Laboratory Performance of Asphalt Emulsion Treated Base for Cold Regions Applications

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Abstract

Asphalt emulsions are one of the alternatives for stabilizing base layers. The use of asphalt emulsion treated mixtures can be cost effective especially in cold regions where supplying hot mix is not economical. However, in cold climates emulsion aggregate mixtures show low strength at early ages and require a longer curing time to develop breaking of asphalt emulsions throughout the aggregates. The breaking period depends on the rate of water loss from the mixture which is impacted by ambient temperatures. Type of asphalt emulsion, curing temperature, curing time and moisture content are four significant factors in early age development of engineering properties of the emulsion base aggregate mixture. In this study, a proposed dense-graded gravel base material was treated with an anionic slow setting emulsion with low viscosity (SS-1). In order to evaluate early curing, one set of samples was cured for 7 days at 5 ° C and another set was cured at 24 ° C. Dynamic resilient modulus and permanent deformation tests were performed to assess the effect of curing and temperature on stiffness and resistance to the repeated traffic load. The study showed that high resilient modulus and low deformation values were attained for 7 days curing at 24° C. The low temperature slows the breaking process of the emulsion and causes the emulsion aggregate mixtures to have a lower resistance to repeated loading.

1. Introduction

1.1 **Background**

In cold regions, Emulsion Aggregate Mixture (EAM) can be considered as a stabilization alternative particularly in climates where other stabilization materials such as cement and lime are ineffective. The treatment allows for the use of locally available aggregates with a type of bitumen emulsions (Asphalt Institute, MS-14,1989). Curing of EAM is expected to be slower in adverse weather conditions, which in turn impacts the rate of strength gain of compacted layers.

Generally, bitumen emulsions are categorized as oil in water emulsions, which contain from 40% to 75% bitumen with droplets range from 0.1—20 micron in diameter and 25% to 60% water plus 0.1% to 2.5% emulsifier (Salomon, 2006). The bitumen emulsion enhances moisture sensitivity, resistance and deformation characteristics of the mixture. The droplet of bitumen similar to a mortar, coats fine aggregates and disperse with fine aggregate through coarse aggregates but in most cases large aggregates are not coated with bitumen (Asphalt Academy, 2009). Since coated particles are not linked to each other and coarse aggregates are not coated; the behaviour of EAM is similar to unbound granular materials but with increased cohesive strength and reduced moisture sensitivity (Asphalt Academy, 2009). Table 1 summarizes key previous studies on stabilization of aggregate layers using bituminous emulsion.

There is no standard laboratory EAM design, however factors such as workability, aggregate coating and maximum dry density are typically considered (Moaveni et al, 2012). In the current study, a dense graded gravel aggregate was stabilized with SS-1 emulsion. Illinois Transportation Asphalt-Aggregate Mixtures Mix Design and Asphalt Academy Manual (2009) were followed for mix design and fabrication. Resilient modulus and permanent deformation tests were performed in order to compare the resistance property of the EAM with the virgin gravel basematerial.

Table 1 Summary of previous investigations of Emulsion Aggregate Mixtures

Reference	Curing techniques	Test programs	Main findings
Terrel and Wang (1971)	• 1, 3 and 7 days curing at 24° C • Adverse condition at 4.4° C • 3 days curing in the oven at 49° C	• Resilient modulus test	• Moisture decrease of the sample reduced resilient modulus sensitivity to the confining pressure. • Resilient modules of the cured samples in the adverse condition was less than cured samples at 24° C.
Mamlouk et. al (1981)	• 1 and 3 days at 24° C • 3 days in the oven	• Indirect tensile strength test (ITS) • Resilient modulus test at 10° C, 24° C and 38° C	• 3 days oven cured samples produced highest resilient modulus • Tensile strength was higher at asphalt emulsion residue content of 3.25% than at 4% asphalt residue.

