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Performance of Continuously Reinforced Concrete Pavement Containing Recycled Concrete Aggregate

Moon C. Won

Performed in Cooperation with the Texas Department of Transportation and the Federal Highway Administration

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16. Abstract: In 1995, the Texas Department of Transportation (TxDOT) began reconstruction in Houston on a section of IH-10 with continuously reinforced concrete pavement (CRCP). The unique aspect of this project was the use of crushed concrete as both coarse and fine aggregates in the new concrete. No virgin aggregates were used. The primary objectives of this study were to evaluate (1) the material properties of recycled concrete aggregate (RCA), (2) their effect on paving operations, and (3) in-situ concrete properties to identify the reasons for good pavement performance. The properties of recycled aggregate measured in this study compared with virgin aggregate are consistent with those reported elsewhere: low specific gravity, higher water absorption, sulfate soundness loss, LA abrasion loss, and thermal coefficient. Little variation was observed in the paving operation due to the use of 100 % recycled coarse and fine aggregates. The moisture control of recycled aggregate, especially fine aggregate, is critical in producing consistent and workable concrete. The performance of the reconstructed CRCP has been excellent, with tight crack widths and little spalling. Between concrete with virgin aggregates and concrete with recycled aggregates, there is no significant difference in thermal coefficient and permeability; however, there are significant differences in modulus of elasticity, compressive and indirect tensile strength, and water absorption. The low modulus of RCA concrete and good bond between recycled coarse aggregates and new mortar appear to be the key ingredients for good pavement performance.

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PERFORMANCE OF CONTINUOUSLY REINFORCED CONCRETE PAVEMENT CONTAINING RECYCLED CONCRETE AGGREGATE

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ABSTRACT

In 1995, the Texas Department of Transportation (TxDOT) began reconstruction in Houston on a section of IH-10 with continuously reinforced concrete pavement (CRCP). The unique aspect of this project was the use of crushed concrete as both coarse and fine aggregates in the new concrete. No virgin aggregates were used. The primary objectives of this study were to evaluate (1) the material properties of recycled concrete aggregate (RCA), (2) their effect on paving operations, and (3) in-situ concrete properties to identify the reasons for good pavement performance.

The properties of recycled aggregate measured in this study compared with virgin aggregate are consistent with those reported elsewhere: low specific gravity, higher water absorption, sulfate soundness loss, LA abrasion loss, and thermal coefficient. Little variation was observed in the paving operation due to the use of 100 % recycled coarse and fine aggregates. The moisture control of recycled aggregate, especially fine aggregate, is critical in producing consistent and workable concrete.

The performance of the reconstructed CRCP has been excellent, with tight crack widths and little spalling. Between concrete with virgin aggregates and concrete with recycled aggregates, there is no significant difference in thermal coefficient and permeability; however, there are significant differences in modulus of elasticity, compressive and indirect tensile strength, and water absorption. The low modulus of RCA concrete and good bond between recycled coarse aggregates and new mortar appear to be the key ingredients for good pavement performance.

Key Words: recycled concrete aggregate (RCA), CRCP, pavement performance, spalling

BACKGROUND

The Texas Department of Transportation (TxDOT) lately determined that, for pavements with heavy truck traffic, continuously reinforced concrete pavement (CRCP) should be used instead of other portland cement concrete pavement types. This decision is based on many years of experience with various types of concrete pavements in metropolitan areas such as Houston, Dallas, Fort Worth, and El Paso. The primary reason for the use of CRCP in metropolitan areas is its durable nature and proven performance history under heavy traffic, which results in significant savings in life cycle cost. However, some CRCP sections have been in service for many years and are approaching the end of their lives.

In 1995, TxDOT's Houston District began a rehabilitation project on a 9.3 km (5.8 miles) section of IH-10 between IH-45 and Loop 610 West to replace the distressed pavement as well as to provide high-occupancy vehicle (HOV) lanes. There are two typical sections. One is a 28 cm (11 in) concrete slab on top of a 2.5 cm (1 in) bond breaker, which sits on the existing CRCP. The other is a 36 cm (14 in) concrete slab on top of a 7.5 cm (3 in) bond breaker, which sits on 15 cm (6 in) of lime-treated subgrade. The original CRCP was constructed in 1968 and served heavy traffic for almost 30 years.

The contractor decided to utilize demolished concrete from the existing pavement for concrete aggregate. The decision was primarily based on economic reasons. All the aggregates used in this project, both coarse and fine, are recycled aggregates, with no virgin aggregate used. It is believed that this is the only CRCP project to date where all the aggregates used in concrete, both coarse and fine, were recycled aggregates.

