Creep Deformation of Unreinforced and Geocell-reinforced Recycled Asphalt Pavements

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ABSTRACT

Recycled Asphalt Pavement (RAP) is a removed and reprocessed pavement material containing asphalt and aggregates. Literature indicates that RAP can be used as a base course material for pavement applications. Permanent deformation or rutting is one of the concerns in the use of RAP as a base course due to creep deformation. However, limited research exists to quantify the creep deformation characteristics of RAP. Since geocell can provide lateral confinement to granular materials, it is expected that geocell can reduce creep deformation of RAP. The objective of this study was to investigate the creep behavior of unreinforced and geocell-reinforced RAP bases under a sustained load in laboratory. Novel polymeric alloy geocell was used in this study. Three laboratory tests were conducted in a test box (60.5 cm x 60.5 cm x 15 cm high) and a compaction mold to investigate the role of lateral confinement in reduction of creep deformation of RAP. Creep tests were conducted at a room temperature of 25ºC. Each test lasted for 7 to 10 days. Creep strain versus time curves were plotted and the results were discussed. The test results showed that lateral confinement could minimize the creep deformation of RAP.

INTRODUCTION

Recycled Asphalt Pavement (RAP) is a removed and reprocessed pavement material containing asphalt binder and aggregates. According to HAPI Asphalt

Pavement Guide (2006), about 100 million tons of RAPs are produced per year from milling in asphalt rehabilitation projects. More than 73 million tons of RAPs are processed each year in the United States (Kelly 1998) with much of them re-used in pavement construction. RAP is obtained either by milling or by a full depth recovery method. Literature shows that RAP has a structural value as a pavement layer. However, limited research has been done to quantify its structural capacity with fundamental engineering properties. According to User Guidelines for Byproducts and Secondary Use Materials in Pavement Construction (2008), RAP can be used as a granular base material in paved and unpaved roadways, parking areas, bicycle paths, gravel road rehabilitation, shoulders, residential driveways, trench backfill, engineered fill, and culvert backfill. .

RAP has been used as granular bases by at least 13 state agencies in the United States in the past decade. Rutting has been observed in some projects a few years after construction (Mamlouk and Ayoub, 1983). However, the long-term performance of RAP has not been well defined. RAP is characterized as a time, temperature, and stress-dependent material. According to Bartenov and Zuyev (1969), static fatigue and dynamic fatigue are two interrelated thermally activated processes for a viscoelastic material like RAP. The material subjected to static fatigue is regarded as one subjected to creep. Cosentino et al. (2003) and Viyanant et al. (2007) both confirmed that RAP creeps under static loading using fully confined and triaxially confined samples, respectively. So far, however, no standard procedure is available to evaluate creep of a granular material such as RAP. The creep test is shown to be sensitive to mixture variables including asphalt grade, binder content, aggregate type, air void content, testing temperature, and testing stress (Little et al., 1993). It is the authors' belief that creep of RAP also depends on confinement, therefore, it can be minimized if confined. In this study, novel polymeric alloy (NPA) geocell, a geosynthetic product having a three-dimensional honeycomb structure, was proposed to provide lateral confinement to RAP within cells to minimize its creep. Creep tests of RAP, unconfined and confined, were conducted at a room temperature of 25°C in a medium-scale loading apparatus designed and fabricated at the Department of Civil, Environmental, and Architectural Engineering at the University of Kansas. For a comparison purpose, a creep test on RAP fully confined in a compaction mold was also conducted.

MATERIALS AND TEST METHODS

Materials

The RAP material was provided by R.D. Johnson Excavating, Co., Lawrence, Kansas, which was milled off from a city street in Lawrence, Kansas. The geocell, made of novel polymeric alloy, was manufactured and provided by PRS Mediterranean, Ltd. in Israel, having 1.1-mm wall thickness, 100-mm height, 19.1-MPa tensile strength, and 355-MPa elastic modulus at 2% strain. The novel polymeric alloy is characterized by flexibility at low temperatures similar to HDPE with elastic behavior similar to engineering thermoplastic. This geocell product, referred as the novel polymeric alloy (NPA) geocell, has a lower thermal expansion coefficient and creep reduction factor, and higher tensile stiffness and strength than HDPE geocells.

