

Full-Depth Cold In-Place Recycling of Asphalt Pavements Using Self-Cementing Fly Ash: Field and Laboratory Study

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ABSTRACT

Reclaimed asphalt base (RAB) can be used as granular base or sub-base material in all pavement types. For low traffic volume roads, RAB may be stabilized using self-cementing fly ash to produce high quality road base using full-depth cold-in-place recycling methodology. Recently, a demonstration project was completed utilizing this technology. This paper presents a compilation of the laboratory test results used to characterize the RAB produced in that demonstration project and fly ash-stabilized RAB physical and engineering properties. The construction procedures and quality control guidelines are also described. Finally, the field performance of the stabilized road base is discussed based upon the field CBR tests.

INTRODUCTION

County and local roads account for nearly 3 million miles of all roadways in the United States. These roads often consist of what are called low-volume flexible or built-up pavements, best described as conglomerates of base course and wearing course of chip seal or other asphalt overlays that have been built up over many years.^{1,2} Performance of these roads is typically inconsistent because of the diversity of materials used in their construction. In addition, many of these roads often go without any maintenance at all because of budgetary constraints.

A proven method of converting conglomerate pavement sections into durable roads that last many more years is by recycling old asphalt pavement and base course into new roadway using a process called Full-Depth Cold In-Place Recycling (CPR) with self-cementing fly ash. Cold in-place recycled pavement and base course (CPR) is similar to subgrade stabilization, in that self-cementing fly ash is used as the cementing agent to stabilize granular materials. Existing asphalt pavement sections in need of repair/rehabilitation are pulverized in-place to full pavement depths, mixed with self-cementing (Class C) fly ash and appropriate water content and compacted into base course in a single process. Up to 12 inches of a conglomerate pavement section may

be pulverized in one pass and then stabilized in a second pass. To complete the process, a new wearing surface is laid on the recycled section.

In this paper we present the results of a preconstruction testing program consisting of existing material characterization and laboratory mix design, as well as a construction testing program consisting of field pulverized material characterization and field evaluation of pavement performance indicators.

PHYSICAL/ENGINEERING PROPERTIES OF RAB

Specific gravity, bulk density and grain size distribution of RAB samples were characterized through laboratory testing. These laboratory studies were conducted on samples obtained from four different locations of the demonstration sites denoted by symbols on site location map given in Figure 1. Bulk samples of the existing asphalt pavement were obtained from these locations using backhoes to excavate all material within a 2 foot square area to a depth of 6-9 inches. Care was taken to avoid excavation into the subgrade soil. Samples of RAB were collected from two locations of two different pavement segments designated as group A and group B. The samples were returned to the laboratory and air-dried. Samples were then machine pulverized using hammer mills. Following pulverization, the samples were remixed and placed in containers to minimize segregation and to avoid accidental mixing with other samples in the laboratory.

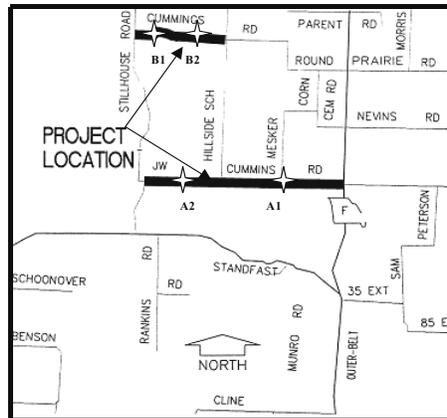


Figure 1. Site location map.

The machine pulverized RAB samples were used to determine the specific gravity and bulk density. Specific gravity of machine pulverized RAB was determined according to ASTM C127 standard and was found to range between 2.24-2.32. Bulk density was determined according to the ASTM C29 standard utilizing the dry rodding procedure. The bulk density of the different RAB samples were as follows: A1= 1797 Kg/m³ (112 pcf), A2= 1624 Kg/m³ (101 pcf), and B1 and B2= 1845 Kg/m³ (115 pcf).

The gradation analysis was conducted according to ASTM C136. Samples were first sieved through the 31.5mm, 16mm, 8mm, 4mm, and 1 mm sieves to obtain the coarse

aggregate grain size distribution. The portion passing the 8 mm sieve was then used for fine aggregate sieve analysis according to ASTM C136.