TxDOT required that the recycled aggregate meet the same specification requirements as virgin aggregates. The performance of the section has been excellent, with tight crack widths, few minor spallings, and no punchouts. The original aggregate in the crushed concrete was siliceous river gravel (SRG). Normally, meandering cracks and spalling problems have been observed within a few years when SRG is used as coarse aggregate in CRCP. It has been a pleasant surprise to TxDOT that the typical meandering cracks and spalling associated with the use of SRG have not taken place in this project. TxDOT is so pleased with the performance of this CRCP section that it is planning to use recycled aggregates in the El Paso District in the near future for an IH-10 CRCP reconstruction project. In the El Paso project, the concrete in the existing CRCP section will be crushed and utilized as aggregates.

During the early stages of the project, some concerns were expressed by TxDOT staff as well as by some researchers regarding potential performance problems with the use of recycled aggregates. Their concerns included low concrete strength, high water absorption of the concrete, sulfate and chloride level in the concrete and a potential for premature concrete deterioration due to delayed ettringite formation (DEF). A research study was conducted to evaluate the use of RCA in CRCP and to address these concerns.

OBJECTIVES AND SCOPE OF THE STUDY

The objectives of this study were to evaluate (1) the material properties of recycled concrete aggregate, (2) their effect on paving operations, (3) in-situ concrete properties to identify the reasons for good pavement performance, and (4) to address the concerns described above. The scope of this study included (1) laboratory evaluation of recycled concrete aggregate, (2) field evaluation of paving operations, (3) evaluation of the field performance of CRCP sections containing 100 % RCA, (4) identification of the in-situ concrete properties using cores taken from CRCP sections, and (5) additional material properties evaluation to address the above-mentioned concerns.

SUMMARY OF RECYCLED CONCRETE AGGREGATE PROPERTIES

Table 1 summarizes the material properties of recycled concrete aggregates as reported earlier *(1)*, as well as newly obtained information. Most of the values are in agreement with those reported elsewhere. A summary of the general properties are described below:

1. Recycled coarse aggregates have lower specific gravity, higher water absorption, LA abrasion loss, thermal coefficient, and sulfate soundness loss compared with those of virgin aggregates.
2. Recycled fine aggregates have lower specific gravity and higher water absorption than virgin siliceous sand.
3. The amount of old mortar attached to the original virgin aggregate is about 30 % by volume of total recycled coarse aggregate.
4. Freeze-thaw of RCA is comparable to that of lightweight aggregates.
5. ASR potential of this specific coarse recycled aggregate as evaluated by ASTM C1260 is less than the limit (0.1 %).
6. Recycled fine aggregates are more angular than virgin siliceous river sand as evaluated by the National Aggregate Association method.

EVALUATION OF IN-SITU CONCRETE PROPERTIES

A total of 15 cores were taken representing the entire project. In-situ concrete properties considered to affect CRCP performance were evaluated. These properties were compared with the in-situ properties of concrete with virgin aggregates. These properties include:

Strength;
Modulus of elasticity;
Thermal coefficient of expansion;
Chloride and Sulfate;
Density;
Water absorption; and
Permeability.

In addition, petrographic analysis was conducted to identify the potential for distress due to chemical reactions in concrete.

Strength – The compressive strength values range from 29.4 MPa (4260 psi) to 36.3 MPa (5270 psi) with an average of 31.8 MPa (4615 psi). Indirect tensile strength values range from 2.9 MPa (415 psi) to 3.7 MPa (535 psi) with an average of 3.3 MPa (486 psi). These values are lower than typical values for concrete with virgin aggregates. A vast amount of in-situ concrete strength data, where all the aggregates used were virgin, were collected as a part of the QC/QA specification development *(2)*. The average compressive strength was 38.9 MPa (5650 psi) and the average indirect tensile strength was 4.1 MPa (593 psi). These comparisons indicate that concrete with recycled aggregate produces lower strength. It has been observed that concrete strength does not correlate well with pavement performance in terms of spalling and punchouts in CRCP. For example, concrete with SRG has higher strength than concrete with limestone or lightweight aggregate; however, the CRCP performance of concrete with SRG is generally poorer than that with limestone or lightweight aggregates *(3,4).* As with limestone or lightweight aggregate, the lower strength of concrete with RCA should not be equated with it being an inferior material or a poor performer.

Modulus of Elasticity – It has been observed that the CRCP performance depends to a great extent on the modulus of elasticity of concrete. The lower the modulus of the concrete, the better the performance. The average value was 17.8 X106 MPa (2.58 million psi), which is much lower than that of normal concrete and is comparable to that of lightweight aggregate concrete. Modulus values obtained from cores taken from lightweight aggregate sections in Houston range from 16.1 MPa to 16.8 MPa (2.34 to 2.44 million psi). Normally, concrete made with SRG has about 34.5 x106 MPa (5 million psi) and limestone concrete has about 27.6 MPa (4 million psi). About 30 % of RCA volume is old mortar attached to the original aggregates and therefore, the concrete with RCA contains more mortar volume than concrete with virgin aggregate. Typical paving concrete mix with virgin aggregate contains 50 % mortar, whereas 68 % of the volume of the concrete in this project is mortar, a 36 % increase in mortar volume. Mortar is less stiff than river gravel and, therefore, the concrete with RCA is expected to have a lower modulus than that with virgin river gravel. However, the reduction in modulus of RCA concrete is greater than expected. A low modulus of concrete results in lower concrete stress due to environmental loading (drying shrinkage or thermal volume change), resulting in fewer cracks. This low modulus of RCA concrete may explain the large crack spacing in the project.