Anderson and Thompson (1995)	• Curing until reaching a constant weight at 38° C.	• Rapid shear test • Resilient modulus • Permanent deformation	• The EAM secant modulus was higher than for the untreated aggregates. • The EAM modulus was improved over the untreated aggregate modulus. • Curing significantly increased resilient modulus and reduced permanent deformation.
Quick and Guthrie (2011)	• 1 year field curing	• Portable falling weight deflectometer (PFWD) • Dynamic cone penetrometer (DCP)	• Resilient modulus had an increasing trend after 7 days • Resilient modulus reached a peak after 4 months. • Freeze and thaw cycles significantly decreased the resilient modulus between fourth month and 1 year.
Moaveni et. al (2012)	• Dry curing of the ITS test: curing at 30° C for 26 hrs then samples were sealed at 40° C for 48 hrs. • Wet curing of the ITS test: samples get soaked in water after curing at 25° C for 24 hrs. • Curing at room temperature for 36 hours for the resilient modulus test.	• ITS test • CBR test • Resilient modulus test • Permanent deformation	• Higher tensile strength for the EAM samples in comparison with virgin aggregate • Increase in the resilient modulus of the EAM was observed. • The permanent deformation was generally lower for the EAM than virgin aggregate.

2. Testing Program

2.1. Material

A gravel aggregate selected for granular base course in Manitoba was used for this study. Gradation and engineering properties of the gravel aggregates are given in Table 2. Asphalt Academy gradation specified from suitable to ideal rages of the aggregate gradation for bitumen stabilization. Figure 1 indicates the selected gradation satisfied the gradation specifications of Manitoba and Asphalt Academy Mixture Guide (2009).

Table 2. (a) Aggregate gradation

Particle size (mm)	Sieve size	Percent Passing (%)
19	3/4″	100
16	5/8″	97.6
12.5	1/2″	83.2
9.5	3/8″	75.0
4.75	No.4	54.4
2	No.10	38.2
0.825	No.20	27.7
0.425	No.40	19.4
0.180	No.80	13.4
0.0075	No.200	9.2

Table 2. (b) Engineering properties

Optimum Moisture Content (%)		Maximum Dry Density (Kg/ m^3)		Plasticity of fines
Standard Proctor	Modified Proctor	Standard Proctor	Modified Proctor	
7	6.4	2223	2345	Non-Plastic

