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Sustainable Reconstruction of Highways with In-Situ Reclamation of Materials Stabilized for Heavier Loads

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ABSTRACT: Development of freight transportation infrastructure, whether it is highway or rail, will need to address several issues to be sustainable and economic. The new infrastructure should sustain higher loads but also last longer, be economic to build, and minimize energy consumption and generation of green house gases for materials production and construction. Upgrading the existing infrastructure to meet the increased load requirements and satisfy these requirements of sustainability is a challenging prospect.

The reconstruction and upgrade can be made using conventional construction materials and methods. However, conventional construction materials are becoming increasingly expensive as demands on resources intensify. In addition, concerns regarding energy use and greenhouse gas (GHG) emissions associated with generating and delivering conventional construction materials have led to significant interest in exploring alternative materials, such as recycled materials (e.g., recycled pavement materials and industrial byproducts) that can be obtained with minimal energy input and GHG emissions, as well as low cost.

One such approach that meets these requirements is reconstruction of highways and railroads by in situ reclamation of existing materials (subgrade, unbound/bound pavement materials and enhancing their mechanical properties by additives to meet the enhanced load bearing requirements and durability. Such additives can be derived from conventional construction materials but also from industrial byproducts enhancing the sustainability aspects such as self-cementing fly ash, cement kiln dust, and flue gas descrubber (FGD) product. Consequently, a stronger and longer lasting highway or railroad infrastructure can be generated using almost entirely recycled materials while meeting objectives of sustainable construction.

To investigate the feasibility of this approach, a field experiment is undertaken at MnROAD facility. Three identical highway sections were constructed except each had a different base course: conventional crushed aggregate, recycled pavement material (RPM), and RPM stabilized with high-carbon fly ash (typically not suitable for concrete production but self-cementitious). A variety of field tests during construction (soil stiffness gauge, dynamic cone, nuclear density, light weight falling weight deflectometer) and post-construction (falling weight deflectometer)

were performed on the instrumented road segments (temperature, moisture content, pavement strain, and stress). Additionally, laboratory material characterization tests (aggregate tests, compaction, permeability, CBR, and resilient modulus) were performed on all three base materials. Comparative behavior and benefits of using recycled materials are investigated.

1. INTRODUCTION

Development of freight transportation infrastructure, whether it is highway or rail, will need to address several issues to be sustainable and economic. The new infrastructure should sustain higher loads but also last longer, be economic to build, and minimize energy consumption and generation of green house gases for materials production and construction. Upgrading the existing infrastructure to meet the increased load requirements and satisfy these requirements of sustainability is a challenging prospect.

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With the increasing awareness of building sustainable transportation system, recycled materials and industrial byproducts are increasingly being used for highway construction, especially in pavement base course. The physical properties of recycled materials and industrial byproducts have to be characterized for the purpose of pavement design. For instance, the deteriorated asphalt pavements could be reclaimed full depth and used for base course for the new pavement. The full-depth reclaimed pavement materials (RPM) could also be mixed with industrial byproducts, such as fly ash and cement kiln dust, to increase the stiffness (*1,2,3*). When compared to traditional base materials, such as crushed aggregates, the recycled materials and industrial byproduct often have unique characteristics. For instance, it was found RPM has higher modulus, but also higher permanent deformation than a certain crushed aggregate (*3*). When these materials are used for pavement construction, the properties, such as resilient modulus and flexural strength (for bound materials only) have to be characterized as specified in the Mechanistic-Empirical Pavement Design Guide (MEPDG). In addition, the MEPDG does not include the use of many recycled materials and industrial byproducts, such as fly stabilized base materials for which the properties have to be determined.

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2. MATERIALS

2.1 RPM and Class 6 Aggregate

The RPM was produced by pulverizing the in-situ asphalt pavement at MnROAD. The RPM consisted of 50% of hot mix asphalt and 50% of existing crushed aggregate base course. The Class 6 aggregate is a granite base course material used by MnDOT. The gradations of the RPM and Class 6 are shown in Table 1.