Coefficient of Thermal Expansion (COTE) – Since the early cracks in CRCP develop due to drying shrinkage and temperature changes, the thermal coefficient of expansion of concrete has a significant effect on early cracking in CRCP *(5).* COTE was measured in accordance with Test Method Tex-428-A *(7).* The average values range from 8.5 to 9.5 $\mu\varepsilon$/C (4.7 to 5.3 $\mu\varepsilon$/F). This value is comparable to that of concrete with virgin aggregates and much lower than the value reported previously *(1).* Since mortar has higher COTE values than aggregates, and RCA concrete has 36 % more mortar volume than concrete with virgin aggregates, it was expected that concrete with RCA would have higher COTE values *(6).* However, the values obtained in this study are comparable to or slightly lower than those of concrete with SRG.

Chloride and Sulfate Content – One of the concerns raised is the potential deterioration of concrete with RCA due to high chloride and sulfate content. The chloride and sulfate values were obtained in accordance with Test Methods Tex-617J and Tex-620J, respectively *(7).* The average sulfate value obtained is 1436 ppm and the average chloride content is 0.03 kg/m^3 (0.04 lb/cy). Chloride and sulfate contents in concrete with virgin aggregates were evaluated from cores off of new bridge decks. The average chloride value from 98 specimens was 0.005 kg/m^3 (0.007 lb/cy) with a standard deviation of 0.011 kg/m^3 (0.015 lb/cy). For the typical concrete mixtures normally used in practice, the threshold chloride content to initiate corrosion is in the range of 0.6 to 0.9 kg/m^3 (0.8 to 1.2 lb/cy) *(8).* Even though it contains more chloride than the concrete in new bridge decks, the chloride content of the RCA concrete is much lower than the threshold value for steel corrosion. However, this result does not mean that chloride might not be a potential problem for RCA concrete in locations where deicing salts are used. Normally, deicing salts are not needed in the Houston area, which explains the low chloride content in RCA concrete. In northern states where deicing salts are used extensively, the use of recycled aggregates might result in higher chloride contents in concrete. The average sulfate value was 1947 ppm with a standard deviation of 2834 ppm. This evaluation indicates that the concrete with RCA has a higher chloride content and lower sulfate content than those from new bridge deck concrete.

Density – Since the RCA has lower specific gravity than virgin aggregate due to the mortar volume attached to the original aggregate, it is expected that the density or unit weight of concrete will be lower than that of normal concrete. The densities of concrete from several mix designs for this project range from 2.16 to 2.21. The density obtained from the cores range from 2.19 to 2.36, with an average of 2.24, which indicates the consolidation of concrete during construction was satisfactory, as further evidenced by few honeycombs and by limited segregation of aggregates.

Water Absorption – Water absorption was evaluated in accordance with ASTM C 642. The average absorption was 10.86 % with a standard deviation of 1.93 %. In TxDOT research project 0-1887, water absorption was analyzed using the cores taken from concrete pavement sections with virgin aggregates. Water absorption values for SRG concrete, limestone concrete, and lightweight aggregate concrete were 5.0 %, 6.6 %, and 12.6 %, respectively. This comparison indicates the water absorption of RCA concrete is much higher than that of concrete with natural virgin aggregates and is comparable to the lightweight aggregate concrete. This higher value is due to the 36 % increase in mortar volume for RCA concrete over concrete with virgin aggregate. It is believed that this high water absorption of the RCA concrete may not cause performance problems in the Houston area due to the mild weather conditions; however, in northern states where freeze-thaw is prevalent, it may have an adverse effect on pavement performance.

Permeability – The permeability of concrete was evaluated in accordance with ASTM C 1202. The values from eight specimens range from 366 to 628 Coulomb, with the average value of 466 Coulomb. These values are surprisingly small compared with those from normal concrete. The values for the concrete from high performance concrete bridge decks vary from 1050 to 1150 Coulomb at one year. This bridge deck concrete had 6 sacks of cement with 30 % Class C fly ash. It was expected that the larger volume of mortar in RCA concrete would make it more permeable; however, this test result showed that was not the case. According to ASTM C 1202, RCA concrete is classified as very low in chloride penetrability, whereas concrete from high performance concrete bridge decks is classified as low in chloride penetrability.