The composite grain size distribution curves obtained from the tests are shown in Figure 2. For comparison, the gradation curve of the theoretical dense graded material is also shown based upon the following equation:

$$\text{Percent passing} = (\text{sieve size}/\text{maximum sieve size})^{0.45}$$

From Figure 2 it is seen that sample A1 had more coarse material compared to sample A2, however, both have the same percentage of fine particles passing the 2 mm sieve. Therefore A1 and A2 were treated separately for further laboratory investigation. As samples B1 and B2 have similar grain size distribution, they were mixed together to make one bulk sample for the future lab testing.

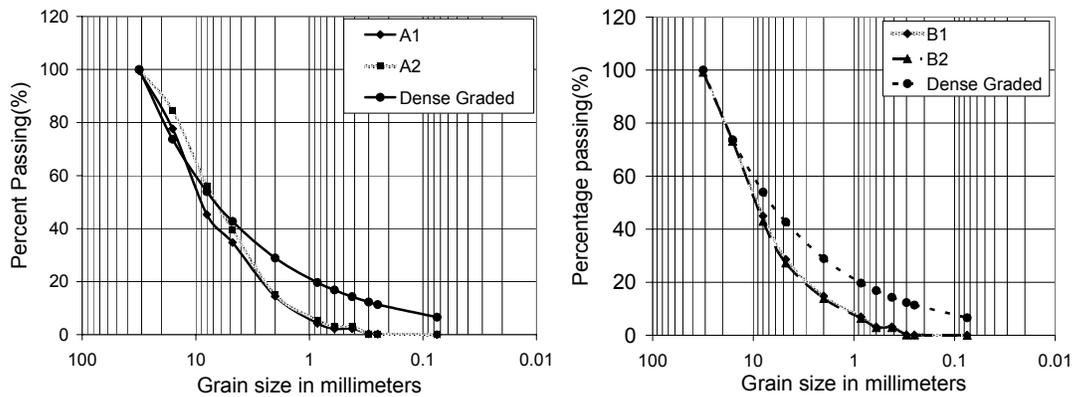


Figure 2. Grain size distribution of samples A and B.

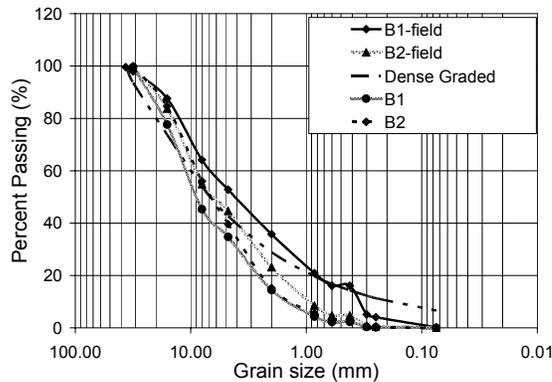


Figure 3. Comparison of lab and field pulverized grain size distributions.

Figure 3 compares the grain size distributions of machine-pulverized RAB (B1, B2) with the field-pulverized RAB obtained from locations B1 and B2. It is interesting to note that the field-pulverized RAB has grain size distribution that is finer than that obtained in the lab using a hammer mill. Moreover, the field-pulverized RAB gradation is very close to

the dense graded material suggesting that better pulverization and compaction are typically achieved in the field than in the lab.

MIX DESIGN OF FLY ASH – RAB MIXTURES

The dry density and moisture content on the RAB-fly ash mixes were determined according to ASTM D698 (Standard Proctor Test). For each sample, RAB and the required amount of Class C fly ash by weight were first mixed dry, and then the proper amount of water was added to the dry mix to obtain the desired moisture content. After the moisture was added, the sample was thoroughly mixed until homogeneous. Then the RAB-fly ash mix was evenly distributed in the Standard Proctor mold and compacted in approximately 3 equal layers, with 25 blows per layer. In consideration of the rapid hydration characteristics of the fly ash, each sample was prepared individually in less than 20 minutes. Figure 4 shows the dry density and moisture content relationship for group B RAB and 15 percent fly ash mix. Group B RAB had a maximum dry density of 2.03 Mg/m³ at an optimum moisture content of 8 percent. A Standard Proctor test was also performed on group B RAB that had been sieved through the 4.75 mm sieve per the methodology specified for soil compaction. It was observed that the sieved group B RAB had a maximum dry density of 1.95 Mg/m³ at an optimum moisture content of 10 percent, which indicates that coarser material will result in higher dry density at lower moisture content. Therefore, to better simulate actual field conditions it was decided to include the coarse fractions in the Standard Proctor test.

