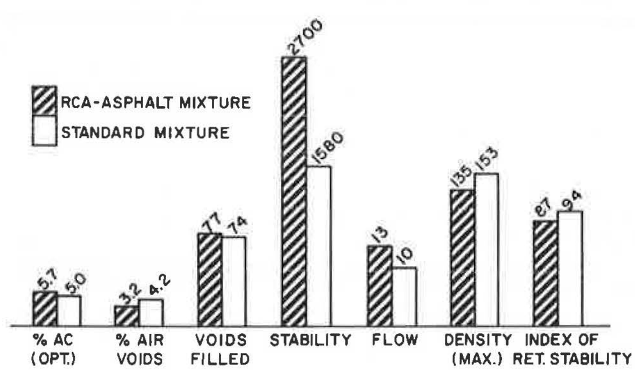


FIGURE 3 Comparison of Marshall properties (NYS type 3 binder).

The mix design comparison shows the following consistent characteristics:

1. At a given percent asphalt content (%AC) the RCA mixes have from 1.5 to 2.0 times the stability of the crushed stone-natural sand mixes.
2. At a given %AC the density of the RCA mixes is approximately 15 percent lighter than the stan-

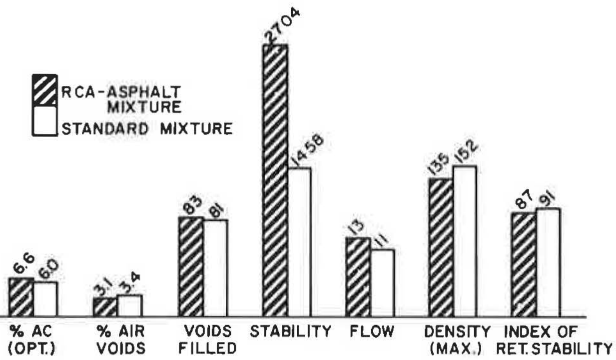


FIGURE 4 Comparison of Marshall properties (NYS type 6 top).

dard mix. The RCA mix will cover 15 percent more volume for the same tonnage as the crushed stone-natural sand mix.

3. The RCA mix requires approximately 0.5 to 1.0 percent more AC to have equal air voids and void filled criteria.

Test Pavement Experiments

Abbey Lane

In June 1981, Lizza Industries and Twin County Recycling Corp. combined their efforts to sponsor a test strip where a RCA-asphalt cement pavement could be constructed and tested. A testing program was developed in order that the quality of the mix could be monitored and compared with other standard paving materials.

The town of Hempstead, the largest township in the United States, volunteered to participate in the experimental road section.

The town had a project under construction in Levittown, New York, and a section of roadway 780 ft long and one lane wide was chosen as the location of the controlled test strip. Lizza Industries was the general contractor of the existing construction project. The consulting engineering firm of Sidney B. Bowne and Son was retained by the town to do the quality control and write an evaluation report for the project. The experimental mix chosen for this investigation was a NYS type 3 binder.

In order to control the construction and strive for uniformity, it was decided to test the subgrade to locate any weak soil conditions. On August 14, 1981, representatives of Sidney B. Bowne and Son performed a Benkelman beam deflection survey on the subgrade area to be used in the test strip. The testing was witnessed by representatives of Nassau County Department of Public Works, Town of Hempstead Department of Public Works, and Twin County Recycling Corp.

Test points were chosen in two paths parallel to the curb line. The first path was 4 ft 3 in. east of the edge of the west-side concrete gutter. The second path was 6 ft east of the first path. Deflection readings were taken at 20-ft intervals along these paths, and 80 readings were obtained from station 4+50 to station 12+50. The proposed test section was 14.50 ft wide (one-half the pavement width) and was bounded by the edge of the west-side gutter and the centerline of Abbey Lane.

An analysis of the deflection reading indicated that the subgrade condition for all three sections of the test strip were approximately equal in strength and unformity. This ensured that one of the most important variables of the experiment (i.e., the subgrade strength) was constant for each of the three bases to be evaluated.