Binder Content

The RAP was sampled by quartering the sample in accordance with ASTM C702-98 Method B. Eleven samples were taken for ignition testing and three for centrifuge testing. The ignition and centrifuge tests were performed following ASTM D6307 and ASTM D2172, respectively. In the ignition test, the oven-dried RAP was burned in an ignition oven at 540**ºC,** and the asphalt binder content was determined from the difference between the masses of the RAP before and after burning. In the centrifuge test of extraction, a loose RAP was placed into a bowl and covered with trichloroethylene for disintegration of the sample and the aggregate and asphalt were then separated by applying a centrifuge force. The asphalt binder content was calculated by the difference from the masses of the extracted aggregate, moisture content, and mineral matter in the extract. The aggregates extracted from the RAP by the ignition method were also tested for their properties including gradation before and after compaction, specific gravity, and uncompacted void content of fine aggregate while the asphalt extracted by the centrifuge method was tested for viscosity.

Gradation

The aggregates extracted from the RAP were washed through a 0.075-mm sieve, and a sieve analysis was conducted on the materials to obtain the gradation of the aggregate in accordance with the ASTM D5444 – 08.

Specific Gravity

Specific gravity is used in calculating void content of aggregate and also used in volume-weight conversion. Bulk specific gravity, SSD bulk specific gravity, and apparent specific gravity of the fine and coarse aggregates extracted by the ignition method were determined in accordance with the ASTM C128-07a and ASTM C127-07, respectively.

Uncompacted Void Content of Fine Aggregate

Void content indicates the stability of the fine-aggregate portion of a base course aggregate. The void content of fine aggregate was determined in accordance with ASTM C1252-06 Method B.

Viscosity

Asphalt is a viscous material. Hot mix asphalt (HMA) pavements are susceptible to rutting and bleeding. Lower viscosity of asphalt indicates higher flowability and deformability and vice versa. The kinematic viscosity of asphalt binder at 135°**C** was determined in this study using a rotational viscometer in accordance with ASTM D4402-06. The 135°**C** temperature was chosen to simulate the mixing and lay-down temperatures typically encountered in HMA pavement construction.

Optimum Moisture Content (OMC) and California Bearing Ratio (CBR)

OMC and CBR are commonly used to evaluate the strength of subgrade, subbase, and base course materials. The OMC of the RAP was determined using the modified Proctor compaction test in accordance with ASTM D1557-09 and the CBR tests were performed in accordance with ASTM D1883-07 on the laboratory compacted RAP samples in a compaction mold.

Unconfined Compression and Plate Loading Tests

An unconfined compression test was conducted to determine the maximum load the RAP sample could sustain. The RAP sample was compacted using the modified Proctor compaction test and was extruded from the compaction mold. Height and diameter of the sample were 120 and 150 mm, respectively. Loads were applied through a rigid metal plate on the unconfined RAP sample in increments by adjusting air pressure in the air cylinder. The deformations of the sample corresponding to each load at every five-minute interval were recorded. The stress at which the sample failed was determined. Due to the low unconfined compression strength, no creep test was performed on any unreinforced unconfined RAP sample.

A plate loading test was conducted by a loading system on unreinforced RAP in the test box to determine the maximum load the unreinforced RAP base could sustain. The loading system had a 15-cm diameter air cylinder with a maximum air pressure of 900 kPa. The loading plate was 15 cm in diameter. **Figure 1** shows the details of the test box which was square and had a plan area of 3660 cm^2 with a 15-cm depth. For unreinforced RAP tests, no geocell was included. RAP was placed into the box and compacted to 95% of the maximum density on the drier side of the compaction curve in three layers (4 cm each). Loads were applied on a rigid metal plate in increments by adjusting air pressure in the air cylinder. Deformations in two perpendicular transverse directions were measured with three digital dial gauges mounted on the loading plate and averages of three were used for calculation. The deformations of the plate corresponding to each load at every five-minute interval were recorded. The pressure at which the RAP failed was determined.