Table 1. Gradation of RPM and Class 6

Sieve Opening	Percent Finer	
	RPM	Class 6
(mm)	(%)	(%)
37.5	100	100
25	99	100
19	96	98
12.7	86	73
9.5	77	55
4.75	60	32
2	39	11
0.425	13	4
0.075	6	2

2.2 Fly Ash

Fly ash obtained from Unit 8 of the Riverside Power Plant in Minneapolis, MN (operated by Xcel Energy) was used to stabilize the RPM. This fly ash has a calcium oxide (CaO) content of 22.37% and a carbon content of 16.35%. Riverside Unit 8 fly ash is a cementitious high-carbon fly ash. A fly ash application rate of 14% by weight of dry mix was used to stabilize RPM as base course.

3. TEST METHODS

3.1 California Bearing Ratio

CBR tests were conducted on all specimens in accordance with ASTM D 1883. CBR tests on specimens without fly ash were performed immediately after compaction, whereas specimens with fly ash were tested after 7-day and 28-day curing. A surcharge (4.54 kg) was used during CBR testing.

3.2 Resilient Modulus

Resilient modulus tests were performed on the subgrade soil, Class 6sp, RPM, and RPM-fly ash mixtures in accordance with the National Cooperative Highway Research Program (NCHRP) 1-28A test protocol. Three replicates were used for each material. M_r specimens were instrumented with both internal and external linear variable displacement transducers (LVDTs).

3.3 Unconfined compressive strength

Unconfined compression tests were conducted on SRPM resilient modulus specimens after the completion of the M_r test, in accordance with ASTM D 5102. All stabilized specimens were loaded at a strain rate of 0.21% per minute. These samples were cured for 7 and 28 days and tested for unconfined compression strength to determine the effect of curing length on unconfined compression strength.

3.4 Dynamic Cone Penetrometer (DCP)

DCP is an instrument designed to provide a measure of the in-situ strength of subgrade, subbase, and base materials. A 7.9-kg weight is raised to a height of 57.4 cm and then dropped, driving the 60-degree 20-mm-diameter cone into the soil or aggregate base. The penetration depth per blow is used to calculate the strength or stiffness of the subject materials.

3.5 Lightweight Deflectomer (LWD)

LWD device is hand-operated and takes measurements of the deflection of compacted soil that is impacted by a falling weight. The LWD has one sensor directly below the falling weight. The device measures the resulting deflection and estimates a modulus value based on the force required to generate a given deflection for that soil type.

3.6 Falling Weight Deflectometer (FWD)

FWD tests were conducted directly on the base courses during the construction. Prior to the placement of HMA, the base course had one month of curing. FWD tests were also conducted on several curing days to monitor the change of the properties of fly ash stabilized RPM. After the placement of HMA surface, FWD tests were conducted on HMA to backcalculate the modulus of base materials.

3.7 Soil Stiffness Gauge (SSG)

A Humboldt H-4140 SSG was used in this study. The soil stiffness gauge (SSG) is a non-destructive testing device, which measures the stiffness (and or modulus) of surficial materials in place. The SSG directly measures in-situ stiffness of materials in a zone lying 125 mm ~ 380 mm below the surface. The SSG stiffness measurements were made in accordance with ASTM D6758.

4. RESULTS

Table 2 summarizes the laboratory test results. It is found that RPM has higher modulus than Class 6sp but also higher plastic strain, indicating higher potential for rutting. The CBR of RPM was significantly lower than Class 6sp. Stabilizing RPM with a high carbon/high calcium fly ash significantly increased CBR, M_r, and lowered plastic strain. The strength of field mixed RPM with fly ash was found to be significantly lower than that of laboratory mixed, in terms of CBR, M_r, and Q_u. It is suggested that the test results based on laboratory mixed specimens should be corrected as MEPDG input.

Table 3 shows the direct measurements on the base layers. It can be seen that for any of M_r and field test methods, fly ash stabilized RPM had higher modulus than RPM, followed by crushed aggregate, as shown in Figure 1 in which the number after the test method indicates the days after the construction of base courses. The resilient modulus was always higher than moduli from field tests. The M_r of RPM was 257 MPa, while the highest modulus for RPM from field tests, DCP in this case, was 105 MPa. The difference between M_r and back-calculated moduli for stabilized materials is even larger. The M_r of 28-day stabilized RPM was 4334 MPa, while the highest modulus from field tests was 364. The M_r is more than ten times higher than moduli form field the tests. In the field tests, DCP tests resulted in higher modulus than LWD, SSG, and FWD. The moduli from SSG were higher than those from LWD and FWD tests, except for stabilized RPM. Between LWD and FWD tests, LWD generated higher moduli. This might be related to the stress/strain-dependence of these materials. Each of these test methods applies different load levels to the materials and induces different strain levels.