On August 18 the controlled test strip was constructed. The purpose of the test strip was to evaluate the structural performance of three base course materials:

1. NYS type 3 binder: 2.5 in. thick made with crushed stone and natural sand with 5.00 percent asphalt cement,
2. NYS type 3 binder: 2.5 in. thick made with 100 percent RCA and mixed with 5.00 percent asphalt cement, and
3. Item 398: DGABC comprised of recycled crushed concrete 5 in. thick.

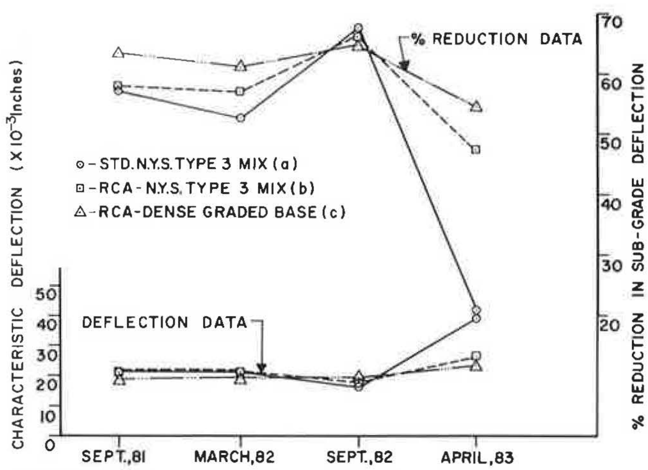
The gradation specifications are given in Table 5.

TABLE 5 Gradation Specifications for DGABC

Sieve Size	Percent Passing	Sieve Size	Percent Passing
1.5 in.	100	No. 16	22-36
1 in.	90-100	No. 30	11-27
0.5 in.	65-85	No. 50	6-20
0.375 in.	55-75	No. 100	3-15
No. 4	40-55	No. 200	1-10
No. 8	30-45		

A 2-in.-thick layer (NYS type 6 mix) was placed on the experimental base strips as a wearing course. All of the asphalt mixes were produced by Midhampton Asphalt Company in Hicksville, New York. (Midhampton Asphalt Company is a subsidiary of Lizza Industries.)

On August 27 a second deflection survey was performed on top of the finished base, and on September 30 a third deflection survey was performed on top of the 2-in. asphaltic concrete wearing course. The deflection surveys on the wearing course were repeated on March 18, 1982, on September 9, 1982, and on April 26, 1983. A summary of the Abbey Lane Test data is shown in Figure 5.



(a) Average core density from 8 tests = 145.26 pcf, average Marshall density from 3 tests = 148.28 pcf, average Marshall stability from 3 tests = 1,544 lb, and average % AC from 6 cores = 5.33 percent.
(b) Average core density from 13 tests = 128.63 pcf, average Marshall density from 3 tests = 129.56 pcf, average Marshall stability from 3 tests = 2,266 lb, average Marshall flow from 3 tests = 11.0, and average % AC from 9 cores = 5.60 percent.
(c) CBR from 1 test = 191 percent.

FIGURE 5 Abbey Lane deflection data.

The final report by Sidney B. Bowne and Son, issued on July 11, 1983, concluded the following (3):

1. "The deflection testing has shown the RCA type 3 to be performing better than the NYSDOT type 3."

2. "The results of the second spring deflection test performed April 26, 1983, as well as a plot of percent change from subgrade versus time, indicate that section III (RCC base) is the most consistent in performance followed by section II (RCA type 3 base) and section I (NYSDOT type 3 Base), in that order."

Blacksmith Lane

In early 1982 a committee of engineers was formed in order to design a second, more extensive test strip on Blacksmith Lane in the town of Hempstead. This experiment would duplicate the work of Abbey Lane with some additional quality control. In addition, a stone base and an emulsion base pavement were tested. A total of seven 300-ft-long, 29-ft-wide test sections were constructed. Two of the seven sections were topped with a NYS type 6 wearing surface mix using RCA. The remaining five sections used a standard crushed stone-natural sand type 6 mix.

