SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I11P115

Volume 13 Issue 11, 270-289, November 2026
© 2026 Seventh Sense Research Group®

Original Article

Creep Behavior and Compressive Load-Bearing Response of Reconstituted Asphalt Materials from Selected Road Sections in Ekiti State, Nigeria

Akinwamide Oluwayinka Glory[1], Amu Olugbenga Oludolapo[2], Fapohunda Ajiboye Christopher[3]

[1]*Department of Civil Engineering, The Federal Polytechnic Ado-Ekiti, Nigeria*
[2,3]*Department of Civil Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria*

[1]*Corresponding Author: akinwamide_og@fedpolyado.edu.ng*

Received: 29 May 2026 Revised: 13 October 2026 Accepted: 14 November 2026 Published: 27 November 2026

Abstract *- Mechanical properties of recovered asphalt materials depend on the service history of the materials as well as laboratory reconstitution. In this study, the time-dependent deformations and compressive load-bearing properties of reconstituted asphalt materials obtained from six selected road sections in Ekiti State, Nigeria are investigated. Asphalt material is heated and reconstituted without addition of new materials. Then, specimens of these materials are compacted with Marshall technique for laboratory tests. Static creep test is conducted at 40°C for 60 min with sustained loading, and compressive loading is done to obtain peak load and nominal compressive stress. The creep properties of the material are studied based on creep strain, creep compliance, creep rate and strain rate, and the load bearing properties are studied through peak load and nominal compressive stress. The results demonstrate that there are different mechanical responses for each road section. AR-IJ has the smallest deformation and compliance values of the road sections, whereas AD-IW has the biggest deformation response; IL-IJ has the biggest creep rate value. OY-IK is seen to have the largest compressive load-bearing response, while AR-IJ has the smallest compressive load-bearing response. It can be seen that there is no direct relationship between small creep deformation and high compressive load bearing capacity of the material, so the two responses complement each other. This study contributes to the characterization of recovered asphalt materials by including the creep deformation and compressive load-bearing parameters to identify the differences between time-dependent deformation and load-bearing response.*

Keywords *- Asphalt material, Creep behaviour, Creep deformation, Load bearing response, Reconstituted Asphalt.*

1. Introduction

Flexible pavements are subjected to repeated traffic loading and environmental actions throughout their service life, resulting in progressive changes in the physical and mechanical characteristics of asphalt mixtures.

Temperature fluctuations, oxidation, moisture exposure, and traffic loading can change the properties of the asphalt binder- aggregate system and thus affect the deformation and load-bearing capacity of the pavement material. The observed response of recovered or reclaimed asphalt materials is affected by the characteristics of the starting material as well as by the prior usage history and condition of the aged binder and aggregate structure.

Research on reclaimed asphalt has indicated that the properties of the binder in the reclaimed material and its interaction with the other mixture ingredients can affect the engineering properties of the produced mixture [1, 2] as well as binder stiffness and rheological properties through the ageing process.

Both volumetric and material properties of asphalt mixtures have significant impacts on their mechanical response. The internal structure of the mixture may be influenced by the air-void content, density, aggregate gradation, and asphalt content and, therefore, may also influence the deformation response of the mixture under loading. In a study of asphalt mixtures prepared with reclaimed asphalt pavement, Daniel and Lachance [3] found variations in the creep compliance of the mixtures and related the behavior to the gradation and combinations of asphalt content and volumetric properties. This means that the physical properties of recovered asphalt should also be taken into account when interpreting the differences in the mechanical response of recovered materials in the laboratory.

Asphalt materials recovered from asphalt pavements may, for various reasons, exhibit different mechanical behavior compared with newly produced asphalt mixtures. The mechanical behavior of recovered asphalt materials may differ from that of new asphalt mixtures due to differences in

This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

binder condition, mixture composition, volumetric properties, and service exposure history. For this reason, previous studies have focused on the mechanical and viscoelastic characteristics of reclaimed asphalt mixtures through laboratory performance tests. [3, 4] Creep testing is one way of characterizing the time-dependent deformation response of an asphalt mixture under a sustained load. Bai et al. [5] studied the compression creep and recovery characteristics of asphalt mixtures, and Safi et al. [6] studied the compression creep compliance of asphalt mixtures with recycled materials. In addition, static creep testing has been explored as a laboratory performance-related testing method for evaluating asphalt mixtures [7], and the time-dependent behavior of asphalt-mixture creep under loading has been demonstrated by Luo et al. [8]. These studies provide a foundation for testing the creep response of recovered asphalt materials in a controlled laboratory environment.

Creep is one of such time-dependent response of asphalt mixtures under sustained loading. The viscoelastic and viscoplastic properties of an asphalt mixture may allow progressive strain, causing progressive deformation over time under constant stress. This time-dependent response is described by creep strain, creep compliance, and creep rate. Creep compliance is the ratio of strain to stress, and creep rate is the rate of deformation under load. Experimental tests conducted using uniaxial creep-compression testing have shown that the deformation behavior of asphalt mixtures changes over time and may vary depending on the loading level and the stage of the creep process. [8]

This has led to the inclusion of laboratory creep testing in the comprehensive testing of asphalt mixtures. The NCHRP Report 465, Simple Performance Test for Superpave Mix Design, suggested that laboratory tests based on static creep could be used to characterize important mechanical responses in asphalt concrete. The report also defines creep as the strain that occurs with time under stress and creep compliance as the strain that occurs with time under stress divided by the applied stress. Although the creep procedure used in the present study is different from the procedures described in NCHRP 465, but the same concept of quantifying the time-dependent response is used to interpret the creep response of the reconstituted materials.

