Use of 100% Reclaimed Asphalt Pavement (RAP) Material in Asphalt Pavement Construction

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ABSTRACT: This paper presents results of a laboratory study on the use of rejuvenators to soften age hardened recycled asphalt binders, and reports data from seven-year old 100% recycled NYCDOT plant mix material produced from reheated millings and rejuvenator. Laboratory samples were prepared with re-graded RAP millings from one specific pavement and a commercial rejuvenator. Dynamic modulus and creep compliance test results of laboratory prepared samples were obtained for a range of temperatures over a five-week period of accelerated aging at 60°C. This data is compared to results reported in the literature for virgin and low percentage recycled mixes. Stiffness of samples with RAP and rejuvenator, and RAP only demonstrated significant softening by the rejuvenator that improved with aging especially at –10^{o}C. Collected data suggests that rejuvenators are a viable option for high recycled mixes currently being produced at conventional asphalt plants. Also presented is a brief discussion of new technology capable of producing 100% recycled material. Steps in the production and air pollution control are discussed. The conclusion is that it is possible to obtain good performing high recycled mixes, up to100% recycled with the use of rejuvenators using currently available technologies.

KEY WORDS: Rap, rejuvenator, recycling agents, modulus, creep compliance

1 INTRODUCTION

Increased use of reclaimed asphalt pavement (RAP) material can have significant positive impact on the economics and environmental sustainability of pavement construction. Unfortunately current RAP practices don't support the evolution of high RAP mixes. The FHWA reports that national RAP utilization remains an abysmal 13% in the US (FHWA, 2009) with many agencies limiting RAP content in all pavement layers. With the specter of long term deficits restricting public spending what can be done to facilitate recycling more RAP? Is it possible to recycle 80 to 100% of the mix binder using existing plants and mixes?

Following the 1974 Oil Embargo FHWA sponsored pilot RAP projects across the nation that by coincidence were a minimum70% recycled content (FHWA, 1995). These mixes were evaluated with the pre-SHRP analytical tools available at the time that indicated the RAP mixes were consistently superior to the original source pavements. (FHWA/EPA, 1993). RAP use exploded following FHWA's demonstration projects with many states accepting 50% recycled content in base layers. That is until Superpave replaced Marshall mixes.

In the post-SHRP/Superpave era, material managers need to know the blended binder grade prior to accepting vendor mixes. At first, standard procedure had been to limit RAP content such that it had minimal impact on the blended binder properties. Ultimately laboratory investigations were conducted to determine how the Performance Grade of the liquid asphalt added to a mix should be adjusted to accommodate higher RAP percentages. These investigations have been carried out on the basis of blended binder properties - viscosity, $G^*/\sin(\delta)$, and later on the basis of mix properties such as dynamic modulus.

The guidance provided by these studies was sufficient for most of the past decade. While the recommendations vary in their specific steps, in essence they are as follows: no change in binder grade for mixes with 15-20% RAP, one grade lower up to 40%, and two grades lower above that, and so on (McDaniel and Anderson, 2001). These recommendations have provided a rational method that supports recycled contents approaching 40% but have done little to prepare for higher rates of recycle needed in today's market.

Perhaps of greater significance, this method of correcting recycled binder hardness with softer grades of liquid asphalt is not producer friendly and discourages widespread adoption by industry. The amount of RAP that can be utilized depends on the availability of the specific binder grade that produces the desired blended grade at that RAP percentage. Obviously, to produce mixes with different percentages of RAP, one needs several different PG grades of binder. This practice has effectively limited the use of RAP to minimum levels, or worse caused producers to use the wrong binder grade on a routine basis. From a practical point of view, it is not possible for producers to maintain a large number of binders of different grades to produce mix with different percentages of RAP.

