Microstructural and rheological investigation of asphalt mixtures containing recycled asphalt materials

Augusto Cannone Falchetto, Antonio Montepara, Gabriele Tebaldi, Mihai O. Marasteanu

University of Minnesota, Department of Civil Engineering, 500 Pillsbury Drive, S.E., Minneapolis, MN 55455, USA
University of Parma, Department of Civil and Environmental Engineering, Viale G.P. Usberti, 181/A, 43100 Parma, Italy

We studied the use of recycled materials in asphalt mixtures at low temperature. We used Reclaimed Asphalt Pavement (RAP), and Recycled Asphalt Shingles (RAS). We used microstructural and analogical back-calculation modeling. Microstructure spatial distribution is not affected by RAP and RAS addition. The analogical model is a good tool to study blending of new and recycled binders.

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Abstract
Using increased proportions of Reclaimed Asphalt Pavement (RAP) in asphalt pavements construction has become a top priority due to significant economic and environmental benefits. A similar trend has also emerged in Recycled Asphalt Shingles (RAS), which represent the main roofing material in US. In this paper, the effect of adding RAP and RAS on low temperature properties of asphalt mixtures is investigated using microstructural analysis and modeling of rheological data obtained on eight asphalt mixtures. Detailed information on internal microstructure of asphalt mixtures is obtained from digital images of asphalt mixtures beams and numerical estimations of spatial correlation functions. It is found that that microstructure spatial distribution is not affected by RAP and RAS addition. Mechanical analog (Sharpe, 2008) and semi empirical models are used to back-calculate binder creep stiffness from mixture experimental data. Differences between back-calculated results and experimental data suggest blending between new and old binder may be only partial.

1. Introduction
Over the past 20–30 years, the search for recycling alternatives has led federal, state, and local agencies to consider a variety of potentially recyclable materials for pavement and other construction applications. The list includes Reclaimed Asphalt Pavement (RAP), reclaimed Portland cement concrete, iron blast-furnace slag, fly ash, waste tire rubber, waste glass, and roofing shingles. Incorporating RAP in new asphalt pavements significantly reduces the usage of new materials, conserves natural resources and solves disposal problems [1]. To address this important issue, the National Cooperative Highway Research Program (NCHRP) has funded a number of projects, such as NCHRP 9-12 [2] and NCHRP 9-46 [3]. Roofing shingles represent another material that is available in large quantity for recycling. According to one estimate, about 10 million tons of waste bituminous roofing materials are generated in United States each year [4]. The use of Recycled Asphalt Shingles (RAS) in hot mix asphalt has seen increased acceptance from government agencies and construction contractors only in recent years. The main obstacle is the potentially detrimental effect of recycled asphalt materials on asphalt pavement durability due to the aged binders present in old pavements and roofing shingles.

2. Previous research efforts
Several past studies were performed to investigate the effect of RAP on recycled asphalt mixtures [5–8] and concluded that RAP content had a significant influence on mixture properties. More recently, research efforts focused on design procedures, forensic evaluation and modeling [1,9]; specifications were also developed with recommendations for selecting RAP content based on traffic...
level. For example, Minnesota Department of Transportation (MnDOT) Specification 2350/2360 (2008) [10] allows up to 40% (by weight) RAP based on traffic level and binder grade.

Regarding the use of Recycled Asphalt Shingles (RAS), two distinct categories are available in the roofing market: Tear-off Scrap Shingles (TOSS), from old roofs that have been exposed to solar radiation and high temperatures for extended periods of time, and Manufacturer Waste Scrap Shingles (MWSS). Both TOSS and MWSS contain a much harder asphalt binder compared to that used in pavement applications: at 25 °C, the penetration values for asphalt binder in shingles ranges from 20 dmm to 70 dmm, while traditional paving binders range from 50 dmm to 300 dmm [11]. Reusing asphalt shingles in asphalt mixture poses significant challenges especially in cold climates, where good fracture resistance is critical for good pavement performance. This is particularly true for TOSS, which contain highly oxidized binders that are more prone to brittle failure. Unlike MWSS, only recently a provisional specification on the use of TOSS was released and limits the content to 5% (by weight) with the provision that at least 70% (by weight) of the required binder is new binder [12].

