Construction of a Full-Scale Recycled Brick Masonry Aggregate Concrete Test Pavement

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Abstract

Use of recycled aggregates in Portland cement concrete (PCC) can offer benefits associated with both economy and sustainability. Recycled brick masonry aggregate (RBMA) can be used as a 100% replacement for conventional coarse aggregate in concrete that exhibits acceptable mechanical properties for use in structural and pavement elements. Recycled brick masonry aggregate concrete (RBMAC) is currently not used in any type of construction in the United States. However, its use could become a viable construction strategy as the popularity of sustainable building practices increases. Although some researchers have studied RBMAC in the laboratory, minimal research on full-scale installations has been performed to evaluate the constructability concerns associated with its use, the performance of which is highly influenced by the relatively low unit weight and high absorption of the RBMA. In this study, RBMA from a demolition site was used in RBMAC mixtures designed for use in a test pavement. The RBMAC test pavement, along with a control section of conventional PCC to facilitate performance comparison, was constructed within the access roadway of a local industry in order to allow researchers to identify and address construction concerns and to evaluate both early age and long-term performance of RBMAC in a full-scale pavement installation. Due to the novelty of RBMA and the associated risk and expense related to its use in a traditional batch plant, mobile volumetric concrete mixing trucks were used to facilitate construction of the test pavement. This paper discusses the challenges encountered during pre-construction and construction of the test pavement. Pre-construction challenges included handling, transporting, and stockpiling of the RBMA, as well as calibration of the truck to achieve the desired mixture proportions. Experience with placing and finishing the RBMAC and control PCC pavement is also presented, along with fresh property and early-age test results for both concrete mixtures.

Introduction and Background

The construction industry is currently facing a significant problem the construction industry in the accumulation and management of construction and demolition (C&D) waste. According to the Environmental Protection Agency, conservation of landfill space, reduction of the environmental impact of producing new materials, and the reduction of overall project expenses can all be realized by recycling C&D waste [1]. Increasing costs and decreasing availability of landfill options to dispose of C&D waste has created an economic incentive to market recycled aggregate materials [2]. Additionally, a market for increased aggregate supply has been created by the long-term and continuously increasing demand for aggregate in many urban areas of the United States [3]. Incentives for use of recycled materials in building construction have been provided by several sustainable construction rating systems, including the Leadership in Energy and Environmental Design building rating system, Green Globes, and others. Ongoing efforts to promote sustainable construction practices in roadway construction include the development of similar rating systems, such as Greenroads and the Green Highways Partnership. The incentives for use of recycled materials in each of these sustainable construction-rating systems tend to change as performance requirements are continually enhanced, and the reader is encouraged to review the most current literature on individual rating systems for details on specific incentives.

The use of recycled concrete aggregate in a variety of new construction applications, including for temporary roads, as a suitable fill material, and as a replacement of virgin concrete aggregates (fine and coarse), has been extensively studied in academia and successfully implemented in the field. However, using RBMA in new concrete construction has not been extensively researched, particularly in the United States. When used in new concrete construction, the resulting mixture can be referred to as RBMAC. Through recycling demolished brick masonry rubble as aggregate in new construction applications such as pavements, the construction industry can divert brick rubble from landfills [4]. Several researchers have published findings relating to the use of recycled crushed brick as a base course material used in pavement applications [5-7]. As the widespread acceptance of recycled materials in new construction continues to grow, research and use of different types of recycled materials obtained from different sources progressively increases. Particularly in the United States, the production and use of RBMAC could offer stakeholders in sustainable construction a new material that could be viable in a number of applications, including pavements.