In the post SHRP-Superpave era, the large majority of funded research has been in support of low RAP percentages, <40%. Too many of those studies were distracted by the age old black rock debate and attempted to determine the short term interactions of the aged binder with the new liquid asphalt. Few researchers recognized that when testing RAP mixes, results will change over time due to the slow paced mixing of the two binders (Noureldin and Wood, 1987). The properties obtained at any point during a typical laboratory study are at best a snapshot of an ongoing mixing process. Consequently a recycled mix can exhibit much softer properties initially than would be predicted by extraction and recovery testing. While dynamic blending is of little concern at low RAP contents, higher RAP contents with binder grade bumped more than one step could be susceptible to rutting failures until the old and new binders blend sufficiently.

1.1 Need for a different approach

Use of softer PG binders has not been widely adopted by either refineries or producers even at low RAP contents. In order for industry to be successful when recycling at increasingly higher RAP contents a new approach is needed to correct for age hardened RAP binders. That approach should accommodate a wide range of RAP contents using one material and require little change from existing practice. Following is a discussion of an old pre-SHRP recycling strategy that at one time was widely accepted but still holds promise for wider use in the future.

Strategy: Use industrial process oils, rejuvenators, to soften age hardened RAP binders. Liquid asphalt remains the PG 64-22 or equivalent binder used for a virgin mix.

Rejuvenators are actually used by some refineries to create the softer binder grades called for by current practice. When used at the plant, a rejuvenator delivers the same softening as different PG binders but with far fewer products and storage tanks. Multiple tanks containing different PG binders can be replaced by a single tank and a single rejuvenator.

This approach is suitable for all levels of recycling right up to 100% recycled. Rejuvenators have the ability to match exactly the recycled binder content while only requiring producers to store one new product in an unheated storage tank. Most existing drum plants are already capable of recycling 80% of mix binder requirements with a combination of fractionated RAP and recycled asphalt shingles. Industry is ready for a new way to increase recycled content. The current practice of bumping binder grade isn't adequate as producers start pushing the envelope with recycled contents greater than 40%.

1.2 Objective

The objective of the ongoing WPI study is to develop a new rational method that can be used by mix designers to optimize rejuvenator addition rates. This paper reports on the first phase of that study which quantified the time dependent effects of rejuvenators on laboratory samples with 100% RAP and evaluated properties of 100% recycled plant mix produced by NYCDOT in 2002 with traditional rejuvenators.

2 APPROACH

The laboratory phase can be summarized as follows: 1. Regrade RAP samples to meet a specified gradation; 2. Determine bulk specific gravity of regraded samples; 3. Add rejuvenator to samples using vendor guidelines based optimum binder content; 4. Compact 150 mm diameter specimens with the gyratory compactor; 5. Determine dynamic modulus of prepared specimens; 6. Condition specimens for five weeks at 60^{o}C; 7. Measure dynamic modulus after 1, 2, 3 and 5 weeks of conditioning; 8. Evaluate change in dynamic modulus values resulting from rejuvenator and aging; 9. Evaluate creep compliance and indirect tensile strength

2.1 Materials for Laboratory Study

Reclamite was selected as the rejuvenating agent to be used in the laboratory on the basis of its proven record of excellent performance. Reclamite is an asphalt rejuvenator which provides maltenes to restore the asphaltenes/maltene ratio in RAP. The effectiveness of Reclamite has been reported in a number of reports, as summarized by Boyer (Boyer, 2000): 1. Air Force study in 1970 (Rostler and White, 1970); 2. Navy study in 1970, 1973 (US Navy, 1970, 1973); 3. US Army Corps of Engineers study in 1976 (US Air Force, 1976); 4. Several unreported studies from states and provinces such as Montana, British Columbia, summarized in reference (Brownridge, 2006). Reclamite was obtained from TRICOR refining, LLC, CA. RAP materials were obtained from a Maine (ME) Department of Transportation (DOT) stockpile near Portland, ME. This RAP consists of 12.5 mm NMAS (nominal maximum aggregate size) aggregate with PG 64-28/AC 20 binder. The asphalt content of the RAP was determined to be 5 %, and the washed gradation was determined. The RAP was then regraded to meet the gradation of a MDOT base course. It is a 12.5 mm NMAS gradation with lower and upper limits of 2 and 8 percent for 0.075 mm sieve, and 23 and 49 for 2.36 mm. The Reclamite content was determined as 0.9% on the basis of the formula suggested by its manufacturer (Brownridge, 2006).