Creep Test Setup

The creep tests were conducted at a room temperature of 25°**C** on the following samples using the same loading system discussed above: unreinforced confined RAP, and single NPA geocell-reinforced confined RAP, and fully confined RAP in a compaction mold. The test setup is shown in **Fig. 1**.

For the unreinforced confined RAP, RAP was placed into the box and compacted to 95% of the maximum density on the drier side of the compaction curve in three layers (4 cm each). For the geocell-reinforced confined RAP, the NPA geocell was placed at the center of the box in a nearly circular shape with a diameter of 20.5 cm and RAP was placed into the geocell and the box and compacted to 95% of the maximum density on the drier side of the compaction curve in two 5-cm and one 2-cm lifts. For the fully confined RAP, the sample was prepared following the modified Proctor compaction test. The load was maintained constant during each creep test for a certain time period.

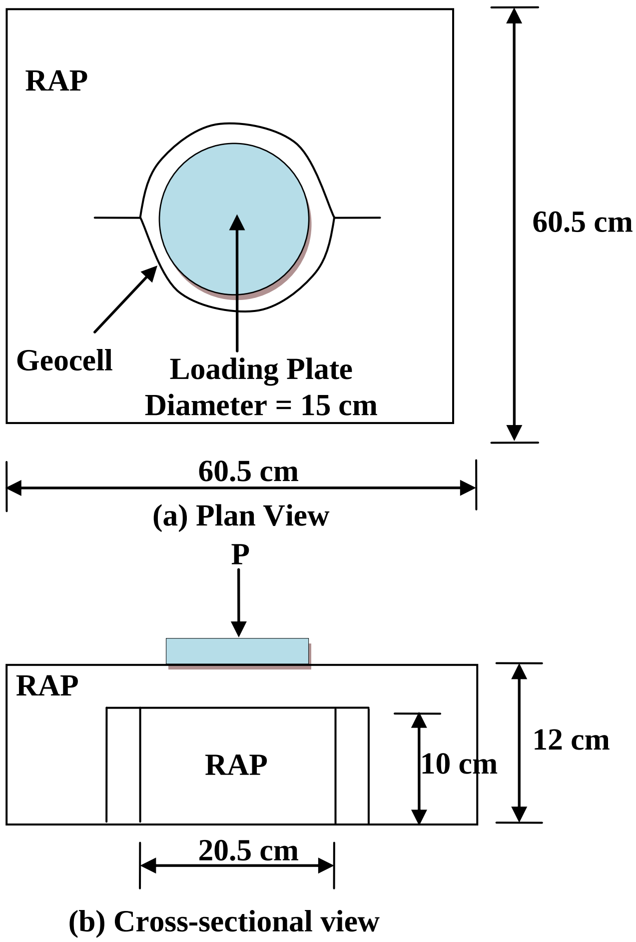

Figure 1. Setup for Unreinforced and Single NPA Geocell-reinforced Tests

TEST RESULTS AND DISCUSSIONS

Binder Content

Table 1 shows the binder contents obtained by the centrifuge and ignition methods of extraction. A correction factor of 0.25% was determined based on the mass difference of centrifuge-extracted aggregates before and after burning and then applied to the test data from the ignition method. Table 1 shows that the corrected binder content by the ignition method was slightly higher than that by the centrifuge method. This finding is in an agreement with that obtained by Thakur et al. (2011).