TABLE 2 Summary of Field and Laboratory Test Results

Material	Curing Time, (d)	CBR, (%)	SRM, (MPa)		Plastic Strain, (%)	Q_u, (kPa)	R, (kPa)
			Ext	Int			
Class 6sp	0	133	154	220	0.71	-	-
RPM	0	19	201	257	2.8	-	-
L-SRPM	7	129	513	2984	0.58	1160	150
	28	176	561	4334	0.56	1380	320
F-SRPM	7	62	-	-	-	350	-
	28	94	-	-	-	480	-

Note: CBR = California Bearing Ratio, SRM = summary resilient modulus, Qu = unconfined compressive strength, R = flexural strength, Ext = based on external LVDT, and Int = based on internal LVDT measurement of deformation.

TABLE 3 Comparison Between Laboratory M_r and Field measurement Moduli

Curing Days	Test Method	Fly Ash+RPM	RPM	Class 6
		Average Moduli (MPa)		
7	M_r	2984	257	220
28	M_r	4334		
8	DCP	3634	105	67
8	LWD	182	42	15
22	DCP	328	83	63
22	FWD	134	36	22
22	SSG	159	70	59
26	FWD	112		

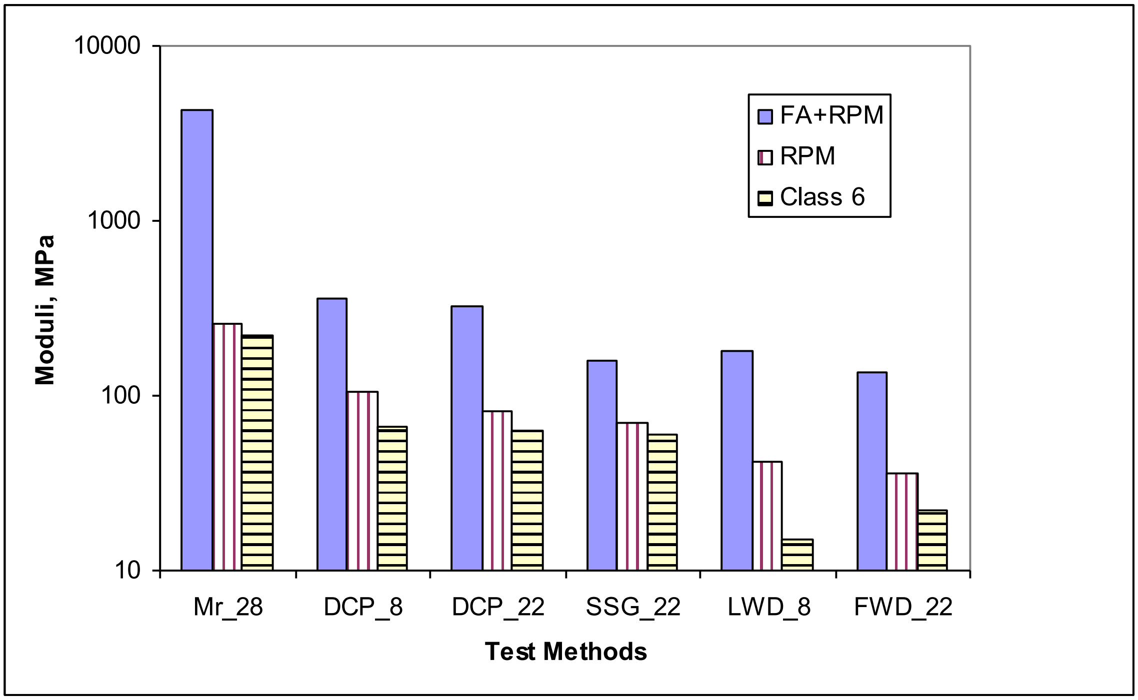

Figure 1. Comparison of Material Modulus as Measured by Different Methods

5. COMPARISON OF INITIAL CONSTRUCTION COSTS, ENERGY CONSUMPTION, AND GREENHOUSE GAS EMISSION

Upon the completion of construction at MnROAD, the initial construction costs are available for comparison between different technologies. As seen from the Figure 2, crushed aggregate has the highest construction costs. Some of the costs for crushed aggregate and untreated RPM are associated with the second base work, due to the rainfall during the construction. At the end, fly ash treated RPM base course had the lowest construction costs.