In one of the first comprehensive studies on the influence of RAS on HMA mixture properties, Newcomb et al. [11] found that up to 5% of MWSS could be used in asphalt mixtures with a minimum impact on the mixture properties. However, addition of TOSS resulted in an embrittlement or stiffening of the mixture that was not desirable for cracking resistance at low temperatures. The 5% limit for MWSS was also proposed by other authors [13,14]. McGraw et al. [15] investigated the combined use of RAP and RAS showing the negative effect of TOSS on mixture strength and binder’s critical cracking temperature. In a recent study [16] on the use of fractionated recycled asphalt pavement (FRAP) and RAS, it was found that the fibers contained in RAS may be beneficial to low temperature cracking resistance.

3. Research approach

In this research, the addition of RAP, MWSS and TOSS to asphalt mixtures used in pavement applications is investigated based on changes in mixtures microstructure and on changes in mixtures and binders low temperature properties, respectively. The changes in material microstructure are evaluated using Digital Image Processing (DIP) and estimating 2 and 3 point correlation functions of the aggregate phase. Huet [17] analogical model [18–20] coupled with ENTPE transformation [21–23] is used to investigate the effect of adding recycled material on both asphalt binder and asphalt mixture creep stiffness. Back-calculation of the asphalt binder creep stiffness is performed using mixture creep stiffness data obtained with the Bending Beam Rheometer (BBR) [24]. The goal is to determine if changes in mixture behavior are due to changes in microstructure from addition of recycled material, or to blending of new and old binder, or due to both.

4. Materials and testing

Eight different asphalt mixtures (Table 1) prepared with a PG58-28 binder were used in this study. The virgin aggregate materials used in the mixtures consisted of pit-run-sand, quarried 3/4 in. (19 mm) dolostone, and quarried dolostone manufactured sand. The recycled material consisted of different amounts of RAP, TOSS and MWSS. More details on these materials can be found elsewhere [15].

Thin beams of asphalt mixtures (three replicates per mixture) were tested using the Bending Beam Rheometer (Fig. 1) following a procedure described elsewhere [25]. BBR tests [24] were also performed on the asphalt binder extracted from mixtures 2, 3, 4, 5, 6, 7 and 8; extraction and asphalt binder tests were performed at MnDOT Office of Materials. BBR creep stiffness was also obtained on the original PG58-28 binder after RTFOT aging; this value was assumed as control in the analysis. To avoid any errors associated with time–temperature superposition, binder and mixture experimental data were obtained at the same test temperature of −6 °C, which represents the binder PG low temperature limit +22 °C.

5. Microstructural analysis

In most research efforts, asphalt mixture is considered either as a two-phase material [26,27], or a three phase material [28,29], and different micromechanical models are applied to describe and predict mixture behavior. Using low order microstructural information, such as volume fraction, leads to poor prediction of mixture properties [30]. More detailed information can be obtained from the estimation of spatial distribution of the micro-components of a material; this type of information is needed when modeling the effective properties of more complex microstructures. In the case of random heterogeneous materials, higher-order microstructural information is critical and statistical function such as n-point correlation function, lineal path function, chord-length density function, are used.

Two- and 3-point correlation functions were used in several works to describe random heterogeneous materials [31–35]. In a two-phase heterogeneous material, with the same volume fraction, the spatial distribution of its particles can dramatically affect the mechanical properties as well as the failure properties [36]. For this reason, spatial correlation functions can be used as a tool to identify fluctuations in the microstructure of a heterogeneous material.

The n-point spatial correlation function measures the probability of finding n points all lying on the space occupied by one of the phases of the specific heterogeneous material [32]. In the case of a two-phase heterogeneous material the 1-point correlation function \( S_1 \) is the probability that any point lies on phase 1; this correspond to the volumetric fraction of phase 1. The 2-point correlation function \( S_2 \) is the probability that two points separated