Table 1. Binder Contents (%) of RAP Samples Extracted by Centrifuge and Ignition Methods

Sample No.	Centrifuge method	Ignition method	Mineral correction factor (%)	Corrected binder content (%)
1	6.62	6.95	0.25	6.70
2	6.80	7.11		6.86
3	6.71	7.22		6.97
4		7.09		6.84
5		7.03		6.78
6		7.20		6.95
7		7.14		6.89
8		7.20		6.95
9		7.26		7.01
10		7.02		6.77
11		7.09		6.84
Average	6.71	7.12		6.87

Gradation

Figure 2 shows the gradation curves for the aggregates extracted by the ignition method before and after compaction. It is shown that compaction did not change the gradation of the aggregates.

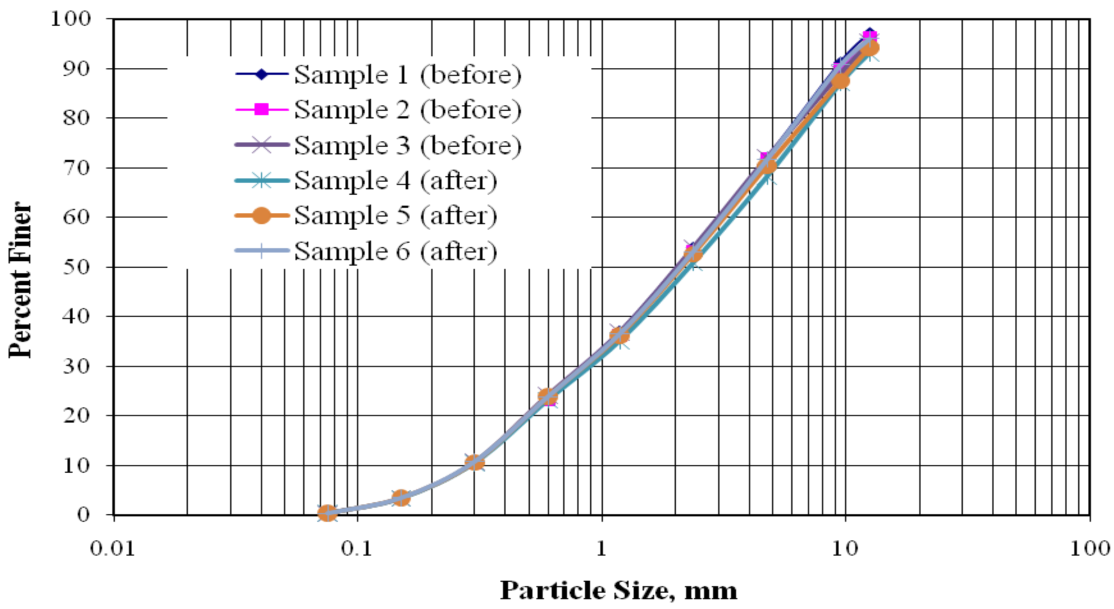

Figure 2. Gradation Curves of the Aggregates Extracted by the Ignition Method Before and After Compaction

Specific Gravity

Table 2 shows the specific gravity of the aggregates extracted by the ignition method. It is shown that the fine aggregate had higher specific gravity than the coarse aggregate.

Table 2. Specific Gravity of Aggregates Extracted by the Ignition Method

Description	Fine aggregate			Coarse aggregate		
	Sample 1	Sample 2	Average	Sample 1	Sample 2	Average
Bulk specific gravity	2.484	2.476	2.480	2.404	2.376	2.390
SSD Bulk specific gravity	2.557	2.553	2.555	2.491	2.483	2.487
Apparent specific gravity	2.592	2.596	2.594	2.584	2.586	2.585

Uncompacted Void Content of Fine Aggregate

Table 3 shows the uncompacted void content of fine aggregate extracted by the ignition method. The average void content was 39.15%.

Table 3. Uncompacted Void Content (%) of Fine Aggregate Extracted by the Ignition Method

Sample No.	Uncompacted void content
1	39.00
2	39.36
3	39.08
Average	39.15

Viscosity

Table 4 shows the kinematic viscosity of the asphalt binder at 135°**C** extracted from the centrifuge method. The average viscosity was 1.408 Pa-s.