Another dimension of mechanical characterization is the amount of sustained-load deformation a reconstructed asphalt material can undergo as it is loaded under compression. Peak load is the maximum load applied during a compression test, while nominal compressive stress is calculated as the maximum load divided by the nominal cross-sectional area of the test specimen. These parameters are used as comparative measures of the compressive load-bearing response for the present study. They are not intended to be used as standardized compressive-strength acceptance limits, as the current test configuration is not the same as standardized strength-testing methods. Laboratory performance tests have shown the benefits of using multiple mechanical response parameters to characterize asphalt-mixture behavior, instead of a single parameter. [9]

The response measured is dependent on the careful laboratory reconstitution of recovered asphalt. The binder system in recovered asphalt may be aged, and its availability and interaction with the aggregate may differ from batch to batch depending on the source of the asphalt and/or the thermal and conditioning histories used during laboratory preparation. The availability of reclaimed binder and blending behavior are influenced by several factors, such as mixing temperature, conditioning period, the source of reclaimed material, and material characteristics, according to Ma et al. [2]. Because of this, preparation and testing of recovered asphalt can affect the condition of the material when it is subsequently tested, and therefore the laboratory results should be interpreted as the behavior of the material that is prepared and tested, and not assumed to be an exact representation of the in-service pavement material. Hence, challenges associated with variable material characteristics, binder condition, and blending behavior exist with the use of reclaimed asphalt materials. [4]

Although there have been several studies on creep deformation, strength behavior, and performance of reclaimed asphalt materials, [10- 13] much attention has not been paid to the combination of assessments of creep behavior and separate compressive load-bearing response of reconstituted asphalt materials recovered from different road sections within the same geographical pavement environment. This paper attempts to fill this research gap by carrying out an evaluation of reconstituted asphalt materials from six selected road sections in Ekiti State, Nigeria and investigating statistical relationships between selected creep parameters and peak-load response of these materials using Pearson correlation analysis.

Creep deformation and compressive load-bearing response are different responses in the mechanical behavior of asphalt materials. Thus, an examination of the statistical relationship between these two responses can shed light on whether the materials that resist sustained load deformation will also withstand high compressive loads. However, there is no direct correlation between the two responses since creep is measured under sustained load for some time while peak load is measured using another load procedure for a shorter period of time. The present study aims to explore correlation between selected creep parameters and peak load response of the asphalt materials using Pearson correlation analysis.

In the present study, the objective is to investigate the creep behavior and the compressive load-bearing response of reconstituted asphalt materials recovered from six selected road sections in Ekiti State, Nigeria. The asphalt materials are

recovered, reheated, remixed with no additives before performing Marshall compaction. The static creep test is carried out at 40 °C for 60 min under a constant axial load of 10 kN, followed by the evaluation of creep behavior of the materials through the parameters of creep strain, creep strain percentage, creep compliance, creep rate, and creep strain rate. Comparative indicators of load bearing response are determined by conducting a separate compression test in order to determine peak load and nominal compressive stress.

Finally, variation in laboratory response of the materials is explained based on the physical properties and rehabilitation history of the materials. The main objectives of this study include characterizing physical properties and rehabilitation history of the recovered asphalt materials, assessing time-dependent creep behavior under the laboratory conditions mentioned above, assessing peak-load and nominal compressive-stress responses, and comparative interpretation of creep response and load bearing response of the reconstituted materials.

2. Literature Review

2.1. Mechanical Behavior and Time-Dependent Deformation of Asphalt Mixtures

Asphalt concrete consists of mainly mineral aggregates, bituminous binder and air voids. The way that asphalt mixture responds to loading is dependent on the interaction between these constituents as well as temperature, stress level, loading duration, compaction and mixture composition. Bituminous binder has both viscous and elastic properties, and hence the asphalt mixtures are likely to keep on deforming when exposed to sustained load. Therefore, mechanical performance of the mixtures can be best characterized by a combination of strength and deformation parameters.

In their review on permanent-deformation modeling in asphalt concrete, Alamnie et al. [14] revealed that deformation prediction must take into account material properties, temperature, stress conditions and loading history. This is highly important when considering recovered asphalt since materials from different road sections may have different compositions and service history despite their origins from the same geographical location.

There are various parameters that are used to assess the mechanical performance of asphalt mixtures, including creep strain, creep compliance, deformation rate, stiffness, and load-bearing capacity. These parameters provide different information about the material. Creep parameters indicate the development of deformation over time, while parameters obtained from a separate compression test provide information about the response of the material under that loading condition. A material that has low creep strain under sustained loading does not necessarily have high peak load during a separate compression test. Hence, it is important to consider both responses in assessing recovered asphalt materials.

2.2. Creep Behavior and its Characterization in Asphalt Materials

Creep refers to the progressive development of strain under sustained loading of a material. In the case of asphalt mixtures, this property is brought about by the combined effect of the bituminous binder and the aggregate structure. The rate and amount of deformation depend on temperature, applied stress, and the characteristics of the mixture, among others.

Creep can be studied using various laboratory procedures. Static creep test involves application of sustained load for some period of time, while repeated-load test exposes the specimen to cyclic loading. Creep-recovery test also involves unloading phases where the recoverable portion of deformation can be assessed. These tests assess different aspects of the material behavior despite the common loading histories involved.

Drescher et al. [15] investigated the permanent deformation in asphalt concrete using uniaxial compression creep-recovery test. Their study illustrates the need to distinguish between the deformation that develops during loading phase and the deformation that persists after unloading. The total strain measured during the loading phase can only be regarded as entirely permanent provided that an appropriate recovery phase is involved in the test.

The interpretation of creep test results is also influenced by the parameters that are used. Creep strain shows the deformation in relation to the initial specimen dimension, while creep compliance shows the ratio between strain and applied stress. Creep rate is an indicator of how strain changes over time. Creep strain percentage is simply the creep strain expressed in percentage form, while creep rate and creep strain rate may be used to refer to the same phenomenon when the time intervals are similar. The definitions and calculation procedures of the two should be stated clearly in order to avoid confusion and unnecessary duplication of parameters.