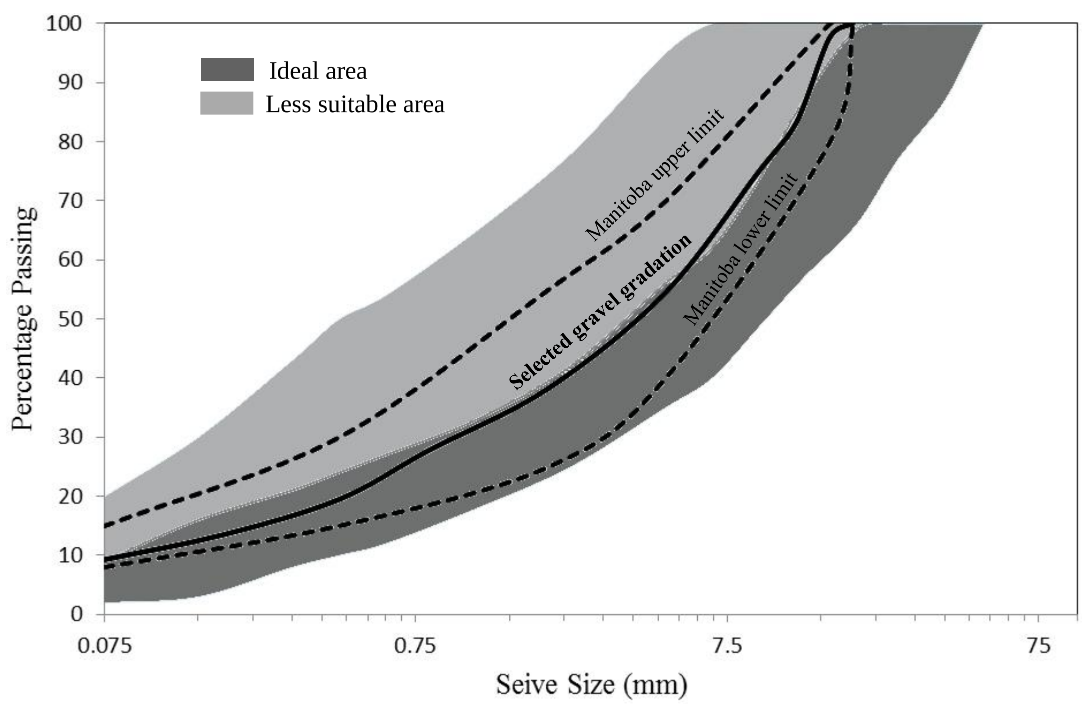

Figure 1.Selected gravel base gradation according to gradation requirement for bitumen stabilization (Asphalt Academy, 2009) and Manitoba specifications.

The asphalt emulsion used in this study is anionic slow setting emulsion with low viscosity (SS-1) manufactured by McAsphalt. The manufacture results of emulsion characterization tests and bitumen residue by low temperature evaporative technique (ASTM D6934) are shown in table 3.

Aggregate type influences the selection of an emulsion type which can be cationic or anionic (Oruc et al, 2007). Asphalt Institute (MS-14) recommends a visual coating test to determine compatibility of aggregate type with the emulsion type. If more than 50% of the colour of the mixture changes to black, the coating is considered acceptable. The coating test was conducted on the aggregate used in this study, and clearly showed that more than 50 percent of the aggregates were coated by the slow-setting emulsion (SS-1).

Table 3. SS-1 emulsion characteristics.

Property	Value
Viscosity @ 25 C	20-60 SFS
Residue by low temperature evaporation technique	62.5%
Oil portion distillate	0%
Penetration @ 25 °C 100gr	10-20 mm
Coating Test	80%

2.2. Emulsion Aggregate Mixture Preparation

Illinois Transportation Department uses equation 1 to determine the required bitumen emulsion content for dense graded aggregate.

$$E\% = \frac{0.00138\ AB + 6.358\ \log C - 4.655}{P} \qquad (1)$$

Where:

E%= required emulsion content asphalt content by weight of dry aggregate, in percent.
A= percentage of aggregate retained on No.4 (4.75 mm) sieve
B= percentage of aggregate passing a No. 4 (4.75 mm) sieve and retained on No. 200 (75 µm) sieve
C= percentage of aggregate passing the No. 200 (0.075 mm) sieve.
P= percent residue of emulsion by distillation.

When asphalt emulsions are utilized for surface treatment, the mixture design normally follows asphalt concrete design process. Similarly, the conventional soil stabilization mixture design can be used for stabilizing base material with an asphalt emulsion. Reaching the maximum dry density of the mixture is the objective of the conventional soil stabilization design. Asphalt Academy (2009) indicates that the optimum moisture content of the EAM is close to the virgin aggregate. The moisture of the EAM is combination of hygroscopic moisture of aggregates, pre-wetting moisture for more coating and workability, and the water included in the emulsion (Moaveni et al, 2012).

The degree of compaction impacts initial strength development in the emulsion aggregate mixture (Quick et al, 2011). Aggregates and pre-mix water were preserved at 5° C for 24 hours before fabrication for samples cured at the low temperature. Compaction can cause water to separate from the asphalt binder and affect the rate of mix curing and cohesion (Asphalt Inistitute-M19, 1997). Samples were prepared with total moisture content equal to the optimum moisture content of the virgin aggregate and compacted with 28 blows of the AASHTO modified Proctor rammer (AASHTO T-180) in 8 layers in the 101.6 mm (4 in) in diameter by 203.2 mm (8 in) mold.

2.3. Curing Method

Curing of the EAM is the process where the mixture loses moisture and the asphalt emulsion particles have to coalesce (Moaveni et al, 2012) and bond to aggregate and involves the development of the mechanical properties of the asphalt cement (Asphalt Institute MS-19, 1997). The reduction in moisture content of the stabilized aggregate increases the tensile and compression strengths and causes greater resistance to permanent deformation. Curing process can be affected by weather conditions, for example high humidity and low temperature would deter curing.