Several impediments to the widespread use of recycled materials in new concrete construction exist, including intrinsic mechanical properties and external factors [3]. The source of each recycled aggregate is unique. Therefore, the variability of mechanical properties of recycled aggregates could present a challenge to the mixture designers [8, 9]. Characteristics of recycled aggregates that affect the quality of concrete have been identified as aggregate strength, shape and texture, absorption, and size and grading [10]. Physical and mechanical properties that must be accounted for when using recycled aggregates include a lower specific gravity, higher absorption, possibly reduced soundness (resistance to chemical and physical weathering), more variable gradation, contaminant solubility and the potential for groundwater contamination [11], particle shape (angularity) [3], and a higher porosity

[12]. The presence of attached cement paste (mortar) contributes to a lower particle density, higher porosity, variation in the quality, and higher water absorption of recycled concrete aggregates [13]. Recycled aggregates can also be viewed as undesirable due to the possibility of contaminants [14]. Since different processes are involved in the manufacture of brick, there is inherent variability in physical, mechanical, thermal, and chemical properties related to brick aggregates. The high absorption of recycled aggregates, including RBMA, can affect the workability of RCA concrete mixtures [4]. Without accommodating this additional absorption, RCA mixtures can be stiffer and can lose workability faster than conventional mixes. Other impediments affecting the widespread use of recycled aggregates in new concrete mixtures include lack of performance history [15] and availability of material in large quantities [9, 16]. External factors such as cost, state specifications, and environmental regulations can also limit the use of recycled aggregates [11]. In the United States, impediments to the widespread use of recycled materials also include lack of standard specifications to provide guidance for use and the local regulatory environment [17].

RBMAC is currently not used in the United States for any type of construction. Testing performed as part of previous work [4, 16, 18] has indicated that pavement applications may be a viable use of RBMAC. In this study, RBMA from a demolition site was used in RBMAC mixtures designed for use in a test pavement. The RBMAC test pavement, along with a control section of conventional PCC to facilitate performance comparison, was constructed within the access roadway of a local industry in order to allow researchers to identify and address construction concerns and to evaluate both early age and long-term performance of RBMAC in a full-scale pavement installation. This approach allowed researchers to identify and address challenges to the use of this product associated with the procurement, production, and placement of RBMAC. Therefore, the viability of RBMAC for use in pavement applications was explored.

Design of Test Pavement

The RBMAC test pavement and control section of PCC were constructed at a crushing and grading facility in Charlotte, North Carolina. The planned dimensions of each pavement were approximately 60 ft (18.3 m) wide by 200 ft (61.0 m) long, although the as-constructed pavement was smaller due to restrictions of the mobile volumetric concrete mixer (discussed subsequently). Both pavement sections were constructed in a single travel lane, in line with the weigh scales that serve the crushing and grading facility. A photograph of the site prior to construction of the test pavement is shown in Figure 1.

Prior to construction of the test pavement and control section, a deteriorated undoweled jointed plain concrete pavement (JPCP) of varying thicknesses and composition was present at the site. The existing pavement was severely distressed, exhibiting extensive cracking and deflection at the joints. Moisture ingress into the subgrade has likely resulted in its substantial weakening. Additional information on this site is presented in another publication [19].

Figure 1. Overview of the test pavement site

Many states, including North Carolina, have implemented the Mechanistic-Empirical Pavement Design Guide (M-EPDG) procedure for pavement design [20], now utilized in the commercially available AASHTOWare Pavement ME Design software. M-EPDG was determined to be a particularly useful tool for evaluating RBMAC pavements because of the level of detail that can be incorporated into M-EPDG design and analysis. Properties of RBMAC that differ from conventional PCC can be input into the software, allowing for the difference in predicted performace between these two types of concrete to be explored [19]. The M-EPDG process is an iterative approach to pavement design. The performance of trial pavement sections is compared to design performance criteria that are selected to "ensure that a pavement design will perform satisfactorily over its design life" [20]. Performance criteria for JPCP include joint faulting, transverse slab cracking, and smoothness. Threshold values for performance criteria are selected by agencies based on a number of considerations, including pavement characteristics that trigger major rehabilitation efforts, impact safety, and require other maintenance. Characteristics of a trial pavement section are input into the software program, along with site conditions including climate, traffic, and subgrade characteristics. Pavement responses such as stresses, strains, and deflections are then computed over the design life, along with incremental damage. Cumulative damage over the design life of the pavement is compared to empirical performance data collected on existing pavement sections. The trial pavement section is evaluated based upon the reliability values specified by the pavement designer based on the desired confidence levels. If the proposed design does not meet the desired performance criteria, it can be revised by the designer and the analysis rerun until an optimal design is identified [20].