The correlation among the variables described above was investigated. Figure 1 shows the relationship between concrete density and compressive strength and absorption. It appears that the compressive strength increases as density goes up to 2.22, after which the density does not have a significant effect on strength. As expected, as density increases, a general trend of decrease in absorption is observed. It is also expected that the permeability of concrete will be affected by absorption; however, the relationship between permeability and absorption was not evaluated due to the fact that the same specimens could not be used for both tests.

Petrographic Analysis – The portion of concrete cores were evaluated under a scanning electronic microscope (SEM) to identify any adverse chemical reactions due to the use of recycled aggregates. Figure 2 shows the SEM image of concrete, which includes both old and new mortar in coarse aggregate. The interface between old and new mortar appears to be sound, even though the bond strength was not quantified in this study. Also, most of the failure planes during the strength testing were not at the interface, but through the new mortar or through new and old mortar. It is observed that all the air voids in the old mortar are filled with deposits, while the air voids in the new mortar remain empty. Figure 3 illustrates the bitmap image of the section shown in Figure 2. High sulfate level of the deposits in the air voids in the old mortar indicates they are ettringite. These ettringite deposits were also observed in the crushed coarse aggregates before they were used for concrete. These ettringite formations do not seem to cause any deterioration in the surrounding concrete and it is believed that these ettringite deposits are innocuous. Even though the maximum concrete temperature was not measured in this project, data from other projects indicate that the maximum concrete temperature in Houston during the summer placement is about 63 C (145 F), which is lower than the temperature that is considered to trigger delayed ettringite formation (70 C) *(9).* Cracks were observed in the transition zone between old mortar and original gravel aggregate surfaces; however, those cracks were free of ettringite. The original concrete that was crushed for this project did not have distress due to alkali-silica reaction (ASR) and no ASR gel was observed in the concrete cores.

EVALUATION OF CONCRETE MIXING AND PAVING OPERATIONS

In the beginning of the project, the contractor had trouble producing concrete with consistent workability and with the minimum strength required. The primary reason for inconsistent workability was due to the lack of moisture control of the recycled aggregates. A better sprinkler system was installed later for aggregate stockpiles, and moisture of the recycled aggregate was better controlled. This system mitigated the inconsistent workability problem. Meeting the minimum strength requirement was a challenge. Strength values fluctuated as the project progressed, and, on several occasions, the average 10 flexural strength value went down below 3.67 MPa (533 psi), in which case the contractor had to make changes in the mix design. The low average strength has been partly due to one or two very low strengths, which might indicate occasional production of low strength concrete or the poor handling of test beams. However, TxDOT recognized the adverse effect of recycled fines on concrete strength and developed a special provision in 1999 to limit the recycled fines in concrete to a maximum of 20 %. Paving operations were closely monitored to identify any variations that might result from using the recycled aggregate. Not much difference has been observed.

Construction crews were interviewed for their opinion and experience with handling RCA concrete. One of the most often heard comments was that the concrete was not consistent. The next was that concrete sometimes set too quickly. This quick-setting problem is believed to be caused by recycled fine aggregate not being saturated during the mixing. In one instance, over 100 feet of concrete had to be removed because the concrete set too quickly and was no longer workable. Construction crews stated that when the concrete was of good workability, the finishing operation was not much different from normal concrete paving.

FIELD PERFORMANCE

Field performance of the pavement was evaluated in terms of transverse crack spacing, crack widths, and spalling. Figure 4 shows the crack spacing distribution. The average crack spacing was 2.19 m (7.19 ft) with a standard deviation of 1.36 m (4.45 ft). This crack spacing is larger than that of SRG concrete and is comparable to that of limestone concrete *(10).* Low modulus of elasticity and medium COTE of this concrete appear to offset the effect of low concrete strength on cracking behavior of this concrete. Crack width was measured in the shoulder. Overall, cracks were tight, with the majority of crack widths ranging from 0.2 mm (0.008 in) to 0.7 mm (0.028 in). For the CRCP to perform satisfactorily, cracks need to be kept tight. Tight crack width provides good load transfer and minimizes the water intrusion into cracks. Even though the measured crack widths are small, the variability in the crack width measurements can be substantial, mainly due to the changes in crack width along a crack. The variability is also due to the temperature effect. In an experiment in this study, crack width was measured every 3 inches along the crack. In one crack, the crack width varied from 0.4 mm (0.016 in) to 0.8 mm (0.031 in). Therefore, during the crack width measurement, caution was taken to measure representative crack width.