In addition to plant extractions and plant Marshall specimens being made, a careful elevation survey was made at the top of each of the pavement layers so that an accurate thickness determination could be made for the base and the wearing course. Deflection surveys were also made on the top of each pavement layer.

The firm of Sidney B. Bowne and Son was retained to do the quality control and write the evaluation report.

A deflection survey and an elevation survey were performed on top of the subgrade on August 5 and 6, 1982, just before placement of the base course. This process was repeated on top of the finished bases on August 5, 6, 10, and 12. The deflection and elevation surveys on the finished pavement were completed on September 9 and 13.

A summary of the deflection data to date from Blacksmith Lane is given in Table 6.

The preliminary report by Sidney B. Bowne and Son, issued in September 1982, stated the following (4):

> Examination of the data will show that all sections are performing approximately the same with the exception of the RCA/EMULSION (insufficient curing time may be the reason). All the S.B. and RCC sections are approximately equal, while the RCA TY 3 is performing better than either the NYSDOT TY 3 or RCA/EMULSION TY 3.

LONG-TERM PERFORMANCE OF RCA-ASPHALT MIXES

The state of Texas and the city of Minneapolis, Minnesota, both have had successful experiences with RCA-asphalt mixes for long periods of time. Texas, in particular, has RCA-asphalt pavements that date back to 1969. Some of the projects in Texas that use RCA-asphalt mixes are given in Table 7.

Two papers that were presented at the annual Association of Asphalt Paving Technologists (AAPT) meetings of 1976 and 1980 outline the details of this work (5,6). The papers present information on mix designs, design gradations, and properties of the in-place mixes.

In July 1983 the authors of this paper made visual inspections of US-54 and State Highway 36.

Construction History of US-54

In 1972 US-54 was reconstructed from Farm Road (FM) 694 (approximately 6 miles southwest of the intersection of US-87 and US-54) for a distance of 15.4 miles southwest to Middle Water, Texas. The original pavement consisted of an 8-in.-thick calieche crushed stone base with a 2-in. asphalt concrete wearing course.

The pavement was widened to include shoulders, and the entire area was overlaid with a 3-in. asphalt concrete base, topped with a 2-in. RCA asphalt concrete wearing surface. The wearing surface was made in a standard batch plant, and the aggregates were 100 percent recycled crushed concrete with a 6.1 percent type AC-10 asphalt cement. The recycled concrete was obtained from an abandoned airport

TABLE 6 Blacksmith Lane Deflection Test Results

Base Pavement Material	RCA Type 3	Standard Type 3	RCA-Emulsion Type 3	Crushed Stone[a]	Crushed Stone[a]	RCA Base	RCA Base
Property thickness (in.)	2.5	2.5	2.5	5	5	5	5
Subgrade characteristic deflection[b] (in.)	0.070	0.068	0.043	0.086	0.067	0.072	0.076
Base characteristic deflection[c] (in.)	0.064	0.048	0.046	0.030	0.052	0.032	0.044
Wearing course characteristic deflection[d] (in.)	0.017	0.027	0.024	0.023	0.020	0.023	0.023
Change in subgrade deflection (%)	76	60	44	73	71	67	70

[a]Wearing course 2-in. thick with RCA-asphalt type 6 mix.
[b]Survey performed August 5 and 6, 1982.
[c]Survey performed August 5, 6, 10, and 12, 1982.
[d]Survey performed September 9 and 13, 1982.

TABLE 7 Texas Projects Using RCA-Asphalt Mixes

Highway	Pavement Type	Location	Date Constructed
US-54	Wearing course	From FM 694 to Middlewater in Hartley County (15.4 miles)	1972
US-60	Wearing course	From Lipsomb County line to Glazier in Hemphill County (5.5 miles)	1974
US-60	Wearing course	From Glazier to US-83 (8.4 miles) in Hemphill County	1979
I-40	Wearing course	1 mile west of McLean to 1 mile west of Alan Reed in Gray County in westbound lane[a]	Under construction
State Highway 36	Base and binder course	From Lyons north to Caldwell (12.12 miles) in Burleson County	1969

[a]Eastbound lane is a 10-in. continuous reinforced-concrete pavement with RCA as coarse aggregate; it is currently under construction.

pavement. The coarse aggregate in the concrete was a local river gravel.