2.2 Test Plan

For laboratory materials, two different mixes were used, one with RAP only and another with RAP plus Reclamite. The Reclamite was mixed with the RAP and compacted immediately at 60^{o}-70^{o}C to a target air void content of 6-8%. Following compaction of 150 mm diameter samples, 100 mm diameter, and approximately 150 mm tall samples were cored out and tested for dynamic modulus at three temperatures and four frequencies. The samples were then kept at 60^{o}C oven for 5 weeks (to facilitate the action of the rejuvenating agent) and tested for dynamic modulus at the end of each week. After the last dynamic modulus test, samples were cut from the dynamic modulus samples and tested for indirect tensile (IDT) creep compliance and indirect tensile strength at -10^{o}C. Indirect tensile strength was derived from the maximum load of IDT strength test without horizontal deformation measurements due to the following considerations: (a) strain gauges could be damaged during instrumented IDT tests; and (b) the purpose of determining IDT strength in this study is to compare relative tensile strength of various mixtures at low temperatures rather than to perform thermal cracking distress analysis. Three samples were used for each test.

For the field mix testing, loose regraded RAP and seven year old field cores, consisting of 100% recycled mix (with rejuvenator), and 15% recycled mix (conventional mix with PG 64-22) were obtained. The loose RAP was compacted as it is at 150^{o}C to obtain samples with 6 - 8% air voids. These samples, along with the cores, were tested for bulk specific gravity, resilient modulus at three temperatures, 5, 25 and 40^{o}C, and creep compliance at -10^{o}C. Resilient modulus was selected over dynamic modulus because of the height of the field cores.

3 RESULTS

The voids for the RAP only samples were 7.0, 5.2 and 7.7, and those of RAP+Reclamiite were 6.6, 6.3 and 6.9. The addition of Reclamite helped in the compaction of the mixes – the voids were reached between 30 and 60 gyrations for RAP+Reclamite samples whereas about 80 gyrations were needed for the RAP only samples. Note that the compactions for the mixes with Reclamite were done at 60-70^{o}C, whereas those for the RAP only were done at 150^{o}C. Table 1 shows the dynamic modulus. For brevity, data for two weeks (initial and final) are shown only. The moduli values increased with the passage of conditioning time; however, the values are clearly below those of the RAP only mix, indicating the effectiveness of the rejuvenating agent. This is evident from the comparisons of data at -10C and 38C (two extremes) as shown in Figure 1.

How do the results compare with those from conventional/commonly used HMA? The answer to this question is a key to understanding the difference between the mixes that are rejuvenated versus the mixes that are recycled using virgin asphalt binder or produced from all virgin HMA. This is particularly true for investigating the extent to which a 100% recycled mix can be rejuvenated. In order to answer this, dynamic modulus values from two regularly used mixes, as reported by Daniel (Daniel, 2009) for NH DOT are used. One is a 0% RAP mix (with a lower limit of dynamic modulus, and the other one is a 40% RAP mix (with the higher limit of dynamic modulus). Two critical temperatures and frequencies are selected for the comparison, -10C and 20C, and 10 Hz and 0.1 Hz, to account for both high temperature rutting and low temperature cracking related properties. The 20C was selected as the high temperature since that was the highest temperature for which the NHDOT data is available at this time. The comparisons (in Figure 2) show that the moduli of the 100% RAP mixes are consistently well above those of the reported mixes (either virgin or with relatively low percentage of RAP). However, the 100% recycled mixes, with Reclamite, show modulus values that are comparable to the regularly used mixes. At the same time, the results show that the values keep on changing over time. Note that the horizontal line corresponding to NH-40% RAP in Figure 2 is just for the sake of clarity rather than for indicating a constant dynamic modulus over time.

Indirect tensile creep compliance and strength of the 5th week samples are shown in Figures 3a and 3b. The error bars in Figure 3b indicate one standard deviation of the IDT strength. Apparently, the addition of Reclamite significantly increased creep compliance of the RAP yet a slightly higher IDT strength was yielded. This implies that the rejuvenating agent (Reclamite) is effective in reducing the embrittlement of the aged RAP and thus improving its low-temperature performance.