Table 4. Kinematic Viscosity (Pa-s)

Sample No.	Viscosity
1	1.412
2	1.425
3	1.387
Average	1.408

Compaction Curve and California Bearing Ratio (CBR)

Figure 3 shows the dry density versus moisture content curve and the CBR versus moisture content curve for the RAP. It is shown that the maximum dry density was 1.96 g/cm^3, which corresponds to the optimum moisture content (OMC) of 6.6%.

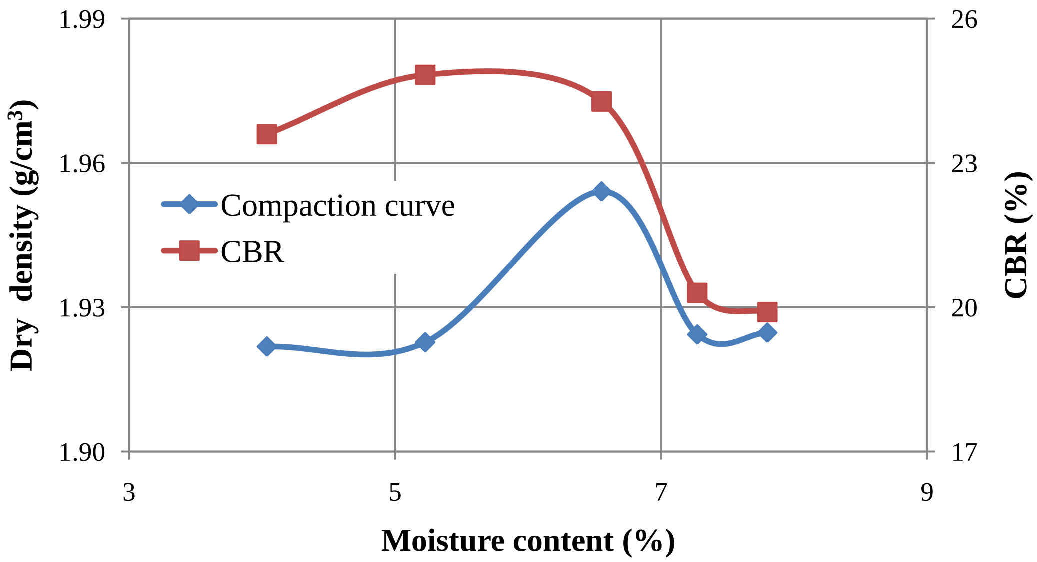

Figure 3. Compaction Curve and CBR

Pressure-displacement Response

The applied pressure versus displacement curves for the unconfined compression test and the plate loading test on the RAP were not shown due to page limit. It is found that the unreinforced unconfined and confined RAPs failed at 172 and 450 kPa, respectively. Therefore, the confinement of the RAP sample in the RAP significantly increased the strength of the sample. It is expected that the geocell confinement will further increase the strength of the sample as demonstrated by Pokharel et al. (2010).

Creep Behavior

The pressure was maintained at 276 kPa in the creep tests for the unreinforced confined RAP and single NPA geocell-reinforced RAP for ten days. This selected pressure was about 1/1.5 the maximum stress of the unreinforced confined RAP. For a comparison purpose, another creep test was conducted on a fully confined RAP sample in a compaction mold. The load for the fully confined RAP was maintained at 551 kPa for seven days. The displacement with time was monitored during each test. The measured displacements were used to calculated axial strains. The axial strain versus time curves for RAPs under three conditions are presented in Figure 4. It is shown that the unreinforced confined RAP had the largest initial deformation within the first few minutes. The NPA geocell significantly reduced the initial deformation as compared with the unreinforced RAP. The full confinement by the rigid compaction mold further reduced the initial deformation.