The initial energy consumption and greenhouse gas emission are also compared, using the PaLATE program, as shown in Figures 3 and 4. Again, the high carbon fly ash treated RPM has the lowest energy consumption and greenhouse gas emission. However, it should be noted that these comparisons are based on initial construction data. Life cycle costs, energy consumption, and greenhouse gas emission are needed, as the pavement performance affects maintenance and rehabilitation activities. It should also be noted that, due to the wet weather during construction, the RPM and crushed aggregate bases had to be removed and replaced, while the fly ash stabilized RPM base was not affected by the weather.

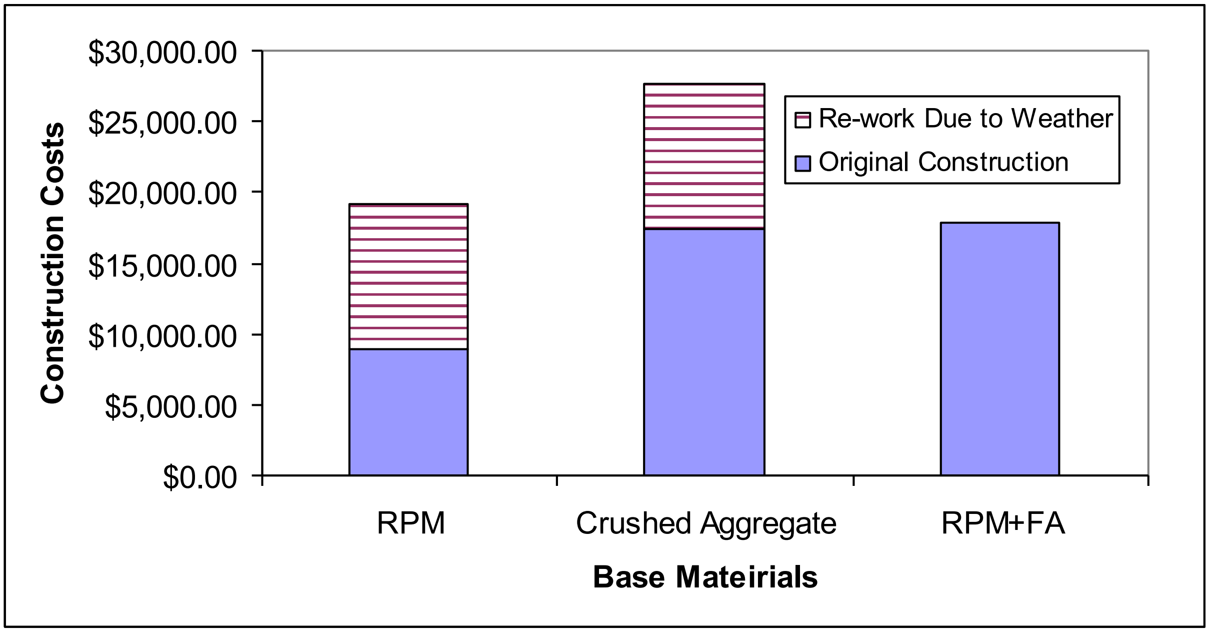

Figure 2. Comparison of Initial Construction Costs

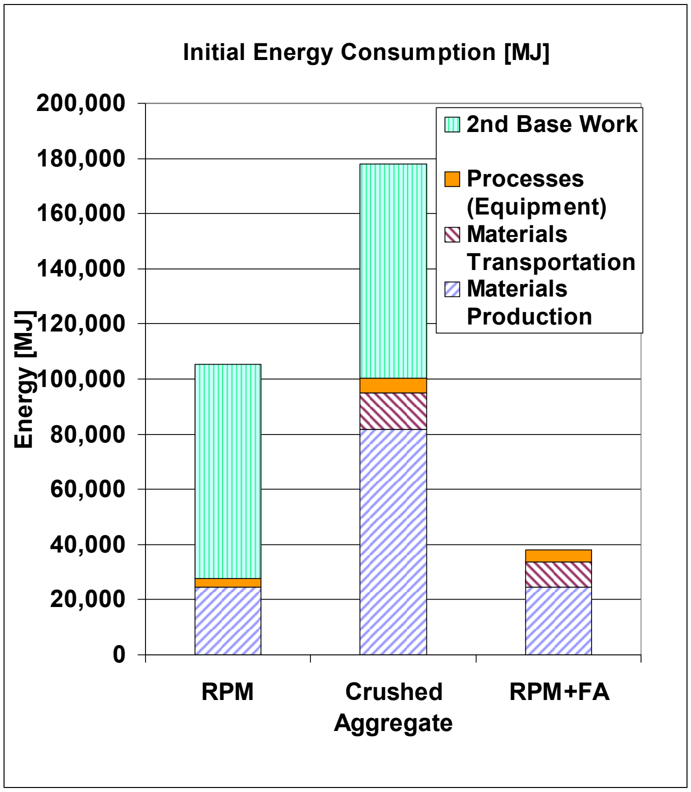

Figure 3. Comparison of Initial Energy Consumption

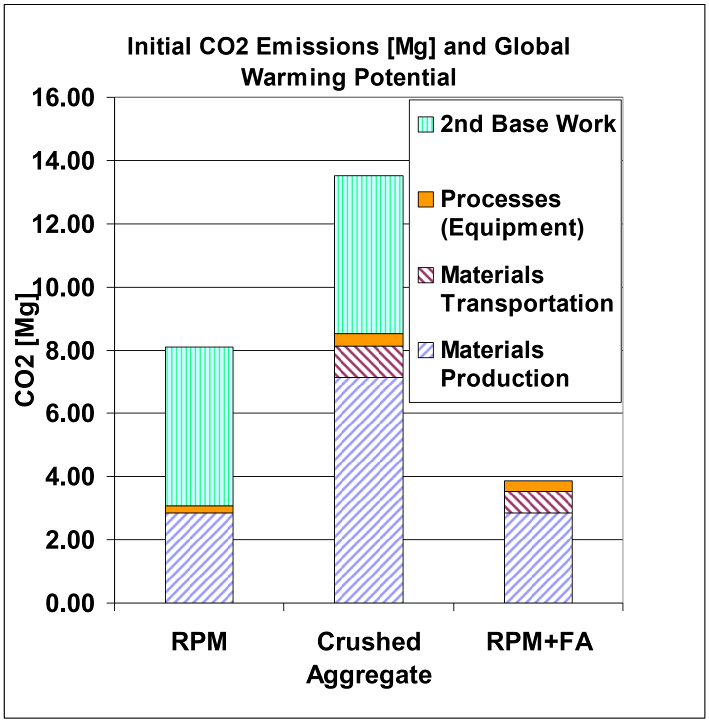

Figure 4. Comparison of Initial Greenhouse Gas Emission

6. CONCLUSIONS

This paper presents the results of characterization of recycled pavement material (RPM) with and without fly ash stabilization as a base material in comparison to a traditional base material, Class 6sp crushed aggregate. The feasibility of using high carbon fly ash to stabilize RPM was demonstrated. The RPM and fly ash stabilized RPM have higher M_r than conventional aggregate. However, the CBR of RPM is significantly lower than that of conventional aggregate. The unconfined compressive strength of field-sample fly ash/RPM materials is significantly lower than that of lab-mixed materials, indicating that the design of stabilized base needs to take the construction quality into account. Different field test methods produced different modulus, indicating that these materials, including the stabilized RPM, are nonlinear materials. The behaviors of these materials depend on the stress/strain levels induced by different test methods. In addition, using RPM and fly ash has potential to generate an enhanced stiffness base to support heavy freight loads, save construction costs, energy consumption, and reduce greenhouse gas emission. Life cycle analysis is warranted for future study.

7. REFERENCES

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