Some researchers have suggested that crack width depends on the crack spacing *(11)* because the crack width is the summation of concrete volume changes in the concrete between the cracks and, therefore, the longer the crack spacing, the larger the crack width. Figure 5 shows the relationship between crack spacing and crack width obtained in this study. Crack spacing used here is the sum of the two halves of the slab lengths on both sides at the crack. Figure 5 does not show a good correlation between crack spacing and crack width. There is at least one study that shows the same finding *(5).*

Several reasons are possible for the poor correlation, even though theoretical models predict a good relationship. One of them is the time of crack occurrence. If the cracks occur at early ages, say within several days after the concrete pouring, those cracks will open up relatively wider than the cracks that occur later. Any decrease in concrete volume due to subsequent drying shrinkage after cracking will show up as wider cracks. On the other hand, if the cracks develop at later ages, the concrete volume change due to the subsequent drying shrinkage will be small, resulting in smaller crack widths. Another reason for the poor correlation would be the existence of cracks that do not go through the slab. During the full depth repair of several CRCP sections that were between 10 and 30 years in service, it has been observed that some cracks do not go all the way through the concrete slab. The widths of these partial-depth cracks will be smaller than those of full-depth cracks due to the restraint provided by the bottom portion of concrete. In this study, not all the cracks were evaluated for their depths and no further analysis was conducted in this regard.

Spalling has not been a problem in this project. Figure 6 shows the typical surface condition of the pavement in this project. As mentioned above, spalling has been the major problem in CRCP in Houston when virgin SRG is used as a coarse aggregate. One 12-year-old CRCP project in Houston, where the coarse aggregate used was SRG, had such severe spalling that the project had to be overlaid with limestone aggregate concrete. Another CRCP project in Houston, which is also about 12 years old and has SRG aggregate, will be overlaid next year due to severe spalls. Figure 7 shows a typical CRCP section containing virgin SRG with a spalling problem. In these two projects, severe spalling occurred within a few years. There are a couple of theories proposed to explain the spalling mechanism. One is the intrusion of incompressible materials into the crack and the other is the development of horizontal cracks due to poor curing *(12).* However, neither theory explains the difference in spalling occurrence between CRCP sections with virgin SRG and RCA. Perhaps poor bond strength at the early ages between the smooth surface of virgin river gravel and mortar might have been responsible for severe spalling problems in sections with virgin SRG. It appears that the weak bond between virgin SRG and mortar develops at early ages when the concrete is still plastic and undergoes large moisture loss. This topic is under investigation in TxDOT research project 0-1887. On the other hand, petrographic analysis shows a good bond between old mortar and original siliceous river gravel aggregate in coarse RCA. It appears that once the bond between mortar and SRG surface survives the volume change strains and stresses during the hardening stages of concrete without cracking, good bond will eventually develop. Also, there is a good bond between old and new mortar, as shown in Figure 2. It is believed that this good bond is responsible for the minimal spalling problems in the RCA section.

CONCLUSIONS

Based on the results of this study, the author has drawn the following conclusions:

1) recycled concrete aggregate properties

- Recycled coarse aggregates have lower specific gravity, higher water absorption, LA abrasion loss, thermal coefficient, and sulfate soundness loss compared with those of virgin aggregates.
- Recycled fine aggregates have lower specific gravity and higher water absorption than virgin siliceous sand.
- The amount of old mortar attached to the virgin aggregate is about 30 % by volume of total recycled coarse aggregate.
- Freeze-thaw of RCA is comparable to that of lightweight aggregates.
- ASR potential of this specific coarse recycled aggregate as evaluated by ASTM C1260 is less than the limit (0.1 %).
- Recycled fine aggregates are more angular than virgin siliceous river sand as evaluated by National Aggregate Association method.

2) In-situ properties of concrete containing 100 % recycled coarse and fine aggregates

- Compressive and indirect tensile strengths are lower than that of concrete with virgin aggregates.
- Modulus of elasticity is much lower than that of concrete with virgin aggregates.
- Coefficient of thermal expansion is comparable to that of concrete with virgin aggregates.

- Chloride content is higher than that in the concrete with virgin aggregates.
- Sulfate content is comparable to that in concrete with virgin aggregates.

- Density is lower and water absorption is higher than those of concrete with virgin aggregates are.
- Permeability is classified as “very low” according to ASTM C 1202.
- Ettringite deposits were found in the air voids in the old mortar of recycled coarse aggregates; however, these ettringite deposits do not seem to cause any damage to the surrounding concrete.

3) concrete mixing and paving operations

- Moisture control of recycled aggregate, especially fine aggregate, is critical in producing consistent and workable concrete mixes.
- No significant adjustment is necessary in paving operations due to the use of 100 % recycled coarse and fine aggregate in concrete.

4) performance of CRCP with 100 % recycled aggregates

- The pavement has performed well. No distresses, including spalling, wide cracks, and punchouts have taken place.
- The transverse crack spacing distributions are comparable to those in concrete with virgin limestone.
- Low modulus of concrete and good bond between recycled coarse aggregate and new mortar appear to be the key ingredient of good pavement performance.
- The large amount of old mortar in recycled coarse aggregate does not appear to have an adverse effect on CRCP performance.

