Experimental investigation on double recycling of asphalt mixture for pavement applications

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Abstract: In this paper, the effect of using different amounts of double recycled Reclaimed Asphalt Pavement (RAP) on the low temperature properties of asphalt mixture is experimentally investigated. Bending Beam Rheometer (BBR) mixture creep stiffness tests and Semi-Circular Bending (SCB) fracture tests were used for this purpose. Creep stiffness, thermal stress, critical cracking temperature, fracture energy and fracture toughness are derived, and then numerical and graphically compared. The results indicate that mixtures with 20% or 40% double recycled RAP show similar low temperature creep and fracture behavior compared to mixtures containing the same amount of RAP. Therefore, re-recycled RAP can be used up to 40% for pavement construction also in regions experiencing cold climates.

Keywords: Asphalt Mixture, Reclaimed Asphalt Pavement, Double Recycling, Low Temperature Cracking.

1. Introduction

In view of economic and environmental considerations [1], recycled materials have been widely used for road pavement construction. In the past decades, different attempts have been devoted by the road authorities and research institutions in incorporating valuable recycled materials into paving mixtures; this includes Reclaimed Asphalt Pavement (RAP) [2, 3], Constructions and Demolition Waste (CDW) [4, 5], steel slags and waste tire [6-8], among others. Within this set of materials, the use of RAP has seen a significant increase over the years [9-11].

Commonly, this material, conventionally identified as RAP, consists of old pavement surface material (aggregate and asphalt binder) which is reduced in small particles during the milling process when the road surface layers reach the end of their service life. Approximately 70 million tons of RAP are reclaimed annually in the U.S., and more than 97% of them have been repaved for road construction, making RAP the most recycled pavement material in U.S. [12, 13]. In Europe, around 47 million tons of RAP are annually produced and used for asphalt pavements [13], with Germany having one of the highest recycling efficiency: 90% of RAP is recycled in hot mix asphalt production and 10% in unbound road layers, within the European Union.

Due to the significant increase in heavy vehicle traffic, a large number of road infrastructures are currently requiring a second stage of rehabilitation (re-rehabilitation), eventually leading to the need for pavement recycling. This is commonly experienced both in developed and developing countries [14-18]. This massive operation on the road networks is prompting the need to manage a large quantity of RAP . However, most of these pavements coming to the end of their service life were originally designed with a certain RAP content, posing the critical question and the scientific challenge of a second generation of recycling or “re-recycling” (double recycling) of RAP.

A considerable number of studies were conducted in Japan and U.K. to evaluate the possibility of re-recycling RAP [14-16, 18]. In 1995, Yoshikane [14] firstly proposed the idea of using re-recycling materials. Field investigation found that the pavement with RAP shown a comparatively good performance service level even after 15 years, suggesting that re-recycling of RAP could be a feasible option for the next generation of asphalt pavements. A study conducted by Su *et al*. [15] indicated that the re-recycled RAP mixed with fresh asphalt binder presented similar properties compared to hot Mix Asphalt (HMA) prepared with virgin material. Laboratory experimentation addressing rutting, abrasion, and mechanical response showed that the properties of re-recycled RAP mixtures are reasonably close to those of fresh HMA. More recently, Heneash [16] focused on the fatigue behavior of re-recycled RAP; results showed that a deterioration in stiffness or fatigue resistance occurs after the first recycling cycle. However, the re-recycling procedure does not induce a further reduction in the deterioration of these properties. A recent research [18] found that when a maximum of 40% of re-recycled RAP is used in pavement construction, comparable properties can be achieved with regard to water sensitivity, fatigue behavior, and plastic deformation compared with conventional virgin HMA.

Although a number of research efforts were devoted to studying the possibility of using re-recycled RAP, few studies centered their attention on low temperature properties. This is on the one side due to the still limited understanding of the interaction phenomena occurring between new asphalt binder and the aged oxidized binder contained in the recycled materials [19, 20] and on the other hand, it is associated with the high complexity of the problem [21]. Such a peculiar characteristic makes the use of RAP very critical, if not potentially deleterious, in an environment experiencing cold climates, where the increased material brittleness may potentially lead to poor pavement performance, cracking, and premature failure ultimately resulting in significant social and economic costs.

In this paper, the effect of adding different amounts of re-recycled RAP on low temperature creep and fracture properties of asphalt mixtures is experimentally investigated with the Bending Beam Rheometer (BBR) [22] and the Semi-Circular Bending (SCB) tests [21, 23] in the laboratory. Then properties such as creep stiffness, thermal stress, critical cracking temperature, fracture energy and fracture toughness were computed. Finally, the influence of re-recycled RAP is evaluated based on these rheological parameters.