The test pavement and the control pavement were designed using M-EPDG. A discussion on the inputs and threshold values for performance criteria used in design of the RBMAC and conventional PCC pavements is presented in a previous publication [19]. A design life of 30 years was selected for the test pavement. Personnel at the site provided information to be used in the pavement design, including truck weights, axle configurations, and trip counts. Trucks entering the facility carry loads of demolition rubble headed to the crushing and grading operations. Trucks leaving the facility typically contain crushed, graded recycled aggregate material or are empty. Facility personnel indicated that the one-day maximum traffic loading experienced by the entrance drive where the proposed test pavement will be constructed is 293 tri-axle trucks at approximately 78,060 lb each. A growth rate of 2% per year was assumed. For the subject site, climatic data for the Charlotte-Douglas airport was downloaded from the M-EPDG website and utilized in the analysis. The depth to the water table was assumed to be 10 ft (3.05 m).

NCDOT performance criteria for concrete pavements were used as limits and reliability levels for international roughness index (IRI), transverse cracking, and mean joint faulting. Level 1 input values (site specific) were utilized wherever possible, including the input values for the RBMAC. Level 2 input values (correlated data) then Level 3 inputs (default values) were used when Level 1 input values were not available. When appropriate, the M-EPDG input values used by NCDOT [19] were used in the design. The M-EPDG input data used for the RBMAC test pavement, along with the reliability summary (output), are shown in a separate publication [19].

Testing indicated that RBMAC exhibits several properties that differ from those of conventional natural aggregate concrete, including unit weight and Poisson's ratio [19]. Additionally, the thermal properties of RBMAC differ from those typically exhibited by concrete using natural coarse aggregates [19]. Therefore, the use of RBMAC in M-EPDG pavement design results in design thicknesses that differ slightly from those obtained using conventional concrete. A summary of M-EPDG inputs used for the RBMAC and conventional concrete pavements is shown in Table 1.

Table 1. M-EPDG inputs for the RBMAC and conventional concrete pavements.

PCC Input Value	**Value used for control section (PCC with natural aggregate)**	**Value used for RBMAC test section**
Aggregate type	granite	rhyolite*
Unit weight (pcf)	150	130
Poisson's ratio	0.20	0.18
Coefficient of thermal expansion (in/in/°F)	5.6×10^{-6}	4.4×10^{-6}
Thermal conductivity (BTU/(hr•ft•°F))	1.25	0.533
Heat capacity (BTU/(ft•°F))	0.28	0.20

*Since brick is not an aggregate type listed in M-EPDG, rhyolite was selected due to its fine-grained structure (which was assumed to be most similar to brick).

The proposed RBMAC test pavement and the control pavement were designed using an unbound crushed stone base, 12 in (0.305 m) thick, with an elastic modulus of 30,000 psi (206.8 MPa). Poisson's ratio was specified as 0.35, with the coefficient of lateral pressure allowed to remain at the default value of 0.5. Based on information on the characteristics of the soils underlying the subject site obtained from the United States Department of Agriculture (USDA) Natural Resources Conservation Service Web Soil Survey (WSS), the characteristics of an A-4 soil was used in the analysis. Based on experience with local soils, M-EPDG suggested values of resilient modulus that are quite high and could result in an unconservative pavement section, falsely indicating successful performance against the M-EPDG performance criteria. It was decided that a more conservative (lower) value of resilient modulus should be used in these designs. A resilient modulus of 6,000 psi was thus used for the subgrade resilient modulus input.

Based upon the input values and assumptions previously described, M-EPDG analyses indicated that the proposed RBMAC and the conventional PCC (control) pavement sections, summarized in Table 2, should perform satisfactorily over the 30-year design life [19]. Predicted reliabilities for both the RBMAC pavement and the control pavement are provided in previous publications [19]. It is noted that the required thickness of the control pavement section, which will be comprised of concrete with natural aggregates, needs to be slightly thicker than the RBMAC pavement in order to provide a similar reliability in M-EPDG distress modeling. However, for practical considerations, it was decided that both pavement sections would be constructed to the same thickness (10 in or 254 mm) for constructability reasons.