The curing method used in this study follows field investigation of the emulsion treated base material showing the sharp increase of the resilient modulus reduces to slight increase trend after 7 days curing (Quick et al, 2011). Curing was accomplished under three conditions for 7 days. Table 4 summarizes curing conditions. Type I curing represent typical lab environment with the specimens cured at the room temperature (24° C) without sealing. Dry curing at 5° C is defined as type II curing. Wet curing (Type III) simulates adverse curing conditions when the groundwater table is near the stabilized layer and moisture condition in the subgrade is close to the saturation level. In the laboratory, the samples were stored on a wetted porous stone and placed inside the environmental chamber.

Table 4. Curing conditions

Type	Condition	Temperature	Relative humidity	Comment
I	Lab environment	24° C	26%	• Unsealed • Without capillary action
II	Cold and dry environment	5° C	6.7%	• Laterally sealed • Without capillary action
III	Cold and wet environment	5° C	22.2%	• Laterally sealed • With capillary action

2.4. Resilient Modulus Test

Tests were performed in a dynamic triaxial cell as per NCHRP 1-28A (2003) resilient modulus test method for unbound materials. The loading was haversine-shape having duration 0.1s and a rest period of 0.9s. The cell pressure was provided by compressed air and measured during testing by a pressure gauge. Two Linear Variable Differential Transducers (LVDTs) were used to measure recovered and permanent vertical deformations. These LVDTs were mounted on the specimen and attached to the ring clamps. Stress sequences recommended in NCHRP 1-28A (2003) for base material were used in this study. The specimens that were cured at 5° C (Type II and Type III) were permitted to adjust to the test temperature of 24° C before loading. The drained dynamic triaxial test was performed on samples cured at 5° C (Type II and Type III), while samples cured at room temperature (Type I) were tested in the undrained condition because the samples had lost most of their moisture in the 7 days of curing.

2.5. Permanent Deformation

The permanent deformation test was conducted using a haversine load pulse of 0.1s loading period and 0.9s rest period for 13,000 cycles. The vertical stress level was 103.4 kPa which included a cyclic stress level of 0.93 kPa and a contact stress level of 10.3 kPa. The samples were confined with 34.5 kPa which was maintained during the test. These stress levels are field representative stress condition in the base layer based on stress analysis of NCHRP 1-28 A (2003).

3. Test Results and Discussion

Moisture content of the EAM during type I curing was estimated according to AASHTO T-255. The moisture contents during curing are shown in Figure 2 which indicates the moisture content of specimens rapidly decreased in the first three days and then converged to 4%. The comparison between moisture content of the EAM immediately after fabrication and optimum moisture content of the gravel material revealed that the moisture content of the EAM after compaction was 5.9% which is close to the optimum moisture content of the virgin aggregate at 6.4%. This finding is compatible with Asphalt Academy (2009) mixture design procedure and Moaveni's study (2012), which mentioned that the optimum mixing moisture content is approximately equal to the optimum moisture content of the virgin aggregate.