2. Materials and Experimentation

2.1. Material Preparations

A set of seven asphalt mixture was prepared in the laboratory, a single plain asphalt binder presenting a performance grade PG58-28 [24] was used for the entire mixture types. First, a standard surface layer mix design, commonly used in cold regions, such as Germany and South Korea, for asphalt mixture was set as reference virgin material. Then, such a mixture was used to artificially produce (in the laboratory) RAP of first and second generation to be recycled in asphalt mixture having same gradation curve and nominal maximum aggregate size, NMAS=12.5mm. The virgin mixture was first aged according to the procedure proposed by [16] and the sample crushed into loose mixture to obtain first generation RAP which was further recycled to produce first generation recycled mixtures (at different RAP contents: 20 and 40%). These sets of materials were further aged according to the same procedure previously used and the specimens subjected to the same crushing procedure previously used to recreate the second-generation RAP which was included in the second-generation recycled mixtures (at different RAP contents: 20 and 40% obtained from the first-generation mixtures). Table 1 provides a summary of the asphalt mixtures prepared.

Table 1. Asphalt Mixtures.

Mix ID	Recycling Level	Asphalt Binder	RAP (%)	Air Voids (%)
A	Virgin	PG 58-28	0	7
B	1^{st} Generation	PG 58-28	20	7
C	1^{st} Generation	PG 58-28	40	7
D	2^{st} Generation	PG 58-28	20	7
E	2^{nd} Generation	PG 58-28	40	7
F	2^{nd} Generation	PG 58-28	20	7
G	2^{nd} Generation	PG 58-28	40	7

2.2. Low temperature asphalt mixture creep testing

Low temperature creep tests were performed on small asphalt mixture beams (l=102mm, b=12.5mm, and h=6.25mm), according to the experimental procedure proposed by Marasteanu *et al*. [22], with the Bending Beam Rheometer (BBR) equipment [25], illustrated in Figure 1 (a). A higher constant force equal to 4N and an extended testing time of 1000s were imposed to the mixture sample, differently from the conventional standard BBR procedure for asphalt binder.

The corresponding parameters creep stiffness, $S(t)$, and m-value can be calculated as follows:

$$S(t) = \frac{1}{D(t)} = \frac{\sigma}{\varepsilon(t)} = \frac{P \cdot l^3}{4 \cdot b \cdot h^3 \cdot \delta(t)}, \quad (1)$$

$$m(t) = \left| \frac{d \log S(t)}{d \log t} \right| \quad (2)$$

where,

$D(t)$ creep compliance,

σ bending stress,

$\varepsilon(t)$ bending strain,

$\delta(t)$ beam deflection.

Based on Equation 1 and 2, the values of thermal stress, $\sigma(T)$, was computed with the Laplace transformation [26]. No strength tests were performed in this research; therefore, the critical cracking temperature, T_{CR}, of asphalt mixture was computed based on Single Asymptote Procedure (SAP) as proposed in previous studies [27, 28], this procedure is shown in Figure 1 (b).

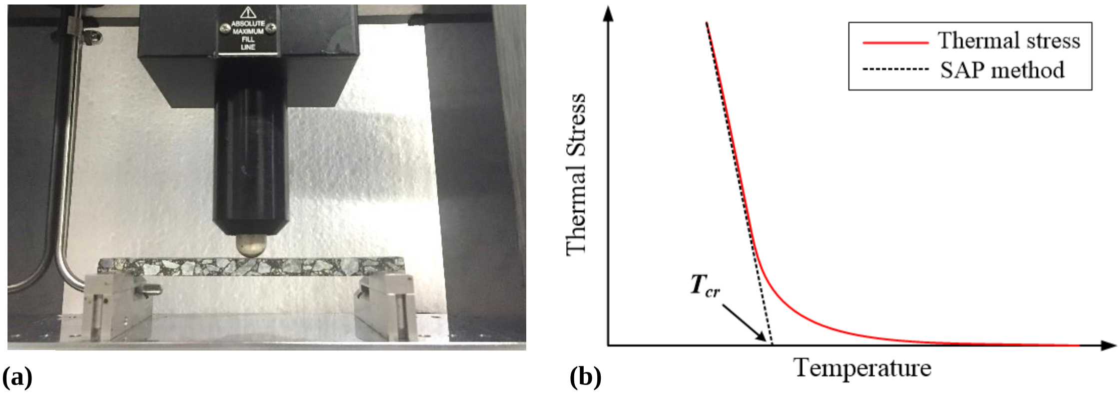

Figure 1. (a) BBR testing device setup; (b) Schematic of the Shenoy [27] SAP method for computing T_{cr}.