Table 2. Pavement layer thicknesses based on M-EPDG analyses

Layer	Control pavement (PCC with natural aggregate)		RBMAC test pavement	
JPCP	PCC with locally available natural aggregate (granite)	10.5 in	RBMAC	9.25 in
Base	Crushed stone base	12 in	Crushed stone base	12 in
Subgrade	Subgrade soils, A-4, with 6,000 psi resilient modulus	Infinite	Subgrade soils, A-4, with 6,000 psi resilient modulus	Infinite

RBMAC and Control PCC Mixture Designs

Demolished brick masonry from a single demolition site was crushed and graded to create RBMA. Although the crushing and grading process produced RBMA in several AASHTO M43 gradations (#4, #57, #78, and fines), the #57 material was used for this project. Physical properties, including the gradation, specific gravity, absorption, unit weight, and abrasion resistance were determined to compare RBMA to other conventional and recycled aggregates. A summary of the properties of the RBMA produced from the case study site is provided in Table 3, along with the values for a locally available natural granite coarse aggregate used in the control PCC pavement. NCDOT requirements for aggregates are outlined in a separate publication [19].

Table 3. Characterization of RBMA produced from the subject demolition site and a locally available granite coarse aggregate used in the control PCC pavement

Property (Test Method)	RBMA	Locally available granite coarse aggregate
Gradation (ASTM C136)	AASHTO M43 #57	AASHTO M43 #57/#67 blend
Specific Gravity (ASTM C127)	2.46	2.62
Absorption (ASTM C127)	9.2%	0.5%
Unit Weight, rodded (ASTM C29)	68.6 pcf (1099 kg/m^3)	95.1 pcf (1523 kg/m^3)
Abrasion Resistance (ASTM C131)	38.4 %	36%

Four preliminary RBMAC mixtures were batched prior to identifying the RBMAC mixture to be used in the test pavement section. Each mixture was proportioned in accordance with

ACI 211.2, Method 1: Weight Method [21]. This method was used due to the high absorption of the RBMA. After the baseline mixture FL.57.1 was proportioned, subsequent variations with different cement contents were developed, batched and tested. The volume of coarse aggregate and the water/cement (w/c) ratio were held constant between Mixtures FL.57.1, FL.57.2, and FL.57.3, as shown in Table 4. Mixture FL.57.1 contains the highest cement content, approximately 800 lbs per cubic yard, which corresponds to the cement content obtained using the ACI 211.2 procedure, resulting in design 28-day compressive strengths of 6,200 psi. Mixture FL.57.2 contains the lowest cement content, approximately 550 lbs per cubic yard. Mixture FL.57.3 represents the mid-point, containing approximately 675 lbs of cement per cubic yard. The target slump of each mixture was 4 inches, and the target air content (ASTM C173) was 5% to 7%. These targets were met for each of the trial mixtures.

To ensure the best odds of achieving the desired strength of pavement using the lowest cement content, Mixture FL.57.4 was designed in which the proportions of FL.57.2 were modified to reduce the w/c ratio from 0.38 to 0.35. The coarse aggregate and cement contents remained the same as Mixture FL.57.2 while the fine aggregate and water contents were modified to keep the total batch volume consistent. A summary of the mixture proportions are provided in Table 4.

Table 4. Preliminary RBMAC mixture proportions

	Mixture			
	FL.57.1	**FL.57.2**	**FL.57.3**	**FL.57.4**
Coarse Aggregate, RBMA (pcy)	1553.6	1553.6	1553.6	1553.6
Fine Aggregate, natural sand (pcy)	818.4	1132.1	984.9	1172.8
Cement (pcy)	802.9	550.8	675.0	550.8
Water (pcy)	305.1	209.3	256.5	192.8
w/c Ratio	0.38	0.38	0.38	0.35
High-Range Water Reducer (oz/cy)	10.4	7.3	9.7	7.3
Air Entraining Admixture (oz/cy)	7.8	7.8	9.0	7.8