In this study, the creep strain, creep strain percentage, creep compliance, creep rate, and creep strain rate are used to characterize the responses of reconstituted asphalt materials tested at 40°C for 60 minutes under constant axial load of 10 kN. These parameters characterize the materials under the chosen laboratory conditions; they do not characterize the long-term performance of the materials under field repeated traffic loading.

2.3. Factors Influencing Asphalt Creep Behavior

Temperature, applied stress, loading duration, aggregate structure, binder characteristics, and compaction have influence on the creep behavior of asphalt mixtures. Temperature is very important factor influencing the creep behavior since the rheological behavior of the bituminous binder changes with temperature. At higher temperatures, the

binder has less resistance to deformation and hence may cause increased deformation of the mixture under similar loading conditions.

He and Wong [11] investigated the permanent deformation in foamed asphalt mixtures containing RAP using dynamic creep test. Their study took into consideration binder grade, RAP content and RAP ageing, in which the responses of the materials were characterized by creep strain slope, intercept and secant creep stiffness. They found that the binder grade had significant influence on creep strain slope, whereas RAP content and RAP ageing did not have statistically significant effects on that parameter within their experimental arrangement. An exponential relationship was also found between the creep strain slope and secant creep stiffness. These results show that the influence of material characteristics can vary depending on the creep parameter.

Applying stress and loading duration also affect the creep behavior. Increased stress leads to increased strain, while loading for longer periods of time gives enough time for the time-dependent deformation to develop. However, the relationship becomes non-linear if the material undergoes significant deformation. In the present study, the same test temperature, axial load, and loading duration are used for the six recovered asphalt materials in order to provide a basis for comparison of the material responses. However, the differences in laboratory responses should be interpreted within the limitations of these conditions and not as rankings of field pavement performance.

2.4. Reclaimed Asphalt Materials and their Engineering Significance

Reclaimed asphalt pavement is derived from the existing asphalt pavement during milling, resurfacing, rehabilitation or reconstruction. Reclaimed asphalt pavement normally consists of mineral aggregates with aged bituminous binder coating. Using this material can help conserve natural resources, minimize demand for new materials and limit the amount of pavement waste for disposal.

Copeland [16], in his Federal Highway Administration Report, has reviewed the usage of reclaimed asphalt in asphalt mixtures and discussed its economic, environmental and engineering implications. His report shows the significance of material characterization, processing, mix design and quality control in achieving satisfactory performance.

Despite these advantages, RAP should not be assumed as a homogeneous material since its characteristics depend on source pavement, original mixture composition, service history, recovery process and subsequent handling. These differences can be reflected in the laboratory responses of the materials. A distinction should also be made between the RAP material blended in newly designed asphalt mixture and the recovered asphalt material that is reheated, reconstituted and tested without any other materials. While the former type of studies usually examines the effects of different RAP contents on the performance of the mixture, the present study uses a different approach since it compares reconstituted recovered asphalt materials from six existing road sections. The objective is not to determine an optimal RAP content or assess blending of RAP with virgin binder.

2.5. Laboratory Reconstitution and Preparation of Recovered Asphalt

The preparation of asphalt specimens influences their internal structure and mechanical performance. Heating, mixing and compaction should therefore be carried out consistently in order to make comparisons between materials from different sources.

Lo Presti et al. [23] have investigated laboratory mix design and specimen preparation of asphalt mixtures containing reclaimed material. Their study illustrates the need to apply proper compaction and specimen uniformity. Although their study involved mixtures incorporating reclaimed material and not just reconstituted recovered asphalt, the study shows the need to take into account specimen preparation in interpreting laboratory results.

Cosentino et al. [10] have compared the modified Proctor, vibratory and gyratory compaction procedures in RAP specimens obtained from four sources. They found that gyratory compaction resulted in the highest density and strength, while the effect of compaction method on creep was less pronounced. This implies that specimen preparation affects deformation and strength indicators to different extents.

In the present study, the recovered asphalt materials are reheated, remixed without any additive and compacted using the Marshall method. Application of the same procedure for the six materials helps in reducing differences that can arise due to laboratory preparation. However, the results only characterize the behavior of the reconstituted specimens under the mentioned conditions.

2.6. Previous Studies on Creep and Mechanical Behavior of Reclaimed Asphalt

Several studies have involved evaluation of reclaimed asphalt in terms of material configuration, preparation procedure and loading method. He and Wong [11] have investigated dynamic creep in foamed asphalt mixtures incorporating RAP and found that the influence of binder grade, RAP content and RAP ageing varied for the creep parameters.

Cosentino et al. [10] have investigated the influence of compaction on RAP specimens and found that its influence on density and strength was greater than on creep. Moon et al. [12] have investigated reclaimed asphalt pavement mixtures

under static and oscillatory loading. Their study makes a contribution in understanding the material response under different loading conditions. It also offers a good point of comparison, although the material configuration and testing procedures used in their study are different from those in the present study.

Yin et al. [13] have investigated the creep behavior of compacted RAP using triaxial compression test under sustained deviatoric stress. They found that compaction and compression under high temperatures influenced the strength and creep strain of the materials. In another study, Yin et al. [17] have investigated the effect of temperature on the creep behavior of compacted RAP using temperature-controlled triaxial testing. Both studies highlight the importance of temperature and loading conditions in the interpretation of RAP behavior. However, both studies involved RAP for geotechnical applications like fill materials, rather than Marshall-compacted asphalt specimens tested using separate compression test. Also, studies have been conducted in Nigeria on reclaimed asphalt. Oluwasola et al. [18] have investigated hot-mix asphalt mixtures containing reclaimed and laboratory-aged reclaimed asphalt, evaluating resilient modulus and tensile strength at different RAP contents. Their study indicates that the mechanical performance of reclaimed asphalt has been assessed within the Nigerian context. However, their objective was to blend reclaimed material in newly designed mixture rather than compare the creep and peak-load responses of reconstituted asphalt recovered from several road sections.