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TABLE 1 Material Properties of Recycled Concrete Aggregates

materials	properties	test method	test result for RCA	typical value for virgin gravel or siliceous sand
coarse aggregate	specific gravity	ASTM C127	2.45 ~ 2.48	~ 2.6
	mortar content	*	about 30 %	n/a
	water absorption	ASTM C127	3.9 ~ 4.1 %	< 2 %
	sodium soundness loss	ASTM C88	1 ~ 9 %	1 ~ 2 %
	magnesium soundness loss	ASTM C88	1 ~ 4 %	2 ~ 6 %
	LA abrasion	ASTM C131	32 ~ 38 %	mostly < 20 %
	thermal coefficient	*	16 ~ 26 /C	**
	freeze-thaw loss	Tex-433C	11.5 %	**(lightweight agg ~9%)
	alkali-silica reactivity	ASTM C1260	0.023 %	varies
fine aggregate	specific gravity	ASTM C128	2.37	about 2.6
	water absorption	ASTM C128	7.9 %	about 1 %
	angularity	NAA Method	38.6 %	34.5 %

* no standardized method exists.
** not available

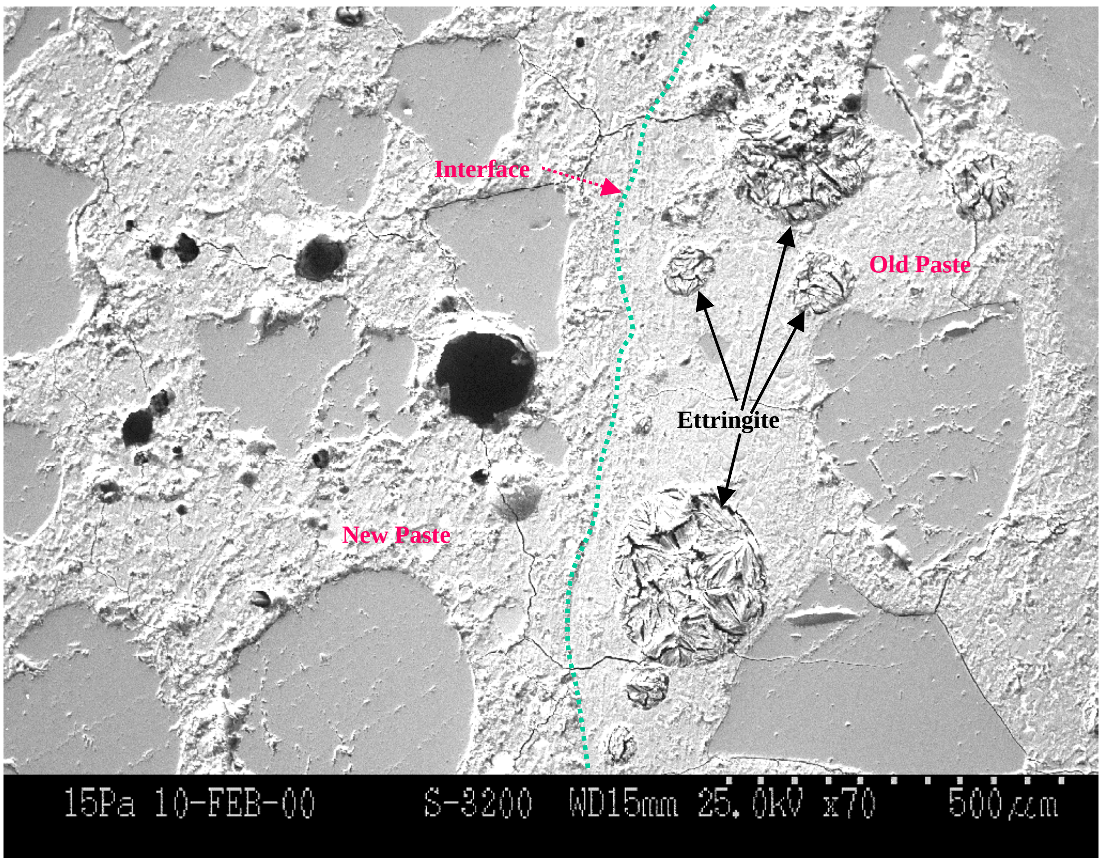

FIGURE 2 Scanning electronic microscope image of concrete containing recycled concrete aggregate.