Traffic

Moderate traffic was noted during the study. Representatives of the Texas State Department of Highways and Public Transportation (TSDHPT) stated that approximately 3,000 vehicles per day used the two-lane highway. Approximately 30 percent of the traffic was heavy trucks. Representatives from TSDHPT noted that there were no weigh stations on US-54 and that there is a serious problem with overloaded trucks with excessively high tire pressure.

Climate

The climate conditions are extremely severe. The yearly high-low temperature range is from 100°F to -15°F.

Present Pavement Conditions

The pavement showed no signs of alligator cracking (fatigue cracking) and there was no evidence of rutting in the cross section. There was a continuous longitudinal crack at the centerline of the road located at the paving construction joint. In addition to the longitudinal crack, there were transverse temperature cracks approximately 25 to 50 ft on center throughout the entire 15-mile length. The cracks appear to be nonload associated and appear to be caused by the severe temperature conditions.

Construction History of State Highway 36

In July 1969 reconstruction of 12.12 miles of State Highway 36 in Burleson County, Texas, was completed. The cross section of State Highway 36 consisted of a prepared embankment of lime-stabilized subgraded material 8 in. thick, overlaid with 10 in. of lime-stabilized crushed clayey sandstone. This was topped with 5 in. of asphalt-stabilized base, 2.5 in. of type B surface mix, and 1 in. of type E modified surface mix.

Before construction the existing pavement was a lightly reinforced-concrete slab with a bituminous concrete overlay that was no longer suitable for traffic. The old concrete and asphalt pavement were recycled together and the material was used for the aggregate in the new asphalt-stabilized base as well as the type B surface mix.

Tests performed on the recycled blend of aggregates indicated that the material had a free asphalt cement content ranging from 0.1 to 0.9 percent and a Los Angeles abrasion value of 32 percent.

Two basic mixture designs were used on the project. The initial design consisted of a blend of the recycled aggregate and a locally available field sand in an 85 to 15 percent proportion at the cold feed.

Job control extraction tests yielded asphalt cement contents of 5.3 to 7.1 percent. Excess asphalt cement present in the recycled aggregate was caused by the old asphalt concrete overlays and was the reason for the relatively high asphalt cement contents obtained from the field samples.

The asphalt-stabilized base was surfaced with 2.5 in. of type B surface mixture in one lift. Two basic mixture designs were used for this layer. The initial design consisted of a blend of 65 percent coarse recycled aggregates, 15 percent fine RCA, and 20 percent field sand combined with 4.8 percent asphalt cement. The second design consisted of a blend of 35 percent coarse recycled aggregates, 25 percent of fine recycled aggregates, 12.5 percent of coarse and 12.5 percent of fine washed river gravel, and 15 percent of field sand combined with 4.6 percent asphalt cement.

The new pavement was surfaced with a 1-in.-thick crushed stone-slag hot-mix surface course. The aggregates used were 30 percent crushed limestone, 45 percent Alcoa slag, and 25 percent field sand. The aggregate blend was combined with 6.5 percent type AC-10 asphalt cement to form a mixture with an average Hveem stability of 40. Construction of the two-lane highway was completed in 1969.

Traffic

Representatives from TSDHPT reported that approximately 7,000 vehicles per day, of which approximately 40 percent are heavy trucks, used this two-lane road. Because of the extreme activity in oil field construction in this area, TSDHPT has issued special overload permits for gross weight to 110,000 lb. However, trucks weighing in excess of 200,000 lb have been recorded on State Highway 36.

Climate

The climate is moderate with no extreme temperature ranges. There was no evidence of non-load-associated transverse cracking in local pavements.