Usanga et al. [19] have investigated the deformation characteristics of asphalt mixtures containing RAP binders under varying stress, temperature and moisture conditions. Their laboratory procedures included dynamic shear rheometric, bending beam rheometric, Hamburg wheel tracking, and uniaxial repeated-load testing. They found that the influence of RAP content on deformation resistance varied depending on the test conditions and that higher RAP contents do not give the same advantages under all stress and environmental conditions.

Overall, these studies illustrate that the mechanical behavior of reclaimed asphalt varies with the source, preparation procedure, temperature, and loading conditions. They offer a good background for understanding RAP deformation and strength. However, their different objectives and experimental arrangements make a room for further comparative assessment of reconstituted recovered asphalt using creep testing and separate compression tests.

2.7. Compressive Load-Bearing Response of Asphalt Materials

Load-bearing response describes how the material responds to compressive loading. Depending on the loading procedure used, the response can be evaluated in terms of peak load, nominal compressive stress, deformation or the relationship between load and deformation. Peak load is the maximum load recorded during compression test. It describes the maximum load reached under the mentioned conditions but should not be automatically referred to as compressive strength unless the test method allows that.

Nominal compressive stress considers the original cross-sectional area of the specimen. This may be used for comparison when the dimensions of the specimens differ, but it is important to consider specimen geometry and loading configuration in interpreting differences between materials.

Cosentino et al. [10] have shown that the compaction method influenced the strength responses of RAP specimens and that its influence was not the same for strength and creep. This indicates that load-bearing and deformation responses should be assessed separately since it is impossible to predict one from the other.

In the present study, peak load and nominal compressive stress are determined using separate compression test. These responses complement the creep measurements by showing the responses of the materials under a different loading procedure. The results are used for comparison under the mentioned laboratory conditions and are not considered as substitute for creep measurement or full representation of field pavement performance.

2.8. Relationship between Creep Behavior and Peak-Load Response

Creep behavior and peak-load response are two different responses in the mechanical performance of asphalt materials. Creep test is carried out by following the deformation development under sustained loading, while peak-load test involves determination of the maximum force attained during a separate compression procedure. Assessment of both responses can help understand the differences between recovered materials.

Drescher et al. [15] have illustrated the importance of loading history and deformation recovery in the interpretation of asphalt creep behavior, while Cosentino et al. [10] have demonstrated that the influence of compaction was not the same for strength and creep responses. These results indicate that both responses can be assessed using the parameters corresponding to the respective test procedures. Low creep strain does not necessarily indicate high peak load. Similarly, a material that reaches relatively high peak load may still accumulate high deformation under sustained loading. The Pearson correlation coefficient can be used for assessing the direction and strength of the linear relationship between these responses. However, the presence of correlation does not indicate the presence of causation, and the absence of weak linear relationship does not mean the absence of any non-linear relationship.

Therefore, the Pearson correlation analysis is carried out in the present study in order to analyze the relations between selected creep parameters and peak-load response. The analysis has to take into account the overlapping between the variables because there is a difference between the values of creep strain and creep strain percentage only in scale, and the values of creep rate and creep strain rate can be mathematically equal depending on the measurement interval.

2.9. Physical Properties and Rehabilitation History of the Source Road Sections

The physical properties and rehabilitation history of the source road sections can be considered as a background for understanding the differences in the behavior of the recovered asphalt materials. Original composition of the mixture, properties of the aggregates, construction, traffic loadings, environmental impacts, and maintenance history of the road can be the reasons for the differences in the behavior of the materials.

Copeland [16] stressed the necessity to describe and process the reclaimed asphalt, while Cosentino et al. [10] showed the influence of specimen preparation on the strength and creep response. Thus, both provenance and preparation of the samples should be considered during the comparison of the recovered asphalt materials.

While the rehabilitation history can give additional information on the conditions in which the material was recovered, it cannot independently serve as evidence of the causes of the laboratory response of the material. Therefore, the physical properties and rehabilitation history of the six road sections are used in the present study as contextual information instead of proof of the causes of laboratory response of the material.

2.10. Research Gap and Contribution of the Study

The studies mentioned above have considered the issues of asphalt creep, permanent deformation, utilization of the reclaimed asphalt, the preparation and characterization of the specimen. He and Wong [11] studied the dynamic creep of foamed asphalt mixtures with RAP; Cosentino et al. [10] have paid attention to the impact of compaction on RAP strength and creep; Yin et al. [13, 17] have researched the creep under sustained triaxial loading and at different temperatures; and Oluwasola et al. [18] have studied the Nigerian asphalt mixtures with the reclaimed material.

Finally, Usanga et al. [19] have researched RAP-binder mixtures under different laboratory conditions. Although the studies mentioned above are relevant, they differ from the present one by the configuration of material, preparation procedure, and research objectives.

The research gap addressed in the present study is the necessity of the comparative assessment of the time-dependent creep behavior and separate compressive load-bearing response in the reconstituted asphalt materials recovered from different road sections in the same regional pavement environment. In addition, the study will consider the statistical relations between the selected creep parameters and peak-load response.

To fill these gaps, the asphalt materials recovered from the six selected road sections in Ekiti State, Nigeria, will be reheated, reconstituted without any additives, and compacted with the use of the Marshall method. The static creep testing will be performed at 40°C for 60 minutes under the constant axial load of 10 kN, while the separate compression test will be applied in order to define the peak load and nominal compressive stress. The analysis of the relation between selected creep parameters and peak-load response will be done with the use of the Pearson correlation analysis.