<table>
<thead>
<tr>
<th>Mix</th>
<th>Recycled material</th>
<th>VMA</th>
<th>VFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Description</td>
<td>RAP (wt.%)</td>
<td>TOSS (wt.%)</td>
</tr>
<tr>
<td>1</td>
<td>PG58-28 Control</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>15% RAP</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>25% RAP</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>30% RAP</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>15% RAP 5% MWSS</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
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<td>15% RAP 5% TOSS</td>
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<td>5</td>
</tr>
<tr>
<td>7</td>
<td>25% RAP 5% TOSS</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>25% RAP 5% MWSS</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 1. Bending Beam Rheometer with thin asphalt mixture beam [25].
by a specific distance are located both in the phase of interest. The
3-point correlation function \( S_3 \) is the probability that all the ver-
tices of a triangle are all located in the same phase. Fig. 2 provides
a geometric interpretation of the 1-, 2-, and 3-point correlation func-
tions of aggregate phase; single points, segments, and triangles re-
ter to \( S_1, S_2 \) and \( S_3 \) respectively.

\[ S_2^n(r_1, r_2, x_3) = \langle f_1^n(r_1) f_2^n(r_2) \rangle \]

The \( n \)-point correlation function is translationally invariant for a
statistically homogeneous material. It means that the function de-

dpends on the differences in the coordinate values of the \( x_i \) vectors
but, not on their absolute position [34,35].

The 1-point correlation represents the volume fraction \( \phi_i \) of the
ith phase. \( S_1 \) is constant and it is the probability that a randomly
selected point in the material belongs to ith phase:

\[ S_1 = \langle f_1^n(x) \rangle = \phi_i \]

The 2-point correlation function \( S_2^n(x_1, x_2) \) is defined as:

\[ S_2^n(x_1, x_2) = \langle f_1^n(x_1) f_2^n(x_2) \rangle \]

When microstructure of the material does not present long
range order, the initial value of the 2-point correlation function is
\( \phi(r = 0) \) and for very large \( r (r \rightarrow \infty) \) it reaches the asymptotic
limit of \( \phi^2 \).

The 3-point correlation function for a heterogeneous material
can be defined according to following equation:

\[ S_3^n(r_1, r_2, x_3) = \langle f_1^n(r_1) f_2^n(r_2) f_3^n(x_3) \rangle \]

In the case of a translationally invariant isotropic material, and
when there is no long-range order, the 3-point correlation function
can be expressed as:

\[ \lim_{|r_1|, |r_2| \rightarrow \infty} S_3^n (|r_1|, |r_2|, u_{12}) = \phi^3 \]

where \( r_1 = x_2 - x_3 \) is the vector; \( r_2 = x_3 - x_1 \) the vector; and \( u_{12} \) is the
cosine of the angle \( \theta_{12} \) between vectors \( r_1 \) and \( r_2 \).

The calculation of all the \( n \)-point correlation functions is re-
quired when a complete description of the microstructure of a ran-
dom heterogeneous material as asphalt mixture has to be assessed.
However, this computation may become particularly complex both
analytically and numerically [34,35]; for this reason alternative
solutions are required.

5.1. Image processing

Estimation of properties such as volumetric fraction of aggre-
gates, particle size distribution, and \( n \)-point correlation functions
can be obtained from digital images of the material through Digital
Image Processing (DIP). Color (RGB) images of the asphalt mixtures
BBR beams were acquired with a scanner at a resolution of 300 dpi
(dots per inch) allowing for detection of aggregates larger than
0.150 mm. MATLAB Image Processing Toolbox was used to obtain
mastic and aggregate phases through a conversion procedure of
RGB images of asphalt mixture to binary images (Fig. 4); white
(1) represents aggregates larger than 0.150 mm, and black (0) rep-
resents voids + asphalt binder + aggregates smaller than 0.150 mm.

The following procedure was used to obtain the binary images
(Figs. 3 and 4): (a) conversion of RGB images to (b) gray scale, (c)
equalization of the histogram of the image to enhance the contrast,
(d) noise filtering and (e) final conversion to binary image through
global thresholding.

5.2. 2 and 3-Point correlation functions

The 2-point correlation function can be computed using a dis-
cretized expression of Eq. (4) accounting for the width and the
height of the digital binary image of interest. However, for high
resolution images containing a large number of pixels, a “brute
force method” is time consuming and sometimes even prohibitive.
For this reason, 2- and 3-point correlation functions of the aggre-
gate phase are hereafter calculated by means of a simplification
of the algorithm proposed by Velasquez [34,35]. This procedure
is based on Monte Carlo simulations and on binary images of the
asphalt mixture BBR specimens. For purpose of comparison with
the initial values of 2 and 3-point correlation functions \( r = 0 \) and
\( r_1 = r_2 = 0 \), respectively), the volumetric fraction of the aggregate
phase was also estimated.
In the case of 2-point correlation, vectors of increasing length and random orientation angles are dropped in the digital image \( N \) times, and the number of times both end points of the vectors are in the phase of interest (Fig. 5) are recorded. The procedure is iterated for vectors of lengths varying from 0 to half the size of the image for a number of drops \( N > 10,000 \) [32,33]. Thus, it seems that, although the content and type of recycled materials are different, there is no significant effect on the microstructure distribution when adding RAP, TOSS, and MWSS.