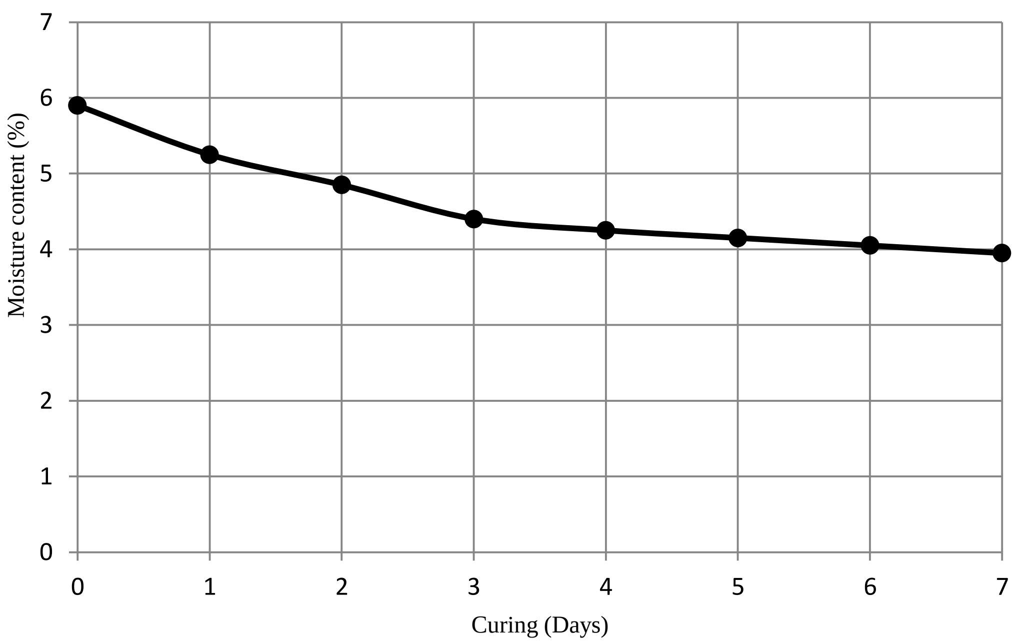

Figure 2. Moisture loss trend of samples during curing type II.

Table 5 compares dry densities of the prepared specimens in the different conditions with the maximum dry density of the virgin gravel base. Furthermore, table 5 expresses the maximum dry density of the emulsion aggregate sample was considerably lower than the maximum dry density of the base gravel due to the immediate effect of emulsion stabilization. Prepared samples at the low temperature showed the lowest dry density which is due to the effect of temperature on the compaction.

Table 5. Dry density comparison between prepared EAMs at 5° C, 24° C and virgin gravel at 24° C.

Material	Emulsified aggregate	Emulsified aggregate	Virgin gravel
Preparation temperature	5° C	24° C	24° C
Dry density (Kg/m^3)	2200	2233	2343

Figure 3 shows the resilient modulus values of the EAM and the untreated gravel aggregate. The resilient modulus trend of the treated aggregates increased over the untreated aggregate. The added emulsion contributes to the cohesion properties of the aggregate and causes shear improvement inside the EAM (Thomas & Anderson, 1995). As shown in Figure 3, the resilient modulus of the emulsified aggregate correlates with the increase of the curing temperature. The increase of the curing temperature from 5° C to 24° C accelerated water evaporation and asphalt droplets breaking which increases cohesion and friction angle of the mixture.