The contribution of the study consists in the simultaneous comparison of the creep behavior and compressive load-bearing response in the common laboratory program. It also considers the statistical relation between the responses and takes into account the physical properties and rehabilitation history of the source road sections.

3. Materials and Methods

3.1. Research Design

The creep behavior and load-related deformation characteristics of asphalt materials from the selected pavement sections were evaluated through an experimental laboratory design approach. The deformation response studied was divided into two components: the accumulated deformation due to the application of a sustained axial load and the peak-load response of the reconstructed specimens. Existing and in-service pavements were stripped of asphalt materials in Ekiti State, Nigeria. Six sections of road were selected, and materials were collected from these sections and then reconstituted in the laboratory with no external addition to the collected materials. The recovered material was not mixed with any additional aggregates, asphalt binder, admixtures, or other modification materials. Marshall specimens were then prepared in the laboratory from the collected asphalt materials and tested.

Static creep testing was performed by applying a sustained axial load of 10 kN to the specimen at 40 °C for 60 min. The temperature for the test was determined according to previous research and laboratory practice. Zhang et al. [20] and Gong et al. [21] conducted uniaxial static creep tests on asphalt mixtures at 30, 40, and 50 °C.

The deformation response of the tested specimen was recorded, and the creep rate and creep deformation were determined. In addition, the creep strain and creep compliance were calculated using the deformation of the specimen and the nominal applied load, respectively. A peak-load testing

experiment was performed independently of the creep testing to determine the comparative load-bearing response among all specimens. The results were then expressed as a nominal compressive stress by dividing the applied peak load by the cross-sectional area of the specimen. The results of the tests were discussed in terms of identifying and comparing material responses.

3.2. Study Area and Pavement History of the Selected Pavement Sections

Six main road sections were selected for investigation, namely: AdoIworoko (AD-IW), IfakiIdo (IF-ID), OyeIkole (OY-IK), IkereIse (IK-IS), AramokoIjero (AR-IJ), and IluomabaIjan (IL-IJ), all in Ekiti State, southwestern Nigeria, which lie between latitudes 7°15′N to 8°05′N and longitudes 4°45′E to 5°45′E. These routes link the major urban centers with surrounding communities for passenger transportation, commercial activities, and the transportation of agricultural products into and out of the state.

The pavement sections selected were chosen to allow for the collection of a variety of asphalt materials to be recovered from these pavement sections for comparison. The study focused on determining whether differences existed in the creep response and load-bearing capacity of the reconstituted asphalt materials taken from different pavement sections under compressive loading.

There was no complete historical information available for the selected pavement sections. Specifically, the original construction dates, pavement layer configuration, original asphalt mixture designs, aggregate gradation, asphalt binder content and grade, original volumetric properties, field density, and in-situ air-void properties could not be consistently obtained.

Documentary information was only available in relation to the most recent rehabilitation, overlay, resurfacing, reconstruction, or other maintenance works from project accountability reports and budget documents, available documentation from the Ministry of Works, and government project records.

The records were not used to present the complete construction and maintenance history of the road sections investigated, but were compiled to provide contextual information on the previous intervention history.

The available rehabilitation records showed that the last rehabilitation work carried out on the selected sections was between 2012 and 2021, while the asphalt materials used in this study were sampled in December 2024. The interventions were in the form of rehabilitation, overlay, reconstruction, and dualization. These records were employed to describe the context of the service and rehabilitation history of the recovered materials, and not to directly link rehabilitation history to the measured laboratory responses.

Since the service histories and all details of the original pavement construction could not be obtained for all sections, the investigation was planned as a largely comparative laboratory study. The following analyses were thus carried out on the laboratory-reconstituted asphalt materials under controlled conditions using the previously determined physical, creep, and compressive load-bearing properties.

3.3. Collection and Reconstitution of Asphalt Materials

Samples of asphalt were collected from the selected pavement areas and brought to the laboratory for preparation and testing. All recovered materials were reprocessed without the use of virgin aggregate, asphalt binder, rejuvenator, additive, or other modifying agents. The materials that made up the asphalt were therefore obtained entirely from the pavement materials recovered at the different pavement sections.

The pavement rehabilitation history and sampling date of each pavement section were recorded, as these data provide the service context of the recovered materials. Some basic physical properties of the reconstituted materials were also determined, such as maximum theoretical specific gravity, bulk specific gravity, air-void content, compacted density, and unit weight.

The measured air-void content ranged from 4.64% to 5.12%, while the measured bulk specific gravity ranged from 2.2581 to 2.3363. The compacted densities varied between 2258.1 and 2336.3 kg/m³, and the unit weights ranged between 22.15 and 22.92 kN/m³. These measurements were used to aid the characterization of the recovered materials and to provide background information for the interpretation of the mechanical responses determined later.

The six pavement sections are described in terms of their physical properties and rehabilitation history, as shown in Table 1. The information is not intended to provide a performance classification of the pavement sections but rather to provide information related to the materials and samples.

When preparing specimens for analysis, the recovered asphalt was heated to about 130 °C to provide uniform laboratory specimens for handling, mixing, and remolding. The preparation followed methods adopted in previous studies for the preparation and characterization of reclaimed asphalt materials. [23, 24] The material was then compacted in a Marshall mold in accordance with ASTM D6926/D6926M-20. [22] Cylindrical specimens having a nominal diameter of 101.6 mm and a height of 63.5 mm were fabricated. Both faces of each specimen were compacted with 75 blows using the Marshall compaction procedure.

Four specimens were prepared from each road section for the static creep test, and four specimens were prepared for the compressive load-bearing test. Therefore, 24 specimens were

utilized in creep testing, and 24 individual specimens were utilized in peak-load testing, resulting in a total of 48 reconstituted asphalt specimens from the six road sections.