FL.57.4 was selected as the RBMAC mixture design to be used in the test pavement. This mixture design exhibited desirable mechanical properties and provided the most economical concrete mixture due to the low cement content. The mixture proportions are shown in Table 5, along with the associated fresh and hardened property test results. Also shown in Table 5 are the proportions used in the conventional concrete pavement section, which utilized a locally available natural coarse aggregate (AASHTO M43 #57 gradation). The contractor selected a previously utilized conventional mixture with proportions similar to the RBMAC section. One notable difference in the two mixtures is in the amount of sand utilized. This is due to the difference in volume occupied by the relatively lighter RBMA. It is noted that due to the contractor's experience with the control PCC mixture, laboratory tests were not performed on this mixture prior to construction of the test pavement. Additionally, due to an oversight during construction, the same admixture dosages were utilized for both the RBMAC and control PCC pavement mixtures. However, fresh property tests indicate that acceptable workability and air contents were obtained, even though the same admixture dosages were inadvertently used for both mixtures.

Table 5. Final RBMAC and control PCC mixture proportions and laboratory test results

		Mixture	
		RBMAC Test Pavement	**Control PCC Pavement**
Mixture Components	Coarse Aggregate, RBMA or granite (pcy)	1554	1554
	Fine Aggregate, natural sand (pcy)	1173	1527
	Cement (pcy)	551	550
	Water (pcy)	192.8	208.5
	w/c Ratio	0.35	0.38
	High-Range Water Reducer (oz/cy)	17.8	17.8
	Air Entraining Admixture (oz/cy)	17.8	17.8
Laboratory Test Results	Slump	4.5 inches	---
	Entrained Air Content	5.5 %	---
	Compressive Strength (28-day)	5240 psi (36.1 MPa)	5000 psi*
	Modulus of Rupture (28-day)	212 psi (1.46 MPa)	---
	Modulus of Elasticity (28-day)	2,990,000 psi (20,615 MPa)	---
	Poisson's Ratio (28-day)	0.18	---

*Typical value obtained via testing of this mixture on other projects constructed using this mixture. No pre-construction laboratory testing was performed on the PCC mixture.

Pre-Construction Considerations and Preparation

Due to the novelty of RBMA and the associated risk and expense related to its use in a traditional batch plant, two mobile volumetric concrete mixing trucks were used to mix and place the concrete for the pavements. A mobile volumetric batch truck (Figure 2) stores material in three hoppers (coarse aggregate, fine aggregate, and cement) and a water tank. Materials are delivered to the chute for mixing by a series of conveyors. Coarse and fine aggregates are delivered simultaneously to the mixing chute. The coarse and fine aggregate hoppers have individual conveyors to draw material through a screeding gate. The amount of each type of aggregate that is delivered to the chute is controlled using a gate setting (Figure 3). Cement is introduced to the mixture of aggregates at a constant rate. The amount of water included in the concrete mixture is adjusted by the technician to ensure that the correct mixture proportion is delivered. Chemical admixtures are added into the mixing water in the correct proportions and introduced to the concrete mixture with the water.

RBMA has a lower unit weight than the locally available natural coarse aggregate. Therefore, it was necessary to calibrate the mobile volumetric concrete mixer prior to construction of the test pavement. In order to calibrate the truck, a load of RBMA was delivered to the contractor prior to placement of the test pavement concrete. The specific gravity and absorption of the RBMA was used to help the contractor calibrate the volumetric batch truck. A ratio of coarse to fine aggregate was used and the gate settings were determined by batching a known quantity of concrete in a given amount of time. The gate settings were adjusted until a calculated quantity was delivered in a given time.

Figure 2. Mobile volumetric concrete mixer

Figure 3. Volumetric batch truck gate setting controls

It was also necessary to calibrate the mobile volumetric concrete mixer to ensure that the proper dosage rates of the concrete admixtures were supplied in the mix water. Admixtures are typically dosed by adding a certain number of ounces of admixture per hundred pounds of cement, per manufacturer's recommendations. The slump and entrained air content of the mixture is then tested to verify that a suitable dosage rate was utilized. To calibrate the mixer, the required dose of each admixture was added into a known volume of water. Using this type of volumetric mixing equipment, cement is introduced to the mixture at a constant rate. Therefore, the mix water is also dosed at a constant rate. Since the w/c ratio is a critical parameter, the mixing water was pumped through the system without introducing other components, and the flow rate verified over several iterations.