Table 1: Dynamic modulus (in MPa) test results

100% RAP

Frequency, Hz	Temperature, °C			
	-10	4.4	21.1	37.8
10	28,932	24,366	9,444	3,835
5	32,446	50,197	8,979	3,286
1	23,049	24,253	8,233	2,155
0.1	23,414	17,438	4,438	1,109

100% RAP+Reclamite

Frequency, Hz	Temperature, °C			
Week 0	-10	4.4	21.1	37.8
10	18,030	8,708	2,606	459
5	18,913	7,816	2,140	362
1	16,884	6,926	1,501	287
0.1	12,700	3,458	756	148
Week 5				
10	14,727	10,661	4,853	1,403
5	15,635	10,062	4,195	1,117
1	14,695	9,026	2,810	965
0.1	10,757	5,416	1,509	425

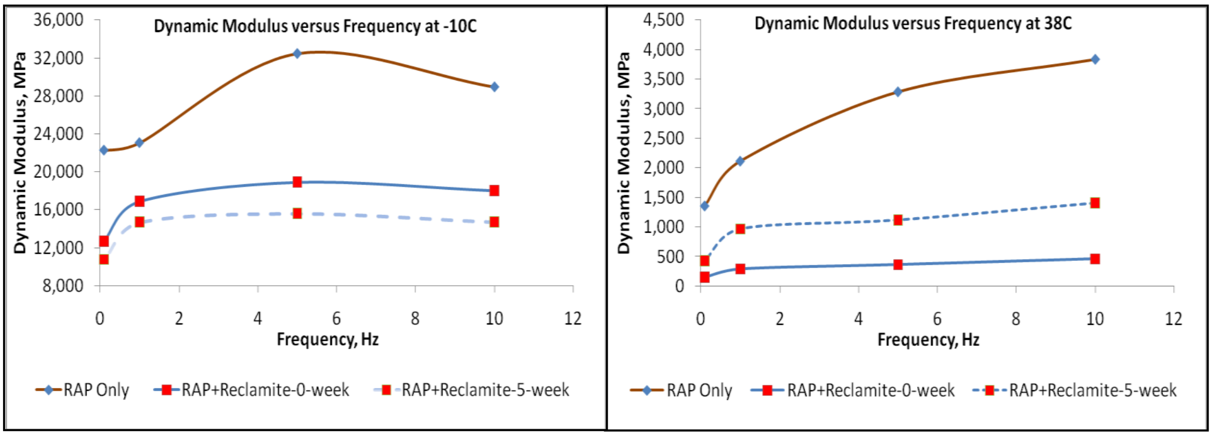


Figure 1: Comparison of dynamic modulus data for different mixes

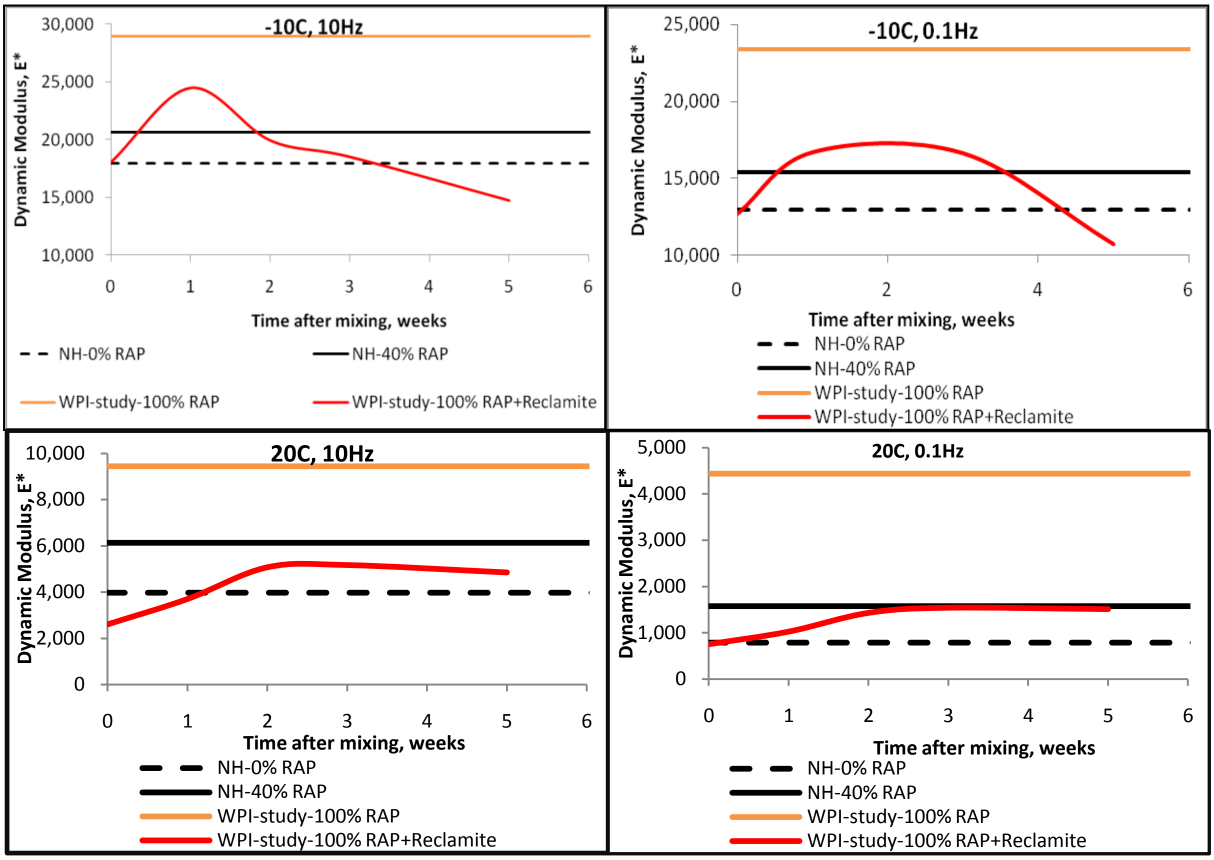
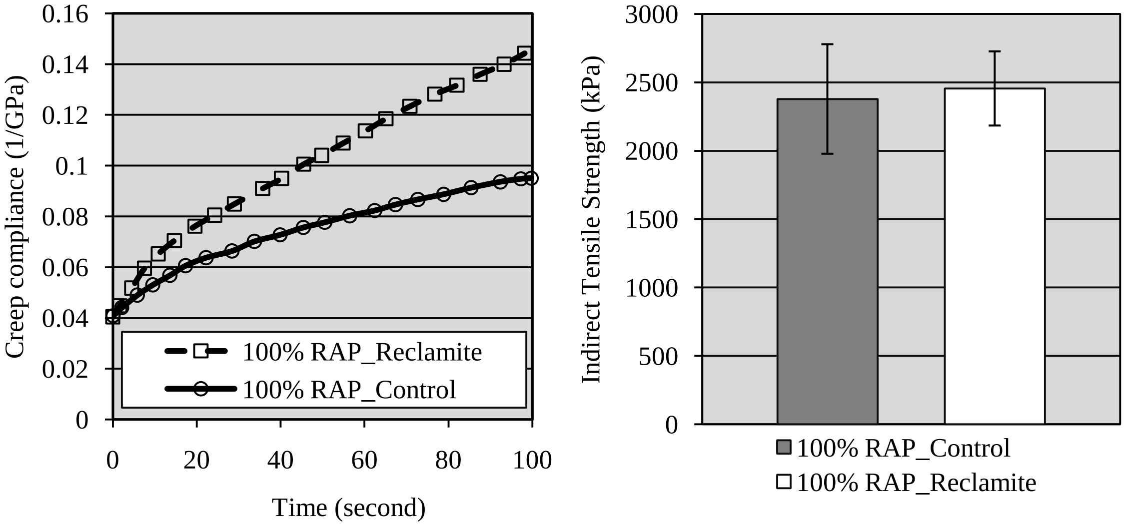