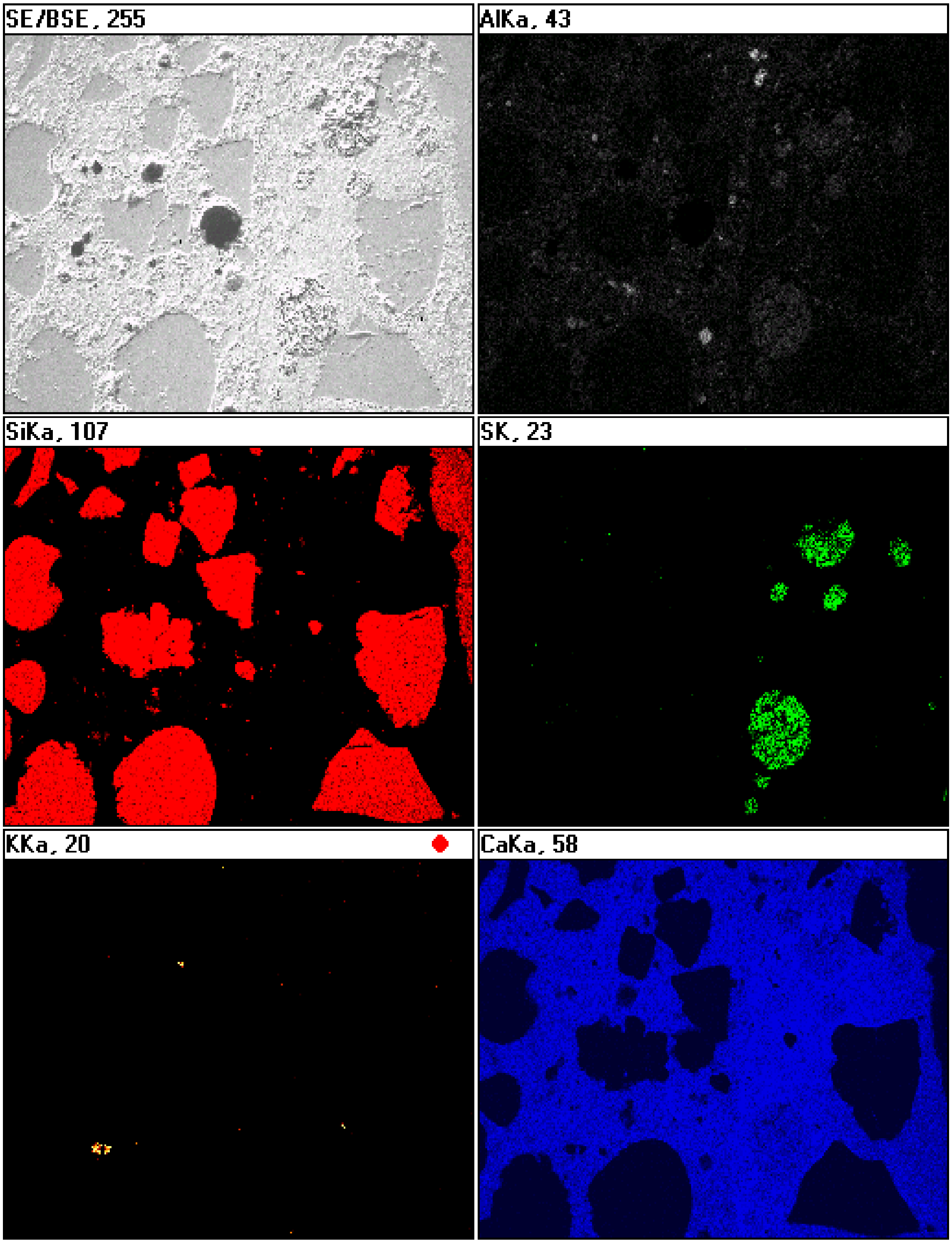

FIGURE 3 Bitmap image of the section shown in FIGURE 2.