The reconstitution procedure was used to ensure that the specimens had consistent geometry and controlled conditions of compaction in the laboratory without removing the constituents of the recovered asphalt. These were therefore considered reconstituted recovered asphalt specimens rather than true replicas of the original in-service pavement layers. This is significant because the recovered material could have a different physical condition and response to mechanical action from that which it had in situ when the material was excavated, heated, remolded, or compacted in the laboratory.

Table 1. Physical properties and rehabilitation history of the recovered asphalt materials

Sample Location	Theoretical max. specific gravity G_{mm}	Air void (%)	Bulk specific gravity G_{mb}	Compacted density (kg/m³)	Unit weight (kN/m³)	Date of sampling	**Last Rehabilitation	**Type of intervention
ADIW	2.40	4.80	2.2848	2284.8	22.41	2024	2021	Rehabilitation/ dualization
ILIJ	2.42	4.82	2.3034	2303.4	22.60	2024	2020	Rehabilitation/ Overlay
IFID	2.40	4.64	2.2886	2288.6	22.45	2024	2017	Rehabilitation
IKIS	2.40	4.76	2.2858	2285.8	22.42	2024	2012	Rehabilitation/ reconstruction
OYIK	2.45	4.64	2.3363	2336.3	22.92	2024	2012	Rehabilitation/ Overlay
ARIJ	2.38	5.12	2.2581	2258.1	22.15	2024	2012	Rehabilitation

***Source: Compiled from available Ekiti State Government project records, Ministry of Works and Transportation documentation, budget documents and accountability reports (Ekiti State Government, 2020, 2021).*

3.4. Description of Equipment and Calibration

Laboratory tests were performed using an ELE ADR 2000 multipurpose compression testing machine (see Figure 1). The equipment was used to apply the prescribed axial load for both the static creep test and the independent compression test to peak load. The loading conditions, test duration, and measurement procedures were varied according to the requirements of each test. In the static creep test, the vertical deformation of each specimen was recorded and used to determine the creep deformation and corresponding creep strain based on the initial specimen height.

In accordance with the laboratory's equipment quality-control procedure, the load-measuring system of the testing machine was maintained and calibrated at six-month intervals. A load conversion factor of 8.4 N/division (0.0084 kN/division) was obtained from the calibration of the load-measuring system. All laboratory tests were conducted within the applicable calibration period.

The calibration information provided traceability for the load measurements obtained during both the creep and peak-load tests. These load measurements were subsequently used to determine the nominal applied stress during the creep test and the nominal compressive stress corresponding to the peak load in the load-bearing test. The same machine that was calibrated to perform the loading processes was used for both test processes. However, the static creep test and the peak load test were considered two separate mechanical tests in themselves.



Fig. 1 Compression loading machine for creep and peak load test

3.5. Static Creep Test

The static creep test was done to evaluate the time-dependent deformation properties of the reconstituted asphalt samples under a sustained axial compressive loading. The methodology used in the test is modified from the existing laboratory methodologies of carrying out static or uniaxial creep tests of asphalt mixtures. A constant axial load instead of cyclic loading was applied in the test. Even though EN 12697-25 [26] prescribes cyclic compressive loading as a testing method of assessing the resistance of bituminous mixtures against permanent deformation, the principles of compression testing as outlined in the standard were used as guidance in the present test and not as a standard for static creep test.

The cylindrical samples were conditioned in an oven at 40 ± 1 °C for about 3– 4 h before testing in order to ensure that there is thermal equilibrium before the test. After conditioning, each sample was loaded in the ELE ADR 2000 compression testing machine in such a way that the center of the sample was aligned in the middle of the machine's compression axis. A constant axial load of 10 kN was applied and maintained for 60 min at a test temperature of 40 °C. Axial deformation was continuously monitored and recorded during the process of loading. The test temperature chosen was similar to those used in other previous laboratory tests on time-dependent deformation behavior of asphalt mixture. [5-8]

The deformation-time response was used to obtain creep deformation, creep strain, creep strain percentage, creep compliance, and creep rate. Creep strain was obtained from the division of axial deformation and initial specimen height. Creep compliance was calculated as the ratio of creep strain to the corresponding nominal applied stress. Creep rate was determined from the rate of change of creep deformation with respect to loading time, while strain rate was determined from the rate of change of creep strain with respect to loading time.

The purpose of the test was to provide a comparative characterization of the time-dependent deformation behavior of the recovered asphalt materials under the controlled laboratory conditions adopted in this study. The test employed a sustained constant load rather than cyclic loading and was therefore not intended to provide a direct measurement or prediction of field permanent deformation or pavement rut depth.

3.5.1. Nominal Applied Stress

The nominal axial stress corresponding to the sustained static load applied during the creep test was calculated from the applied load and the nominal cross-sectional area of the cylindrical specimen. For a cylindrical specimen, the cross-sectional area was calculated using Equation 1.

$$A = \frac{\pi D^2}{4} \quad (1)$$

Where:

A = the nominal cross-sectional area (mm²) and
D = the specimen diameter (mm).

For the nominal specimen diameter of 101.6 mm,

$$A = \frac{\pi(101.6)^2}{4} = 8107.3\ mm^2 = 8107.3\ \text{mm}^2$$

The nominal applied axial stress was then calculated using Equation 2.

$$\sigma = \frac{P}{A} \quad (2)$$

Where:
σ = the nominal applied axial stress (MPa),
P = the applied load (N), and
A = the nominal cross-sectional area (mm²).

For the sustained load of 10 kN,

$$\sigma = \frac{10{,}000}{8107.3} = 1.23\ MPa$$

Thus, the static creep test was conducted under a nominal axial stress of approximately 1.23 MPa.