Figure 2: Plot of dynamic modulus (in MPa) versus time

4 PROPERTIES OF 100% RECYCLED FIELD MIXES

The basic premise behind 100% recycled mix is that the aged RAP provides stiffness to prevent rutting, whereas rejuvenating agents provide the desirable ductility and low temperature properties. There are several plant mix technologies suitable for producing 100% recycle mix.



a) Creep compliance of the mixtures; b) Indirect tensile strength

Figure 3: Results of indirect tensile creep and strength tests at -10°C

Most notable is Cyclean's venture and ten year experience with the city of Los Angeles. In 2000 New York City Department of Transportation (NYCDOT) solicited bid to demonstrate high recycle technologies for city paving programs. RAP Technologies was the successful bidder and provided a pilot plant to the city that began operation in October 2001. Production steps**:** RAP millings were provided by NYCDOT own milling crews; Stockpiled millings were screened to minus 12.5 mm with excess liberated fines removed. Oversize RAP was crushed and rescreened. Due to site limitations, stockpiled RAP was less than 500 tons at all times. Sized RAP was heated to conventional hot mix temperatures >300^{o} F then discharged to a drag slat conveyor for surge storage (Figure 4). The rejuvenator was sprayed onto the material at the discharge chute into the drag slat. Rejuvenator mixing took place going up the drag. 100% recycled mix was loaded into conventional tandem dumps and placed with conventional paving equipment.

Figure 4: NYCDOT 100% Recycle Pilot Plant

4.1 100% Recycled mix properties

It is common knowledge that most RAP stockpiles contain excess fines when compared to typical Superpave gradations regardless of source. This was especially true in NYC where sand mix overlays had been used for many years to extend pavement life. Several different bottom deck screen sizes were tested to find one that removed just enough excess and liberated fines. Ultimately a 3mm harp screen was selected since that size produced 50 blow

Marshall samples with 4% voids. Typical asphalt content of the recycled mix averaged 4.8 % after addition of approximately 0.5% of a commercial rejuvenator. The required amount of rejuvenator was determined by analysis of the extracted blended binder. Test results (AASHTO MP1) indicated at 0.5% rejuvenator the binder satisfied PG 70-28 criteria. These mixes were laid down using conventional equipment and continue to perform well after seven years of service (Figure 5).

Figure 5: Photos during construction and after 7 years of service

Two materials were tested. First, loose milled (regraded to meet requirements of a 12.5 NMAS mix) material was obtained and compacted at 150^{o}C to a target of 6 % voids. These samples were then tested for bulk specific gravity and resilient modulus. Additionally, seven year old field cores were obtained. Some of the cores contained 100% RAP and rejuvenator, and the rest contained 15% RAP. These cores were also tested for resilient modulus. The results of testing are shown in Figure 6. The results clearly show that the rejuvenator-recycled (100% RAP) mix has lower stiffness compared to both the RAP only and the mix with 15% RAP. This indicates that the rejuvenator is effective in improving the RAP materials. IDT creep compliance tests at -10^{o}C were also performed on the following samples with similar air voids: laboratory compacted samples with 100% RAP: L1 and L2; laboratory compacted sample with 15% RAP: 2A top; and field cores from 100% RAP with rejuvenator: 3bottom, 4, and 5A. Results from laboratory compacted plant mix containing 40% RAP are also shown.