2.3. Low temperature asphalt mixture fracture testing

Fracture tests were performed to investigate the low temperature fracture energy of the material. For this purpose, Semi-Circular Bend (SCB) configuration [21, 23] was selected as testing method. This test was performed on a specimen with a diameter of 150mm, a thickness of 25mm and a straight notch 15mm long and 1.5mm wide (see Figure 2). A Load Line Displacement (LLD) and a Crack Mouth Opening Displacement (CMOD) were used together for displacement measurements.

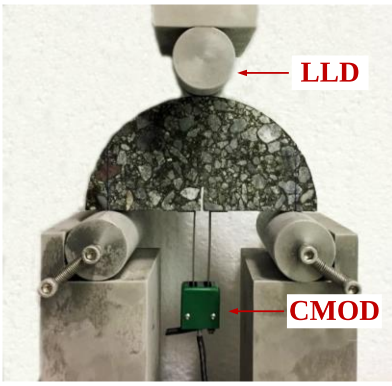

Figure 2. SCB testing device setup.

The CMOD signal was used to obtain a stable crack growth with a loading rate of 0.0005mm/s, then the peak load, P_N, was measured. Load versus LLD plots can be generated from SCB data and two main fracture parameters, fracture energy, G_F, and Mode I fracture toughness, K_I, were then calculated according to the following expressions:

$$K_I = [P_N / (2 \cdot r \cdot t)] \cdot \sqrt{\pi \cdot a} \cdot \left[Y_{I(S_0/r)} + (\Delta s_0 / r) \cdot B \right] \quad (3)$$

$$G_F = W_f / A_{lig} \quad (4)$$

where,

P_N	peak load in SCB test;
t and r	thickness and radius of SCB specimen,
a	notch length (15mm),
W_f	work of fracture,

A_{lig} area of ligament.

Y_I is the normalized stress intensity factor expressed as:

$$Y_{I(S_0/r)} = C_1 + C_2 \cdot (a/r) + C_3 \cdot \exp[C_4 \cdot (a/r)] = 4.796 \quad (5)$$

$$B = 6.55676 + 16.64035 \cdot (a/r)^{2.5} + 29.97042 \cdot (a/r)^{6.5} + 215.0839 \cdot (a/r)^{16} \quad (6)$$

where,

C_1, C_2, C_3 and C_4 constants,

Δs_0 a geometry parameter,

3. Results and Analysis

3.1. BBR tests results

Figure 3 summarizes the results of creep stiffness and thermal stress for the different mixture used in this research effort.

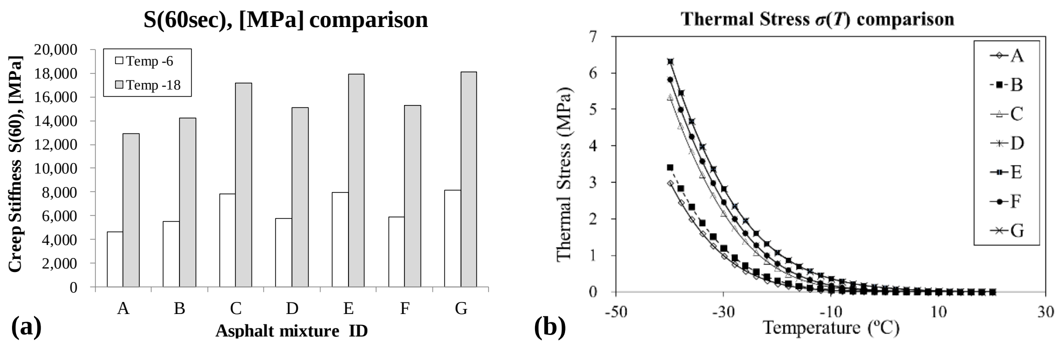

Figure 3. (a) BBR creep stiffness at t=60s; (b) $\sigma(T)$ comparison of different mixture.

The experimental results obtained from BBR creep tests suggests an increased stiffness and partially reduced relaxation properties associated with the increasing percentage of RAP and recycled generations (Figure 3a). According to Figure 3b, a similar trend of thermal stress is obtained; this is especially true for mixtures of first and second generation presenting higher percentages of recycled material.

The calculated critical cracking temperature, T_{CR}, are listed and compared in Table 2. In the case of mixtures prepared with 20% and 40% RAP, slightly higher T_{CR} were found compared to mixtures designed with virgin material, where the material prepared with a higher percentage of RAP corresponds to a higher T_{CR}. When the re-recycled RAP was applied, a very close response to that of mixtures prepared with RAP was observed. The relatively good low temperature performance of asphalt mixtures containing re-recycled RAP seems to support the point that the re-recycled RAP can be used for pavement construction [14-16, 18].