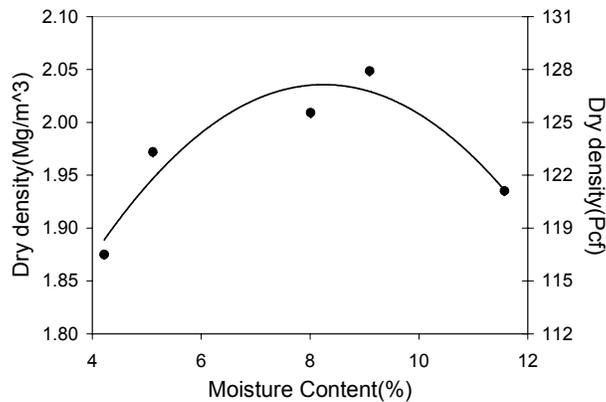


Figure 4. Dry density and moisture content relationship of Group B RAB at 15 % fly ash content based upon Standard Proctor test.

Figure 5 shows the dry density obtained for group B RAB and 15 percent fly ash mix samples compacted for unconfined compressive test as well as that for samples compacted for the CBR test. The RAB and fly ash samples were mixed using the same procedure as for the standard proctor test.

For the unconfined compressive test, samples were compacted in a mold 2.8 inches in diameter and 5.6 inches in height. The samples were compacted in three layers using 19 blows per layer in order to keep the compactive effort comparable to the standard

proctor test. Samples were then extruded after 12 hours of compaction and weighed, for dry density and moisture content relationship. Figure 5a shows the dry density of 2.05 Mg/m^3 (128 pcf) at optimum moisture content of 7.8 percent. In the case of samples for CBR testing, higher compactive effort was used to prepare the samples as per the test specifications. Therefore, as seen from Figure 5b, a higher maximum dry density of 2.17 Mg/m^3 (135 pcf) at a lower optimum moisture content of 7.5 percent was obtained.

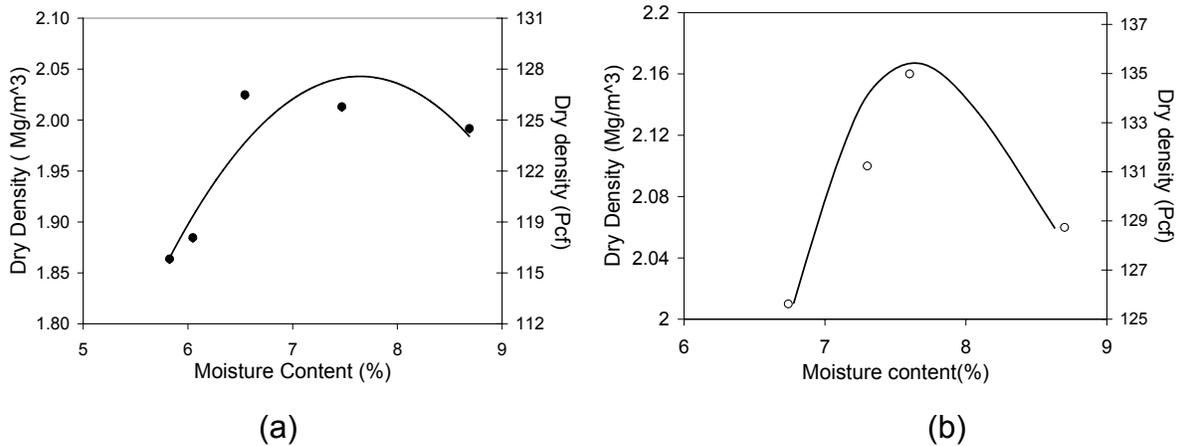


Figure 5. Dry density and moisture content relationship Group B RAB at 15 % fly ash content for samples compacted for (a) unconfined compression test, and (b) CBR test.