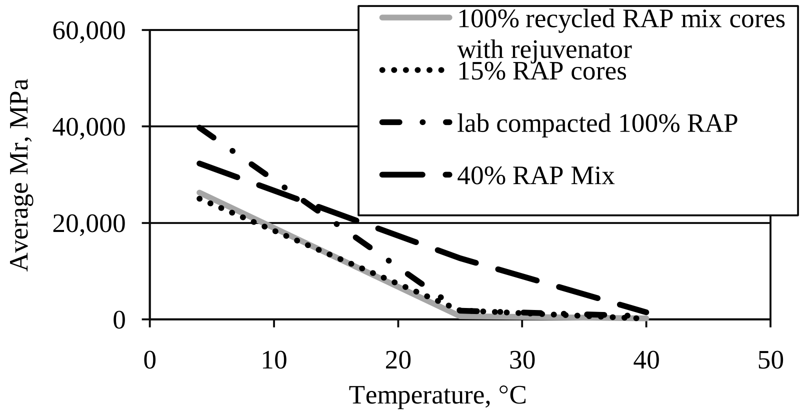


Figure 6: Average resilient modulus results of different mixes

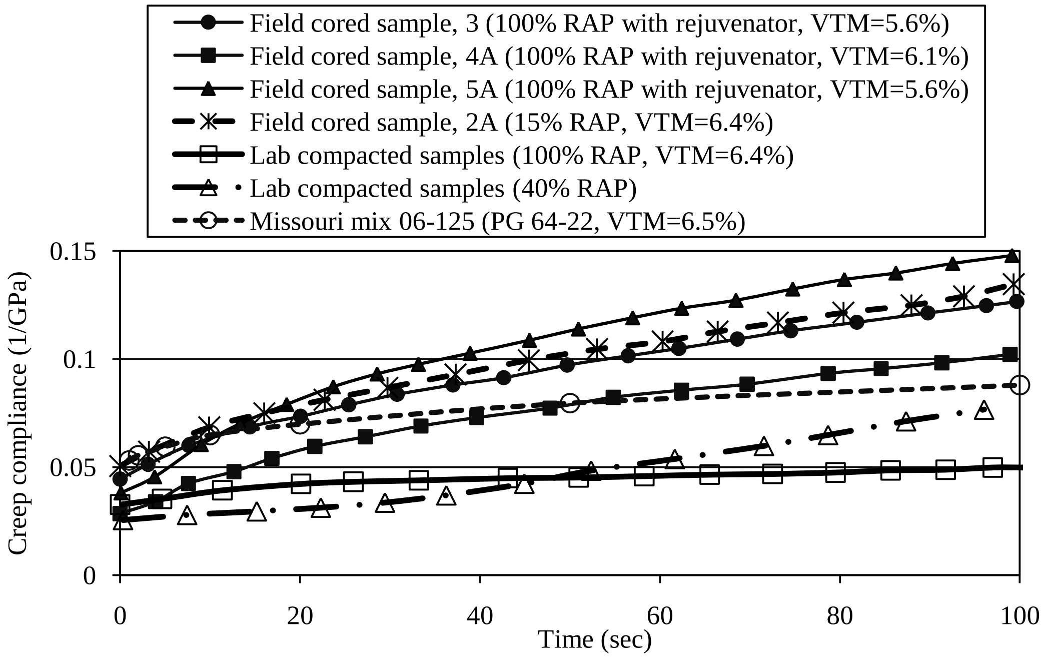


Figure 7: IDT creep compliance of different mixtures at -10°C (VTM: void in total mix)

The IDT creep compliance results for these samples are shown in Figure 7. Field cores with rejuvenated 100% RAP exhibited much higher creep compliance compared to laboratory compacted 100% RAP, and the field cores also had creep compliance comparable to that of field cores with 15% RAP and laboratory compacted plant mix with 40% RAP. Note that creep compliance values of a regularly used Missouri DOT mix are also shown for comparison (Richardson and Lusher, 2008). The results once again illustrate the effectiveness of the rejuvenator (Renoil in this case) in increasing creep compliance.

5 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made on the basis of the work reported in this paper.

1. The addition of rejuvenating agent is effective in lowering the stiffness of RAP, and providing mixes with dynamic modulus values that are similar to mixes that are regularly used in the US.
2. The addition of rejuvenating agent is also effective in increasing low-temperature creep compliance, and probably improving low-temperature performance of mixture with 100% RAP content, which has been a major concern for all RAP mixes used in northern latitudes.
3. 100% recycled mixes with good performance can be produced with existing quality control procedures in a suitable plant.
4. Studies should be conducted to develop a step by step procedure for assisting mix designers to utilize rejuvenators for high RAP content recycling.

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