Table 2. Comparison of critical cracking temperature, T_{CR}.

Mix ID	A	B	C	D	E	F	G
Recycling Level	Virgin	1	1	2	2	2	2
RAP (%)	0	20	40	20	40	20	40
T_{CR} (ºC)	-23.06	-22.82	-22.18	-21.63	-21.32	-21.59	-21.28

3.2. SCB tests results

The effect of re-recycled RAP on the low temperature fracture properties of asphalt mixture was investigated with simple SCB fracture tests. Table 3 presents the results of peak load P_N, fracture energy, G_F, nominal strength σ_n, and fracture toughness, K_I, obtained from the SCB tests, while Figures 4 present the Load vs LLD curves for the all mixtures.

Table 3. SCB tests results.

Mix ID	Recycling Level	RAP (%)	RAP Mixture Origin	P_N (kN)	G_F (kN/m)	σ_n (kPa)	K_I (MPa*m$^{0.5}$)
A	Virgin	0	-	3.78	0.411	988	1.119
B	1st Generation	20	A	3.88	0.422	1,175	1.122
C	1st Generation	40	A	4.13	0.484	1,351	1.168
D	2st Generation	20	B	3.82	0.420	1,211	1.118
E	2nd Generation	40	B	3.81	0.401	994	1.115
F	2nd Generation	20	C	3.78	0.415	1,105	1.110
G	2nd Generation	40	C	3.75	0.392	977	1.108

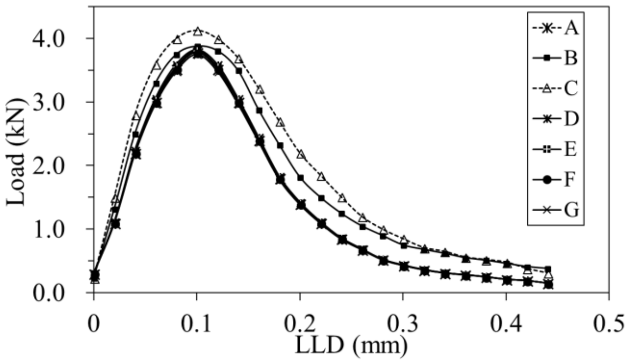

Figure 4. Load vs. LLD curves for all the different mixtures.

A substantial increase in the peak load and peak stress is found from the SCB tests in the case of recycled asphalt mixtures of first generation (B and C), while a decreasing trend is experienced for the mixture containing RAP of second generation. A similar pattern is observed for fracture energy and fracture toughness (Table 3). Moreover, the increase material brittleness, experienced for the different recycling levels, is highlighted by the shape of the softening part of the load-displacement curve that is more and more squeezed toward the y-axis (Figure 4).

This overall trend suggests that the presence of the first generation of RAP is surprisingly improving the fracture response of the mixture, not only in term of material strength, but also with respect to the overall fracture energy which is dissipated when the material fails. However, this is not the case when a second generation of RAP is used for producing double recycled mixtures. The overaged asphalt binder contained in the recycled material, together with the much higher quantity of fines typically present in the RAP introduces a higher brittlenss component in the mixture, ultimatley reducing the material performance in terms of frature.

4. Summary and Conclusion

In this paper, the effect of the use of re-recycled (or double recycled) RAP on the low temperature creep and fracture performances of asphalt mixture was experimentally investigated based on BBR mixture creep stiffness and SCB fracture test. Seven asphalt mixtures with two different amount of recycled materials, 20% and 40%, and difference recycled generation materials were prepared and tested. Based on experimental work and data analysis the following conclusions can be drawn:

- BBR results indicate that mixtures prepared with re-recycled RAP have similar low temperature response to that of mixtures designed with recycled RAP, when higher percentages of RAP are used. This translate in moderately higher stiffness and an increase in thermal stress.
- Similar fracture performances were found for mixture prepared with re-recycled RAP in comparison to the conventional fresh mixture, where a substantial increase in the peak load and peak stress is found in the case of recycled asphalt mixtures of first generation. This is most likely associated to the increased brittleness of materials.

The present experimental study provides evidence on the possibility of investigating the repeated recycling of RAP. Nevertheless, it should be remarked that only limited asphalt mixtures with re-recycled RAP were prepared and tested in the laboratory. Additional materials and experimentation, such pavement structure simulation, and analysis including, microstructural investigation and material modeling need to be performed to further evaluate the effect of re-recycled RAP for pavement mixtures. This is part of a current research effort which aims to provide simple, cost-effective, and environmentally friendly recycling solutions to the pavement industry.

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