Figures 6a and 6b show the relationship between the unconfined compressive strength, CBR, and compaction moisture content for group B RAB and 15 percent fly ash mix after 7 days of air-curing. Maximum unconfined compressive strength is found to be 1.24 MPa (~180 psi) at a moisture content of 7.25%. The CBR value at 0.1 inch penetration for 7-days curing period was found to be greater than 100 in the range of compaction at the optimum moisture content.

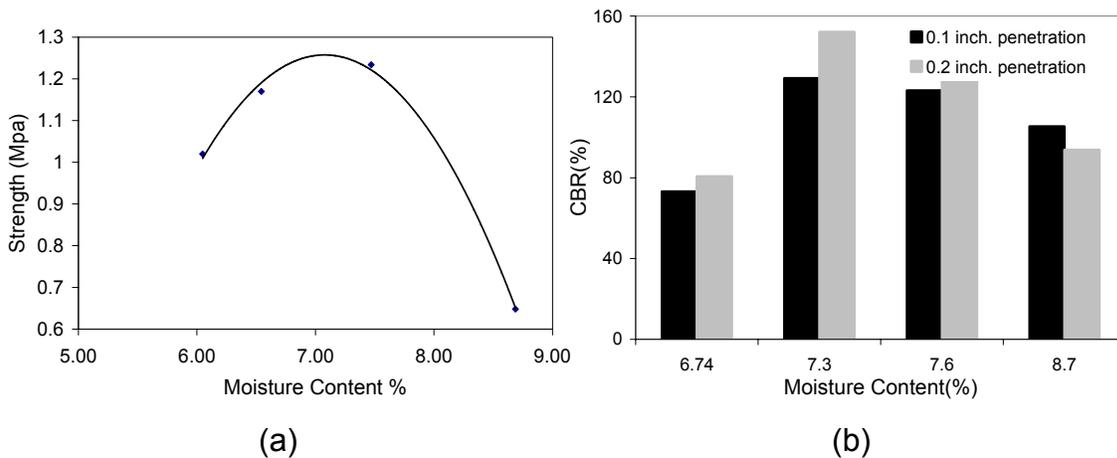


Figure 6. Relationship between unconfined compressive strength, CBR and moisture content for mix for Group B RAB and 15 percent fly ash with 7 Days Curing.

CONSTRUCTION PROCEDURE AND QUALITY CONTROL

To obtain the best results of Class C fly ash stabilization of Recycled Asphalt Base (RAB), clear and consistent construction guidelines must be followed. Based upon the information culled from other case studies and specifications developed for soil stabilization using self-cementing fly ashes, an outline of construction guidelines are presented here. It is noted that the Class C fly ash treatment of RAB must be comprised of a uniform fly ash and RAB mixture with no loose or segregated areas. It should have a uniform density and moisture content. The surface of the treatment of RAB should be smooth. A detailed construction sequence must be specified along with the proper amount of Class C fly ash and water to obtain effective stabilization of RAB.

Preparation of Recycled Asphalt Base (RAB)

The area where the fly ash-stabilized material is to be placed should have all vegetation and any other unsuitable soil or material like organic soils, debris, etc. removed. The subgrade should be firm and have enough stability to support the construction equipment to enable in-place fly ash treatment. If the subgrade is soft or otherwise not suitable, some engineering improvement must be performed to correct the situation, such as stabilizing with fly ash, prior to treating the RAB.

The combination of pulverized seal coat materials, soil, and asphaltic concrete materials passing the 1.5" sieve is referred to as Recycled Asphalt Base (RAB). To obtain RAB, the existing pavement and subgrade material must be pulverized to a minimum depth of 9 inches over the required width of stabilization. The existing pavement must be pulverized to a maximum particle size of one and one half (1.5") inches. The depth of pulverization will be carefully controlled to provide a uniform thickness of material to be stabilized. Any oversized material, such as stones retained on a 1.5" sieve, and unsuitable materials must be removed and discarded. RAB shall be used to construct windrows along the edges of the road as a barrier to prevent the fly ash from flowing into ditches, as well as to allow ease in mixing of fly ash with the RAB. When the possibility of fly ash leaving the mixing area has ended, the windrows must be incorporated into the fly ash – RAB mix.