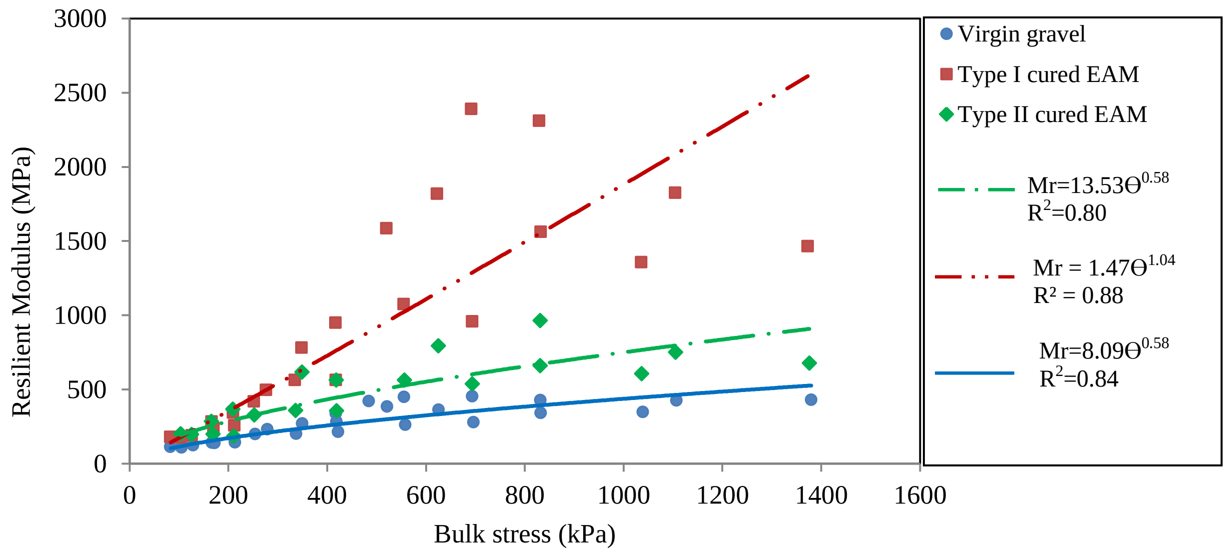

Figure 3. Resilient modulus for virgin gravel and dry cured EAMs at 5° C and 24° C.

The resilient modulus test of the wet cured specimens at 5° C (type III) is shown in figure 4 and illustrates that emulsion can enhance resistance of the virgin base material. Additionally, the capillary moisture decreased the resilient modulus slightly in comparing with 7 days dry cured specimens at 5° C (type II). However, during the resilient modulus test the total strain in the curing type II samples exceeded 5%.

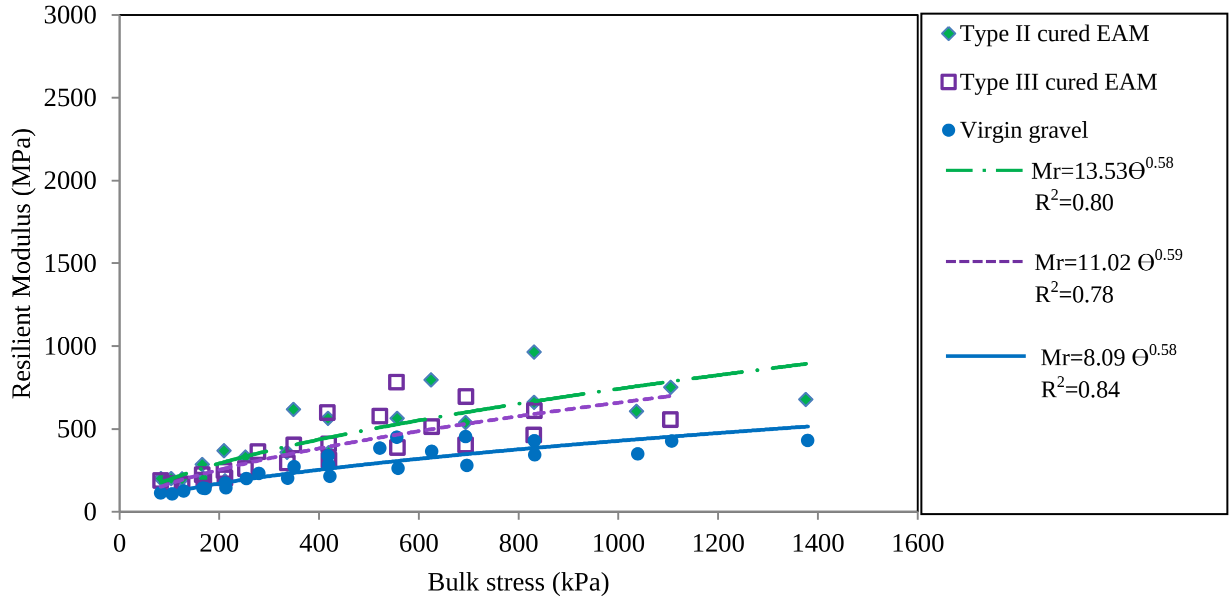

Figure 4. Resilient modulus for virgin aggregate, wet cured and dry cured EAMs at 5° C.