The binary images of the different specimens were used to compute the 2-point correlation functions of the aggregate phase. The single values of the 2-point correlation function for each specimen is calculated as average of the two larger sides of each specimen.

Two-point correlation function starts at approximately \( \phi_{\text{aggregate}} \) and smoothly drops to \( \phi_{\text{aggregate}}^2 \), corresponding to the asymptotic limit of Eq. (4) as \( r \) approaches to infinite. All the curves are very close and almost overlapping, suggesting an almost identical autocorrelation length among the different mixtures [32,33]. Thus, it seems that, although the content and type of recycled materials are different, there is no significant effect on the microstructure distribution when adding RAP, TOSS, and MWSS.

For the 3-point correlation function, a set of lattice commensurate triangles [34] and the symmetries (shaded area of symmetry in Fig. 7) of the 3-point correlation function can be used to reduce computational time. The set of triangles used for the estimation of the spatial correlation function are defined by three integers, \( l, m, \) and \( n \) (Fig. 7a) which are related by the following conditions:

\[
m \leq 1/2 \quad \text{and} \quad m^2 + n^2 \leq 2ml
\]

Each triangle defined by the integers \( l, m, n \) is randomly dropped \( N = 100,000 \) times in the binary image [34,35]. The number of times \( N_{\text{hit}} \) the three vertices of the triangle are in the aggregate phase is counted (Fig. 7b).

The results of the 3-point correlation function are shown in Fig. 8 for a set of triangles defined by \( L = 2, M = 1, N = 1 \), and a size factor \( p = 0–32 \). As in the case of the 2-point correlation function, the coefficients of variation were small with a maximum of 5.5% for mixture 2.

The average 3-point correlation functions computed for asphalt mixtures materials have a similar pattern for all eight asphalt mixtures considered. No large fluctuations on \( S_3 \) are observed as the size factor \( p \) increases. \( S_3 \) begins at \( \phi_{\text{aggregate}} \) and smoothly drops to \( \phi_{\text{aggregate}}^2 \) as described by Eq. (6), showing no evidence of clustering or preferred paths in the aggregate spatial distribution [36]. The similar pattern shown by all the curves confirms the results of the 2-point correlation function that the recycled material added to the mixtures does not affect the microstructural spatial distribution of the aggregate phase.

6. Back-calculation of asphalt binder creep stiffness

Since no changes were found in the mixtures based on the microstructural investigation, the change in rheological properties due to the addition of aged binders is investigated next.

6.1. Analogical and semi-empirical models

In a previous study [37,38], analogical models were used to obtain creep stiffness of asphalt binders from creep stiffness of the
corresponding asphalt mixtures (inverse problem). It was found that Huet model [17] fitted very well the experimental data obtained from BBR tests at low temperatures for both asphalt binders and mixtures. This model is composed of two parabolic elements, \( D_1(t) = a(t/\tau)^p \) and \( D_2(t) = b(t/\tau)^q \), plus a spring with stiffness \( E_{\infty} \), combined in series (Fig. 9).

The analytical expression of the Huet model for creep compliance is:

\[
D(t) = \frac{1}{E_{\infty}} \left( 1 + \delta \frac{(t/\tau)^p}{\Gamma(k+1)} + \frac{(t/\tau)^q}{\Gamma(h+1)} \right)
\]

where \( D(t) \) is the creep compliance; \( E_{\infty} \) the glassy modulus; \( h, k \) the exponents such that \( 0 < k < h < 1 \); \( \delta \) the dimensionless constant; \( \tau \) the time; \( \Gamma \) the gamma function; \( \tau_0 \) the characteristic time varying with temperature accounting for the Time Temperature Superposition Principle (TTSP); \( \tau = \alpha(T) \tau_0(T) \), \( \alpha \) the shift factor at temperature \( T \); \( \tau_0 \) is the characteristic time determined at reference temperature \( T_0 \).