3.5.2. Creep Deformation

Creep deformation is referred to as the amount of axial deformation that the specimen exhibited during the 60-min period of constant load application. The amount of deformation was measured in millimeters (mm). As the asphalt material was extracted from the current pavement section, melted, and reconstituted in the lab, the amount of deformation can be considered as an indication of the time-dependent deformation characteristics of the reconstituted asphalt material under the particular lab load and temperature conditions. Hence, the amount of deformation is viewed as a relative measure of time-dependent deformation characteristic and not the accumulated deformation under field conditions.

3.5.3. Creep Strain

Creep strain was calculated by normalizing the measured axial deformation with respect to the initial specimen height using Equation 3.

$$\varepsilon(t) = \frac{\Delta h(t)}{h_0} \quad (3)$$

Where:
$\varepsilon(t)$ = the creep strain at time t (dimensionless),
$\Delta h(t)$= the measured axial deformation at time t (mm),
h_0 = the initial specimen height (mm).

The creep strain was also expressed as a percentage using Equation 4.

$$\varepsilon\%(t) = \varepsilon(t) \times 100 \quad (4)$$

The percentage form provides a convenient representation of the deformation relative to the original specimen height.

3.5.4. Creep Compliance

Creep compliance was calculated as the creep strain divided by the nominal applied stress using Equation 5.

$$J(t) = \frac{\varepsilon(t)}{\sigma} \quad (5)$$

Where:
$J(t)$ = the creep compliance at time t (MPa^{-1}),
$\varepsilon(t)$ = the creep strain at time t, and
σ = the nominal applied axial stress (MPa).

Under the specified test conditions, lower creep compliance indicates a smaller strain response per unit applied stress and therefore a comparatively more restrained deformation response.

3.5.5. Creep Rate

The creep rate was determined from the rate of development of axial deformation with time. When the deformation rate was calculated over the complete loading period, it was expressed with Equation 6.

$$\dot{\delta} = \frac{\Delta\delta}{\Delta t} \quad (6)$$

Where:
$\dot{\delta}$ = the average deformation rate (mm/s),
$\Delta\delta$ = the change in measured deformation (mm), and
Δt = the corresponding loading-time interval (s).

For the 60-min test period, the calculated deformation-rate values were expressed in mm/s. A lower deformation rate indicates a slower accumulation of deformation under the specified sustained-loading condition.

Where a secondary-creep region was identifiable from the deformation- time curve, the slope of that region was used to characterize the corresponding creep rate.

3.6. Peak-Load Compression Test

A separate compression test was performed to characterize the compressive load-bearing response of the reconstituted asphalt specimens. The peak load was described as the maximum load recorded by the testing machine during the compression test and was indicated in kilonewtons (kN).

Peak load test was considered an independent mechanical test different from static creep test. Therefore, peak load was not used as a measure of creep resistance or to substitute the creep parameters. Rather, it was used to give comparative information on the compressive load-bearing capacity of the reconstituted asphalt samples.

3.6.1. Nominal Compressive Stress

The nominal compressive stress at the point of peak load was computed by dividing the measured peak load by the nominal cross-sectional area of the cylindrical sample through Equation 7.

$$\sigma_\rho = \frac{P_{max}}{A} \quad (7)$$

Where;
σ_ρ = the nominal compressive stress at peak load (MPa),
P_{max} = the maximum recorded load (N), and
A = the nominal specimen cross-sectional area (mm^2).

The results are the nominal compressive stress considering the original nominal cross-sectional area of the sample.

3.7. Statistical Analysis

Pearson Product-Moment Correlation analysis was performed to analyze the linear associations between the measured creep and compressive load-bearing behaviors of the reconstituted asphalt samples. The analysis took into account the existing specimen level data for the creep and peak load tests. Creep strain, creep rate and creep compliance were taken to be representative deformation related parameters, while peak load was taken to be the primary load bearing parameter. The pairwise Pearson Correlation Coefficient (r) was computed in order to find out the strength and nature of the linear association between the variables. The coefficient ranges from −1 to +1, and values near either −1 or +1 indicate strong negative or positive linear associations, respectively. Values near 0 indicate either weak or non-existent linear association.

Statistical significance was tested at the 5% significance level ($\alpha = 0.05$). -Value less than 0.05 was regarded as the existence of statistically significant linear association.

Nominal compressive stress was not taken as an independent variable from peak load in the correlation analysis since it is calculated directly from peak load by using the same nominal cross-sectional area for all the samples. Hence, correlation of nominal compressive stress gives the same ranking and correlation strength as the correlation of peak load. Therefore, peak load was kept as the primary load bearing variable in order to avoid redundant statistical analysis.

Similarly, the nominal applied stress in the static creep test is constant at about 1.23 MPa for all the samples. Therefore, creep compliance, which is the ratio of creep strain to constant applied stress, is directly proportional to creep strain. This information was taken into consideration when interpreting the correlation of the creep parameters.

The correlation analysis was done for characterizing the association of the measured laboratory responses. It was not meant for establishing causality, predicting pavement performance or substituting peak load response for creep resistance.

3.8. Performance Interpretation Criteria

The measured and calculated performance parameters were used to compare the load-bearing behavior and time-dependent deformation characteristics of the reconstituted asphalt materials obtained from the different pavement sections.

Performance interpretation was based on the observed trends in the principal indicators, including creep deformation, creep strain, creep compliance, creep rate, peak load, and nominal compressive stress.

For the creep-related parameters, lower values of creep deformation, creep strain, creep compliance, and creep rate were interpreted as indicating a comparatively more restrained deformation response under the specified sustained-loading conditions. Conversely, higher values indicated a greater time-dependent deformation response.

For the compressive load-bearing response, higher peak-load and nominal compressive-stress values were interpreted as indicating greater load-bearing response under the specified laboratory compression conditions. These criteria were used for comparative interpretation of the reconstituted asphalt materials and were not intended as direct field pavement-performance. The indicators were not treated in isolation from each other when drawing conclusions based upon them. A sample with a greater resistance to peak loading is not guaranteed to show a lower degree of deformation when creep stress is applied.