Once the fine and coarse aggregate gate settings that delivered the proper volumetric proportion of aggregates were identified, and the water delivery and admixture dosage rates were calibrated, several trial batches of RBMAC mixtures were produced. A box of known volume (1/2 cubic yard) was used to contain the concrete. A gage located at the rear of the truck helped the operator to determine the quantity of concrete that had been delivered. The gate settings were adjusted until the box of known volume and the quantity of concrete delivered (according to the gage) matched, completing the calibration process for volumetric mixing of the RBMAC using the mobile volumetric concrete mixer.

Construction of Test Pavement

The existing concrete pavement was removed using a small excavator. The subgrade was excavated to a depth of 22 inches below the finished pavement surface, allowing installation of the 12 inches of compacted stone base and the 10 inches of concrete pavement. Prior to installation of the stone base material, soil samples were obtained and returned to the laboratory for testing. Laboratory testing indicated that the subgrade beneath the stone base material had a California Bearing Ratio (CBR) of approximately 2.2, which supports the decision made during design to use the relatively conservative resilient modulus of 6,000 psi.

Crushed stone base material meeting AASHTO M147 was installed to a thickness of 12 inches. Since the adjacent, existing pavement at the subject site was significantly distressed and joints were not doweled, a bituminous-treated fibrous joint filler material was utilized to isolate the new pavements from the surrounding pavement and from each other (Figure 4). Wood formwork was installed between the RBMAC test section and the control section, and the bituminous-treated fibrous joint filler was also used to separate the two new pavements. The RBMAC test pavement was installed first, utilizing one of the two volumetric concrete mixer trucks. The conventional PCC control pavement was installed second, utilizing the second volumetric concrete mixer truck. Welded wire mesh (6 x 6 – W4.0/W4.0) was installed at mid-depth of each of the two pavement slabs. The surfaces of both pavements were screeded, floated, and received a broom finish (Figure 5).

Figure 4. Compacted stone base, formwork, and isolation joint material

During placement of the RBMAC slab, issues related to conveyance of the aggregate material through the volumetric mixer truck were encountered. It is suspected that the lighter nature of the RBMA, along with the higher fines content, resulted in an excess of fine material clogging the conveyor belt. Although the RBMA stockpile was washed prior to use, it may not have been washed as thoroughly as typical washed stone. It is suggested that in future use of RBMA, the aggregate be washed thoroughly using washing procedures typically utilized in preparing other aggregates. Workers tasked with placing and finishing the pavements reported that the RBMAC mixture was harsher than the conventional PCC mixture, and was more difficult to finish. However, a satisfactorily finished surface was achieved on both the RBMAC and conventional PCC pavements.

Figure 5. Finished RBMAC test pavement (foreground) and conventional PCC control pavement (background)

Both the RBMAC and conventional PCC pavements were covered with plastic sheeting and allowed to cure for five days (Figure 6), at which point the sheeting was removed due to exhibiting distress from wind. The sheeting was removed, and the pavements were opened to traffic at an age of nine days, a point at which the Owner needed to utilize these drive lanes.

Figure 6. Curing of the finished RBMAC test pavement (foreground) and conventional PCC control pavement (background)

Early-Age Test Results and Performance

Testing was performed to determine the fresh and hardened properties of the RBMAC and conventional concrete batched, respectively, for the test pavement and control pavement sections. Cylinder and beam specimens cast during placement of the test pavement were allowed to cure for 24 hours on-site, and then returned to the laboratory. Curing was performed in accordance with the methods prescribed in the testing standards listed below. A summary of these test results is presented in Table 6.