The authors [38] also found the following relationship between the characteristic time of mixture, \( \tau_{\text{mix}} \) and the characteristic time of the corresponding binder, \( \tau_{\text{binder}} \), at the reference temperature \( T \):

\[
\tau_{\text{mix}}(T) = 10^6 \tau_{\text{binder}}(T)
\]

where \( \tau_{\text{mix}} \) is the characteristic time of mixture at temperature \( T \); \( \tau_{\text{binder}} \) the characteristic time of binder at temperature \( T \); \( \alpha \) is the regression coefficient depending on mixture and aging.

This expression is identical to the equation proposed by Di Benedetto [22,23] and obtained from 2S2P1D model for complex modulus data [22,23].

From Eqs. (8) and (9), the following transformation that relates the creep stiffness of the asphalt binder \( S_{\text{binder}}(t) \), to the creep stiffness of the corresponding asphalt mixture \( S_{\text{mix}}(t) \) can be written:

\[
S_{\text{mix}}(t) = S_{\text{binder}}(10^{-6} \frac{E_{\infty_{\text{mix}}}}{E_{\infty_{\text{binder}}}})
\]

where \( S_{\text{mix}}(t) \) is the creep stiffness of mixture; \( S_{\text{binder}}(t) \) the creep stiffness of binder; \( E_{\infty_{\text{mix}}} \) the glassy modulus of mixture; \( E_{\infty_{\text{binder}}} \) the glassy modulus of binder.

Expression (10) is independent of the model used to derive it and it represents a special case of ENTPE transformation [21–23] for low temperatures.

A different back-calculation method based on the semi empirical Hirsch [39] formulation was used by several authors [1,35, 38,40]. In this model, the effective response of the material is obtained assembling the elements of the mixture (air voids, asphalt binder and aggregate) in parallel and in series. The general equation is:

\[
E_{\text{mix}} = P_c \left[ E_{\text{agg}} V_{\text{agg}} + E_{\text{binder}} V_{\text{binder}} \right] + (1 - P_c) \left[ \frac{V_{\text{agg}}}{E_{\text{agg}}} + \left( \frac{1 - V_{\text{agg}}}{E_{\text{binder}} V_{\text{binder}}} \right)^{-1} \right]
\]

where \( E_{\text{mix}} \) is the effective modulus of the mixture; \( E_{\text{agg}} \) the modulus and volume fraction of the aggregate; \( E_{\text{binder}} \) the modulus and volume fraction of binder, and \( P_c \) is the contact volume is an empirical factor defined as:

\[
P_c = 0.1 \ln \left( \frac{E_{\text{binder}}}{a} \right) + 0.609
\]

where \( E_{\text{binder}} \) is the relaxation modulus of the binder in GPa; and \( a \) is the constant equal to 1 GPa.

6.2. Back-calculation procedure

In this section, asphalt binder creep stiffness is estimated from creep stiffness experimental data of asphalt mixture. The results can provide useful information on the blending process between...
the new virgin binder and the aged binder contained in RAP and RAS and help understand whether total or partial blending occurs.

Expression (10) was manipulated using Huet model to obtain simplified mixture stiffness function for mixtures 1 and 2, Fig. 10.

In previous studies [21–23,38], it was found that Huet model parameters are the same for binder and for corresponding mixture. Therefore, the difference between asphalt binder and asphalt mixture is represented by \( a \);

\[ E_{mix} = a \cdot \ln(E_{binder}) + b \]

where \( a \) and \( b \) are regression parameters. Finally, the binder stiffness is simply calculated using Eq. (15) over the entire range of loading times.