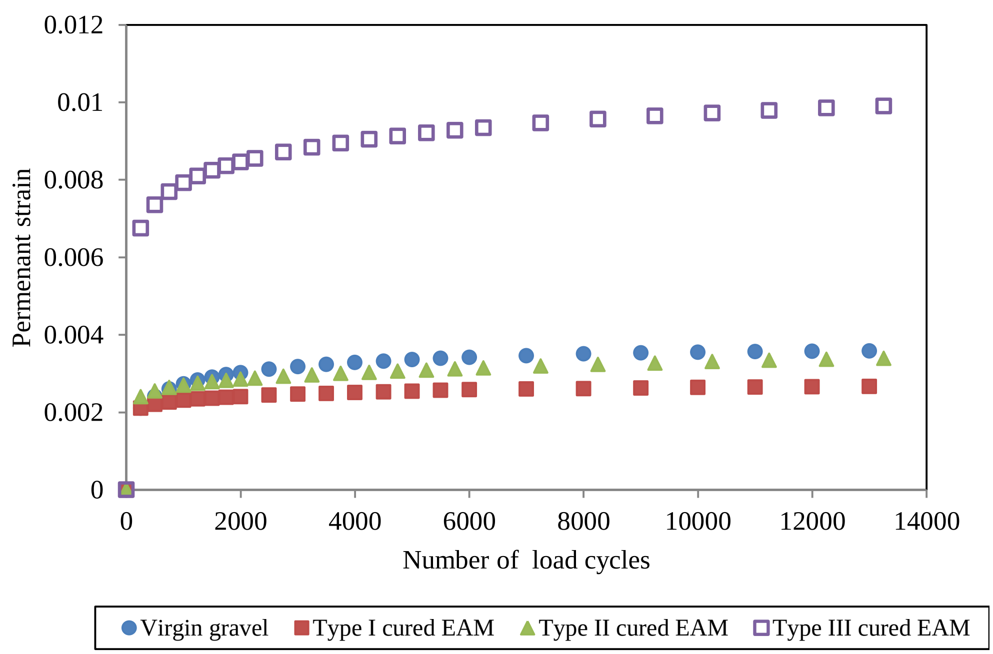

Figure 5. Permanent strain of virgin gravel in comparison with wet cured EAM at 5° C, dry cured EAM at 5° C and dry cured EAM at 24° C.

The permanent deformation results are shown in Figure 5. It is noted that the overall trend of permanent strain of the cold dry cured mixtures (type II) is slightly less than the virgin gravel, followed by the normal cured mixture (type I). Permanent strain values of the EAM and virgin gravel are close because asphalt binder is not completely broken and has lubrication effects between particles. Nevertheless, the capillarity phenomenon influence hardly on permanent strain and the mixtures cured in the cold and wet condition (type III) involves the highest permanent strain. The capillary action increases moisture of the base material and causes rise of pore water pressure under dynamic loads and prevents curing the mixture and breaking of asphalt binders inside the emulsion.

4. Conclusions

This study consisted of resilient modulus and permanent deformation tests on emulsion gravel mixtures that were cured 7 days in various conditions. Gravel aggregates mixed with SS-1 type anionic emulsion and samples were fabricated in the laboratory. Curing conditions included curing at room temperature, cold dry curing and cold wet curing. The purpose of the cold wet curing condition was to consider adverse climate and the moisture susceptibility of the mixture. Treated base materials were tested after curing to evaluate improved resistance and stiffness properties by means of resilient modulus and the permanent deformation tests respectively. The findings of this study are summarized as follow:

- The dry densities comparison showed that EAMs have lower dry densities than the virgin aggregate
- Resilient modulus test showed that the EAMs typically exhibited higher shear strength than virgin aggregate. The resilient modulus showed an increasing trend with increased stress states. However, the total permanent deformation of cold wet cured samples after 1100 kPa bulk stress exceeds 5% because the moisture level was above the optimum moisture content.
- The permanent deformation test exhibited considerable improvement in the accumulated permanent strain for mixtures cured at 24° C. On the contrary, the emulsion had a slight effect when water evaporation becomes slow due to curing at 5° C. The permanent deformation significantly increased when the capillary action and low temperature simultaneously extended moisture and obstructed curing process of the treated base material.
- This paper aimed to produce design inputs for use of EAM in cold regions and under adverse climates. In those conditions, the rate of curing decreases and the benefits of stabilization are reduced,

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