Existing Pavement Condition

There was no sign of pavement rutting or shoving in the cross section. Cracking was minimal, and only three small patched areas were noted in the entire 12-plus miles of pavement.

SUMMARY AND CONCLUSIONS

Test data for RCA from 1977 to the present have been compiled and summarized herein. During this period an enormous amount of data has been obtained. All physical test results have been uniform and have shown high strength, stability, and durability qualities.

An independent study of RCA by the Port Authority of New York and New Jersey shows close agreement with the Hicksville plant data with respect to test results on strength, stability, and durability of RCA. This close agreement of test values indicates a consistency of physical properties. Finally, both reports indicate that any degradation caused by handling and compaction is equal to or less than that which would occur with standard quality granular base materials.

An attempt has also been made at measuring and comparing the in situ strengths of various pavement types by using pavement deflection test results from 1974 to the present. Five projects, totaling approximately 310,000 square yards, have demonstrated that roads constructed with recycled crushed concrete bases can provide strong, stable, and economical pavements that exhibit strengths equal to or greater than other standard quality granular base materials.

Laboratory studies to determine the feasibility of using RCA in asphaltic concrete indicated that the RCA mixes had 1.5 to 2.0 times the stability of crushed stone-natural sand mixes. The RCA mixes are approximately 15 percent lighter than standard mixes, and therefore will cover 15 percent more volume for the same tonnage. The RCA mixes will require approximately 0.5 to 1.0 percent more AC to have equal air voids and voids filled criteria.

Based on the laboratory findings, two controlled test strip pavements were constructed. A testing program was developed so that the quality of the mix could be monitored and compared with other standard paving materials. Test results from the two controlled strips indicate that the RCA mixes are performing better than the standard paving mixes, and that if properly designed and constructed, RCA-asphalt mixes are capable of providing a strong, economical, stable pavement that will yield low deflections.

Pavements constructed in Texas as long as 14 years ago confirm that the RCA-asphalt mixes can yield excellent long-term performance. TSDHPT has enough confidence in RCA-asphalt mixes to have let a contract to pave an Interstate highway with an RCA-asphalt mix.

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Study of Aggregates Used for Concrete in Kuwait

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ABSTRACT

The research reported in this paper was necessitated by (a) the great volume of local and international building contracts in the Middle East and (b) the search for the reasons behind the phenomenon of extensive concrete deterioration. Petrological classification, and chemical and x-ray analyses were performed on the aggregates used for concrete production in Kuwait. The results indicated that the coarse aggregates contain no deleterious materials and have no potentially adverse reactions. Thus the aggregates are suitable for good concrete production. Fine aggregates in their unwashed condition are contaminated with clay and contain too much fines, which necessitates careful washing before being used. High-quality concrete made with these aggregates should be expected if efficient washing of the sand is made and if proper mix design and workmanship are provided.

Concrete in the Middle East has been the subject of several recent publications (1-4). The Middle East, however, is a large area that is vaguely defined. Most of the papers that have the words Middle East in their titles tend to generalize certain conditions that may be true only in a limited part of the area. Evans (5) summarized some important information related to the geology and soil conditions of the countries in the Arabian penninsula: Iran, Iraq, and Egypt. His report implied the distinct differences in concrete products in each of these various countries because of several different factors related to materials, geology, climate, and other variations. Thus, in spite of the temptation for arriving at general rules, it should be borne in mind that local conditions in each state can be of major significance. It is believed that determination of the properties of the constituents of concrete in each region is essential for understanding the factors that influence its behavior in the fresh and hardened conditions.

In this paper identification and properties of the aggregates used in the concrete industry in Kuwait are reported. The reported results are part of continuing research aimed at obtaining a basic understanding of the causes of concrete deterioration in this part of the Middle East.

GENERAL DESCRIPTION

The state of Kuwait is situated in the northeast corner of the Arabian peninsula. It is bordered by Iraq to the north and west, by Saudi Arabia to the south, and by the Gulf of Arabia to the east (Figure 1). Kuwait covers about 15,900 km^2 and has a popu-