### Table 2

<table>
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<tr>
<th>ID</th>
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<th>( \delta )</th>
<th>( k )</th>
<th>( h )</th>
<th>( E_m ) (MPa)</th>
<th>Log(( \tau ))</th>
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### Table 3

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<td>25% RAP 5% MWSS</td>
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Fig. 10. Simplified mixture stiffness function for mixtures 1 and 2, \( T = -6^\circ C \).
6.3. Comparison with experimental data

The asphalt binders creep stiffness values predicted from Huet-ENTPE formulation and Hirsch model, respectively, were compared to the experimentally determined creep stiffness values obtained on the RTFOT condition of original binder and the extracted asphalt binders (mixtures 2–8). The BBR data on the recovered binders was obtained at MnDOT Office of Materials for the standard time of 240 s. The original binder (short term aged) and the asphalt mixtures were tested at University of Minnesota for 240 s and 1000 s, respectively. For this reason, in the plots shown in Figs. 11–14, the creep stiffness curves of asphalt binders are shorter than those obtained through back-calculation from mixture data.

Hirsch model predictions are higher at shorter time and tend to become smaller at longer time compared to experimental data. The ENTPE transformation predicts very well the creep stiffness of the RTFOT original binder. The stiffness curves of asphalt binders obtained from the recycled mixtures (2–8) experimental data do not match the creep stiffness curves of extracted binder, however a common trend is observed: the back-calculated and the experimental data appear to reach the same asymptote. The extracted binder curves are flatter, suggesting less relaxation capabilities compared to the back-calculated ones. It can be reasonably hypothesized that two mechanisms may be responsible for this observation:

- The extracted binder still contains very fine particles, in spite of the extraction process. However, this would also contribute to a higher asymptotic value, which is not observed.
- Blending of the new and old binder occurred only partially. Therefore, the mixture creep behavior was affected by all new binder and only a part of the aged, oxidized binder. The extraction and recovery process resulted in a 100% blending and, therefore, the resulting binder had worse relaxation properties since all of the aged binder contributed to the properties of the blend.

The second mechanism was also discussed by other authors; Bonaquist [41] suggested that due to insufficient heat transfer during mixing there may be a partial or little melting of the aged RAP

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**Fig. 11.** Creep stiffness of back-calculated and extracted asphalt binder for mixture 1 and 2, $T = -6^\circ C$.

**Fig. 12.** Creep stiffness of back-calculated and extracted asphalt binder for mixture 3 and 4, $T = -6^\circ C$.

**Fig. 13.** Creep stiffness of back-calculated and extracted asphalt binder for mixture 5 and 6, $T = -6^\circ C$. 
and shingle binder when mixed with virgin material in the asphalt mixture production plant. This can explain the discrepancy between the actual binder stiffness in the mix and that obtained from extraction.

7. Summary and conclusions

In this paper, the effect on low temperature properties of asphalt mixtures due to the addition of various percentages of RAP, MWSS and TOSS was investigated. Microstructural analysis of the mixtures was first performed, followed by the analysis of changes in rheological properties of asphalt mixtures and corresponding asphalt binders. Asphalt mixture specimens (two-dimensional projections of BBR beams) were analyzed based on digital image processing, and microstructure properties were determined using correlation functions. Since no large variations were observed between 2- and 3-point correlation functions of the mixtures, it is hypothesized that the recycled materials added to the mixtures did not affect the spatial distribution of the aggregate phase. Huet model coupled with ENTPE transformation and semi-empirical Hirsch model were used to back-calculate the asphalt binder creep stiffness of the binder present in the mixtures. Back-calculation results were compared to experimental creep stiffness data obtained on the RTFOT aged original binder and on the binders extracted from the other seven recycled mixtures.

Hirsch predictions overestimate the creep stiffness of RTFOT original binders and of the seven extracted asphalt binders. ENTPE transformation predicts very well the creep stiffness of the RTFOT original binder. The stiffness curves of asphalt binders back-calculated from recycled mixtures data do not match the creep stiffness curves of extracted binder. It is hypothesized that the extracted binder still contains very fine particles; however, this would also contribute to a higher asymptotic value, which is not observed. Another explanation is that blending of the new and old binder occurred only partially. Therefore, the mixture creep behavior was affected by all new binder and only a part of the aged, oxidized binder. The extraction and recovery process resulted in a 100% blend of the binders extracted from the other seven recycled asphalt materials. Back-calculation results were compared to experimental creep stiffness data obtained on the RTFOT aged original binder and on the binders extracted from the other seven recycled mixtures.

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The findings of this study suggest that, at low temperature, the stiffness properties of asphalt mixture is little influenced by the spatial distribution of the aggregate skeleton. Asphalt binder blending appears to control the creep stiffness when recycled asphalt materials are added in the mixture.

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