Application of Fly Ash and Compaction

The rate of application should be specified in terms of the dry weight of the existing material. The specification must be based upon laboratory mix design using a combination of moisture-density tests, unconfined compression test and the CBR test. Before application of fly ash, the area should be bladed to ensure uniform distribution of fly ash. Spreading equipment must uniformly distribute the fly ash without excessive loss and in such manner as to reduce dispersion of fly ash so that it does not become air-borne. The scattering of fly ash by wind must be minimized and the use of fly ash on windy days should be avoided.

The fly ash and RAB must be thoroughly mixed with at least one pass of mixing equipment, such as a horizontal-shaft pulvamer (Bomag MPH 100R bullet tooth drum recycler or equivalent). Moisture content is critical in achieving maximum density and compressive strength. Care must be taken to ensure that the final moisture is homogeneous, and that the mix is of uniform color and friability, and without clods and lumps. If the RAB-fly ash mixture contains clods, they shall be reduced in size by additional pulverization. Additional water may be added to achieve optimum compaction conditions and the materials shall be remixed to achieve a uniform mixture. The fly ash stabilized RAB shall not be mixed when the ambient air or RAB temperature is below 40° F, or it is raining, or if rain is forecast, or if the RAB or the supporting material is frozen.

Compaction shall commence immediately after the completion of mixing and grading. Compaction shall consist of two or more passes with a Vibratory padfoot roller and it shall be completed within two hours. In order to accomplish this, the area to be stabilized should be divided into segments that permit mixing and compaction within this time frame. Any section that is too wet, too dry, or insufficiently treated must be improved. The improvement may be accomplished by loosening the affected areas, adding or removing material as required, and reshaping and recompacting by sprinkling and rolling to meet the requirements.

Upon completion of a section, sample tests should be made by the supervising engineer. Sample tests may be made with a nuclear density device to assess the density requirements. Alternatively, the sample tests may be made with a dynamic cone penetrometer (DCP) to assess the field CBR values. Since the field CBR values are directly related to the performance of the road base, the DCP tests are preferable. If the sample fails to meet the specified requirements, the engineer may require that the area be reworked as necessary to meet the requirements. Occasionally, the construction method may be altered to satisfy project-specific requirements. If for some reason, the RAB – fly ash mixture loses the required stability and density, it should be reprocessed. Reprocessing should follow the same construction guidelines as the initial stabilization including the addition of fly ash.

Finishing

After the road base has been compacted, the surface must be shaped to the required line, grade, cross-slope and cross section. Moisture may be added to the surface at this time to facilitate curing. The final surface of the stabilized material must be rolled with an approved steel-wheeled roller. The compacted surface must be smooth, free of cracks, ridges, and loose material. If directed by the engineer, a protective cover of liquid asphalt may be applied. The protective coat shall be placed not later than 48 hours after finishing a section of the fly ash treated base. Otherwise water should be sprinkled to facilitate curing and prevent dehydration until such time as the pavement is placed.

FIELD CBR ASSESSMENT WITH DCP

The dynamic cone penetrometer (DCP) test for sub-grade evaluation has proliferated in recent years, and it is being increasingly utilized for assessing the California Bearing Ratio (CBR) values in the field.^{5,6} The preference for DCP stems from the following: 1) the DCP instrument is inexpensive and portable; 2) the test is easy to conduct and takes less than 10 minutes to complete at a location; and 3) the instrument can penetrate thin, hard surface layers to assess the CBR-value of underlying base course. Moreover, the DCP test can provide CBR values that are directly related to the performance of the road base.

Therefore, in order to evaluate the behavior of fly ash-stabilized RAB, a DCP with an 8-kg hammer was used in this study to obtain the field CBR values. The DCP tests were performed at the completion of compaction, which was typically 2 hours after the addition of water. DCP tests were also performed at the same locations after 24 to 48 hours of curing. The tests were conducted at regular intervals along the two road segments, and the field CBR values are plotted in Figure 7 for the various locations.

Clearly, from Figure 7, the field CBR values are found to increase with curing period. At the end of compaction, the mean and standard deviation of the CBR values on Cummings Road were found to be 28 and 9, respectively. After 24 to 48 hours of curing, the mean and standard deviation of the CBR values on Cummings Road were found to be 52 and 16, respectively, showing an increase of 86%. It is interesting that the mean and standard deviation of the CBR values on JW Cummins Road after 24 to 48 hours were also found to be 52 and 16, respectively, indicating that the stabilization process was consistent.