Table 6. Test results for RBMAC and PCC used in pavement construction

	Mixture	
	RBMAC Test Pavement	**Control PCC Pavement**
Slump	3.5 in	5.5 in
Entrained Air	4.5%	6.5%
Yield	136.4 pcf (8.5 kg/m^3)	142.9 pcf (8.9 kg/m^3)
Compressive Strength (28-day)	5195 psi (35.8 MPa)	4200 psi (28.9 MPa)
Modulus of Rupture (28-day)	208 psi (1.4 MPa)	220 psi (1.5 MPa)
Modulus of Elasticity (28-day)	4,040,000 psi (27,854 MPa)	4,045,000 psi (27,887 MPa)
Poisson's Ratio (28-day)	0.20	0.19

It can be seen in Table 6 that the RBMAC and the control PCC exhibited similar fresh and hardened property test results. A key difference between the two is shown in the results for compressive strength. RBMAC had a stronger 28-day compressive strength by approximately 1,000 psi (6.9 MPa). It is noted that in addition to having a slightly lower w/c ratio, the RBMAC had less fine aggregate than the control concrete. The higher compressive strength of the RBMAC could possibly be attributed to the larger volume of RBMA coarse aggregate used in the RBMAC mixture. Whole brick obtained from the demolition material were tested in accordance with ASTM C67 to determine the compressive strength of 7,260 psi. Additional work is needed to determine the cause(s) of the difference in compressive strengths observed, but the RBMAC's is likely higher due to its slightly lower w/c ratio. The entrained air content of the RBMAC is also somewhat lower than the control PCC, which may influence future durability performance.

The test pavement was observed several times during early ages, typically weekly for the first two months, to monitor the progression of early-age cracking, if it were to occur. Observations were performed using FHWA-recommended procedures, during dry conditions and by bending at the waist. To date, no cracks have been observed on either pavement section. Ongoing work is being performed to monitor the performance of the pavement, which is still in service. This work includes removal of cores to evaluate strength gain and other mechanical properties, as well as durability performance. Ultimately, it is of interest to compare distresses observed in the RBMAC to distresses observed in the PCC over the service life of the pavement.

Conclusions

In this study, brick masonry demolition waste from a single site was successfully utilized to develop RBMAC mixture designs suitable for use in a pavement application. An RBMAC test pavement section, as well as a control section of conventional concrete, was constructed at a private industrial complex, and is currently serving up to 300 loaded triaxial dump trucks per day. Construction challenges, including processing, handling, and staging of the material prior to construction of the test pavement were addressed. A mobile volumetric concrete mixer was shown to be a suitable method of constructing small-scale pavement installations incorporating recycled aggregates that require separate handling. The volumetric concrete mixer truck may also be suitable for similar recycled aggregate concrete construction applications that utilize novel materials in sustainable construction.

Early-age test results indicate that acceptable mechanical properties were achieved for both the RBMAC and control concrete. No early age cracking was observed in either the test pavement or control pavement during visual surveys performed during the first 11 months of service. Although the test pavement constructed as part of this work was not instrumented, the successful performance of this test pavement has spurred interest in constructing a second, instrumented test pavement at a future time. An instrumentation plan was developed using industry standard technology for use in a future RBMAC pavement [19].

Since RBMA is produced from existing brick masonry construction, variability of material produced from different sources is a concern. This is, however, no different from the potential variability in RCA produced from different sources of waste concrete. Proponents of RCA implemented strategies that promoted understanding and control of the source material. These strategies typically include assessing potentially recyclable concrete for existing materials-related distress, such as ASR, as well as reuse of concrete in the same project being reconstructed [22]. Strategies for proper stockpile management also aid in ensuring consistency and minimal contamination [16, 22]. Research and field implementation has shown that, with proper evaluation of the source concrete, RCA concrete exhibiting acceptable performance can be produced. Similar strategies could also be utilized in RBMA production and transport to help ensure adequate performance of RBMAC. Ultimately, it will be the burden of the recycled aggregate supplier to demonstrate that their RBMA product meets the requirements of owners and/or state agencies. Additionally, more research demonstrating successful performance of RBMAC in both laboratory and field installations will be needed to provide agencies and owners a comfort level with this material [23].

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