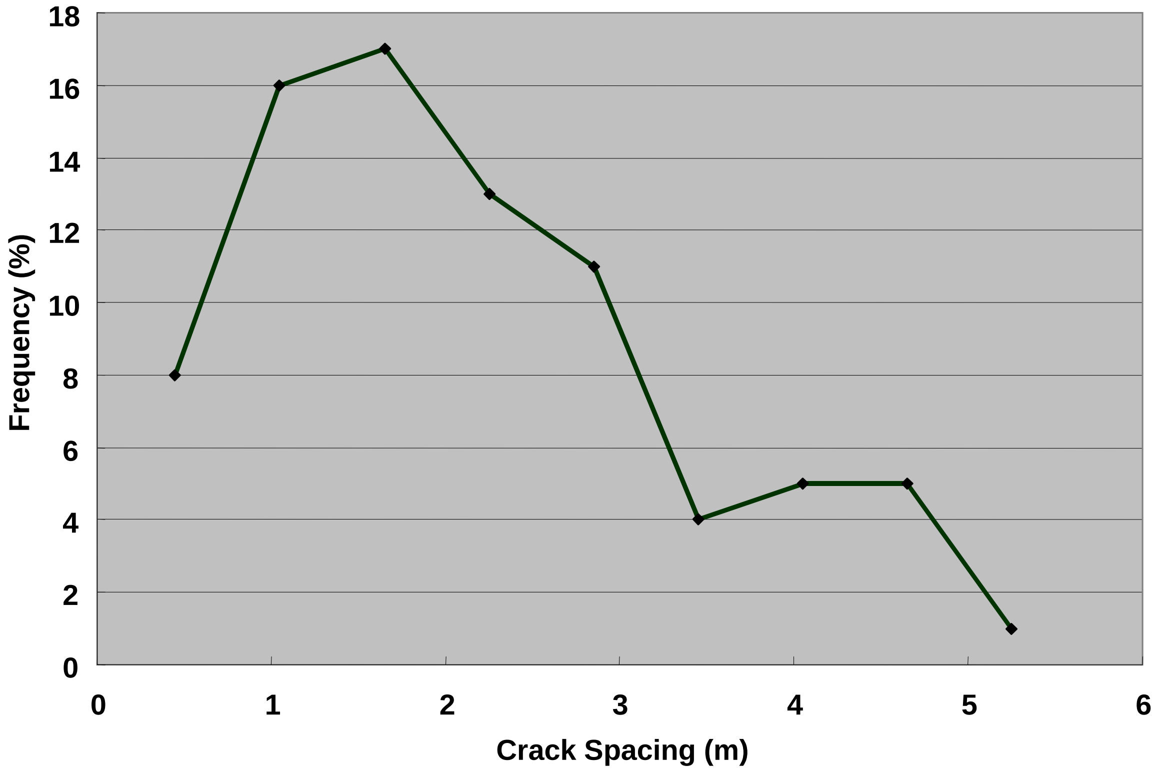

FIGURE 4 Transverse crack spacing distribution.

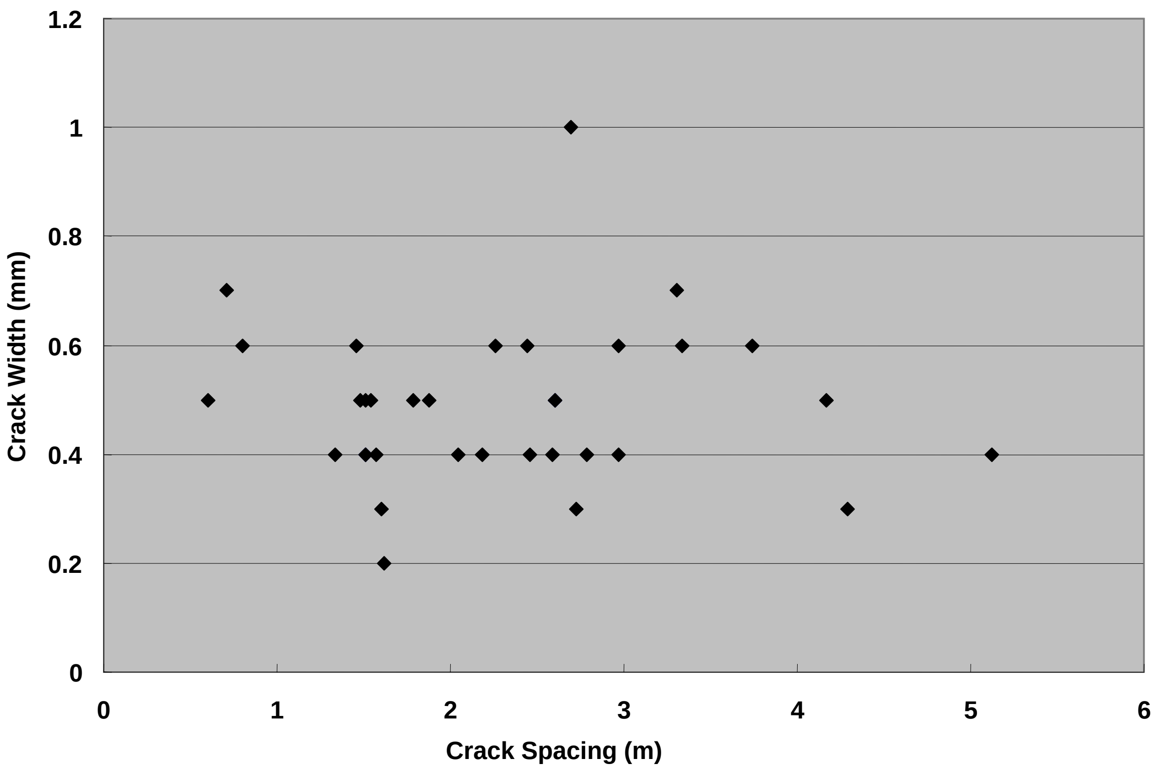

FIGURE 5 Correlation between crack spacing and crack width.

FIGURE 6 Typical CRCP section with 100 % recycled aggregates.

FIGURE 7 Spalling in CRCP with virgin siliceous river gravel.