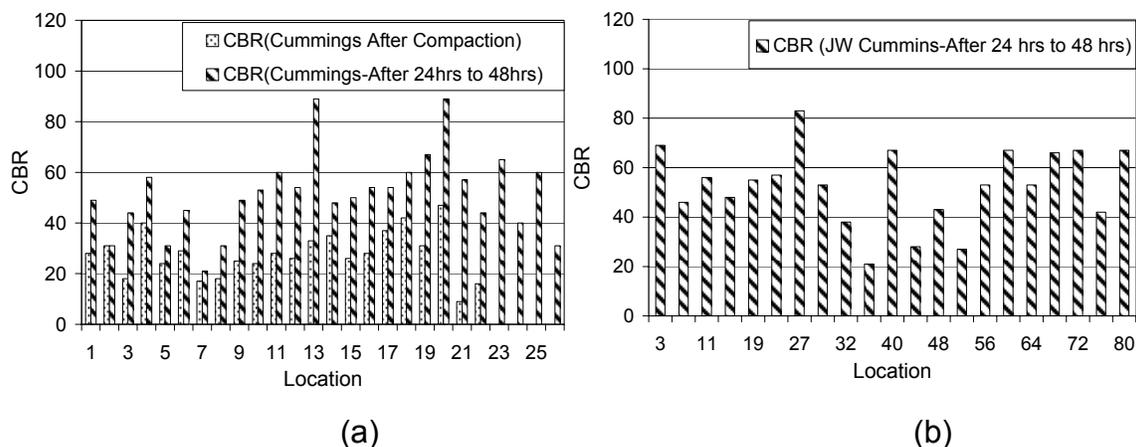


Figure 7. Histogram Plot shows the values of field CBR at various locations along Cummings and J.W. Cummings.

SUMMARY AND CONCLUSIONS

Stabilization characteristics of RAB with self-cementing class C fly ash were investigated in the laboratory and field as part of a demonstration project of full-depth cold in-place recycling of low-volume road asphalt pavement. On the basis of the results obtained in this study, the following conclusions are made:

1. The self-cementing fly ash is characterized by rapid hydration. Fly ash-to-water ratio in the range of 0.3 to 0.35 result in optimal strength. Higher water contents will generally reduce the strength, while lower water contents result in mixes with low workability. These findings indicate that both compaction time and water content must be carefully controlled during construction.
2. The field pulverized RAB has grain size distribution that is finer than that obtained in the lab using hammer mill pulverization. The field pulverized RAB gradation is very close to the dense-graded material, suggesting that better compaction could be achieved in the field than in the lab.
3. The optimum moisture content for RAB-fly ash mixtures are in the range of $7.5\pm 1\%$ as obtained from the standard proctor tests and verified with the unconfined compressive strength and CBR tests. This low optimum moisture content may be due to the grain size and composition characteristics of RAB. Materials with larger grain sizes typically have lower optimum moisture content. In addition, the inherent asphalt content of RAB may also lead to lower moisture requirements.
4. The grain size distribution of RAB is an important property controlling the unconfined compressive strength of the RAB and fly ash mix. RAB with coarser grain size distribution has higher dry density at a lower optimum moisture content compared to RAB in which the coarse fraction has been removed.
5. RAB-fly ash mixtures have higher unconfined strength and CBR at lower-than-optimum moisture contents.
6. To obtain the best result of Class C fly ash stabilization of Recycled Asphalt Base (RAB), clear and consistent construction guidelines must be followed.
7. Homogeneous mixing is necessary to obtain consistent results in both the lab and the field. Monitoring of moisture levels is critical in order to achieve maximum density and compressive strength.
8. Compaction should commence immediately after the completion of mixing and grading and should be completed within two hours. The area to be stabilized should be divided into segments that permit mixing and compaction within this time frame.
9. Field CBR tests may be used to assess the performance of the road base. Field CBR values measured using the dynamic cone penetrometer are found to increase with curing period.
10. The high CBR values obtained by using Class C fly ash to stabilize recycled asphalt and base course may allow for thinner asphalt wear surfaces, thereby reducing construction costs.

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