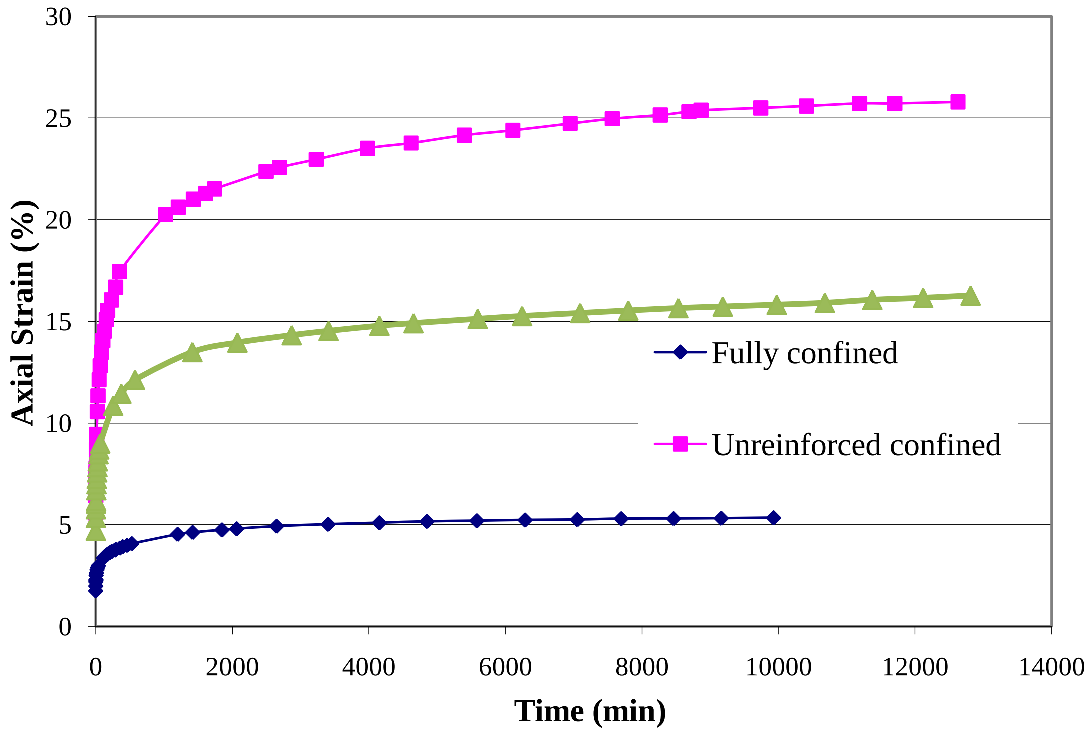

Figure 4. Creep Deformation Behavior of RAPs

The creep behavior of the RAP can be evaluated by calculating the slope of the curve as the rate of creep (Cosentino et al., 2003). In Cosentino et al. (2003)'s study, the slopes of the curves were calculated between 1,000 and 4,000 minutes because the curve became linear within this range. In this study, however, the curve became linear after 4,000 minutes; therefore, the slopes of the curves were calculated between 4,000 and 9,000 minutes. The slopes of the curves expressed in percent per minute, under three conditions are presented in Table 5. It is clearly shown that the unreinforced confined RAP had the largest creep rate, followed by the single NPA geocell-reinforced confined RAP and the fully confined RAP. The creep rate for the fully confined RAP is similar to those obtained by Cosentino et al. (2003).

Table 5. Slopes of Axial Strain versus Time (between 4,000 and 9,000 minutes)

Stress Level (kPa)	Test Sample	Slope of Curve (%/min)
571	Fully confined	4.30E-05
276	Unreinforced confined	3.23E-04
276	Single geocell-reinforced confined	1.77E-04

CONCLUSIONS

The following conclusions can be made from this study:

(1) The ignition method resulted in a slightly higher asphalt content in the RAP as compared with the centrifuge method.
(2) Compaction did not change the gradation of the RAP.
(3) The confinement of the RAP significantly increased its strength.
(4) The novel polymeric alloy geocell significantly reduced the initial deformation and the rate of creep of the RAP. Further reduction could be achieved if the RAP was fully confined.

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