Table 2. Performance interpretation criteria

Parameter	Preferred direction	Interpretation
Creep rate	Lower	Indicates a slower rate of deformation accumulation under sustained loading.
Creep deformation	Lower	Indicates lower total deformation accumulated during the test period.
Creep strain	Lower	Indicates lower deformation relative to the original specimen height.
Creep compliance	Lower	Indicates lower strain response per unit applied stress and, therefore, lower deformation susceptibility under the applied loading condition.
Peak load	Higher	Indicates greater load carried by the specimen before reaching the peak-load condition.
Nominal compressive stress	Higher	Indicates greater peak-load capacity relative to the specimen's nominal cross-sectional area.

4. Results and Discussion

The results from the static creep and compressive load bearing tests are combined in Table 3 for a complete evaluation of the mechanical response of the recovered asphalt materials. The creep parameters (magnitude and rate of the time-dependent deformation under sustained loading) and the peak-load and nominal compressive stress parameters (showing the load-bearing response of the materials) are indicated. The overall presentation allows for the comparison of the deformation behavior and load-bearing capacity of the six road sections examined under the conditions used in the laboratory. The statistical parameters of the creep and compressive load-bearing are given in both Tables 4 and 5. The analysis summarizes the variance and distribution of the responses measured on the road sections tested and offers a foundation for evaluating consistency of recovered asphalt materials as they relate to both time-dependent deformation and load-bearing.

4.1. Creep Performance of the Recovered Asphalt

Creep properties of the retrieved asphalt samples were determined from parameters such as creep strain, creep strain percentage, creep compliance, creep rate, and strain rate. These parameters provide different means of evaluating the degree and rate of time-dependent deformation under sustained compressive loading conditions. The results are similar to the previous findings that studied creep compliance and creep flow of asphalt mixes with reclaimed asphalt pavement by Daniel and Lachance [3] and the time-dependent creep behavior of asphalt mixes subjected to uniaxial compression by Luo et al. [8]

The mean creep properties were different for the six roads sampled. The lowest mean creep strain (8.70×10^{-5}; 0.00870%) and creep compliance (7.07×10^{-5} MPa^{-1}) were noted on AR–IJ, which showed the least cumulative deformation under the prescribed test conditions. OY–IK had relatively small mean creep strain (9.49×10^{-5}) and creep compliance (7.73×10^{-5} MPa^{-1}). On the other hand, the highest mean creep strain (1.65×10^{-4}; 0.01646%) and creep compliance (1.33×10^{-4} MPa^{-1}) were observed on AD–IW, which showed the greatest cumulative strain under the stated constant-loading conditions.

The deformation-rate parameters provided additional information on the time-dependent response. IL–IJ recorded the highest mean creep rate (9.39×10^{-7} mm/s) and strain rate (1.48×10^{-8} s^{-1}), followed by AD–IW, with values of 8.73 ×

10^{-7} mm/s and 1.37×10^{-8} s^{-1}, respectively. AR–IJ recorded a comparatively lower creep rate of 7.20×10^{-7} mm/s and strain rate of 1.13×10^{-8} s^{-1}. Thus, AR–IJ exhibited relatively low accumulated deformation and deformation rate, whereas AD-IW exhibited relatively high accumulated deformation and deformation rate. It is important to note, however, that IL- IJ had the highest deformation rate but did not have the highest accumulated strain. This indicates that deformation magnitude and deformation rate represent related but distinct aspects of time-dependent behavior. This observation is consistent with Luo et al. [8], who reported that the creep response of asphalt mixtures varies with loading conditions and time.

The observed differences can also be considered in relation to the physical characteristics of the recovered materials. The air-void contents were relatively close, ranging from 4.64% to 5.12%, while the compacted densities ranged from 2258.1 to 2336.3 kg/m³. OY– IK had the highest compacted density (2336.3 kg/m³) and one of the lowest air-void contents (4.64%), together with a relatively low creep response and high peak-load and nominal compressive-stress values. AR- IJ had the lowest compacted density (2258.1 kg/m³) and highest air-void content (5.12%), while also exhibiting the lowest creep response. These observations suggest that the volumetric properties may be associated with the measured mechanical responses; however, no causal relationship can be established because the individual effects of these properties were not experimentally isolated. Other factors, including aggregate gradation, asphalt content, binder condition, ageing, and previous service exposure, may also have contributed to the observed differences. Similarly, Daniel and Lachance [3] reported that gradation, asphalt content, and volumetric properties influenced the creep-compliance behavior of asphalt mixtures containing reclaimed asphalt pavement.

The rehabilitation history provides additional background to the observed differences. The estimated service periods since the last recorded rehabilitation of the investigated sections ranged from approximately 3 to 12 years, with sampling conducted in 2024. The sections had undergone different forms of intervention, including rehabilitation, dualization, overlay, and reconstruction. These differences indicate variations in construction history, traffic exposure, and environmental exposure before sampling and may have contributed to the differences in mechanical response. However, rehabilitation type and service age should not be interpreted as causal factors because their individual effects were not experimentally separated in the present study.

The results should also be interpreted in the context of the adopted test procedure. The present investigation employed static sustained-load compression at 40 °C rather than the cyclic compression procedure specified in EN 12697-25. [26] Therefore, the measured creep parameters represent a comparative assessment of the deformation characteristics of the recovered asphalt materials under the specified laboratory conditions and should not be interpreted as a direct prediction of field permanent deformation.

Furthermore, the recovered materials were reheated and reconstituted prior to the testing. Hence, the results represent the reaction of the recovered materials after laboratory preparation and do not necessarily reflect their actual in-situ condition. According to ASTM D1074 [25], the reheating of the bituminous mixtures may impact their compressive properties due to binder viscosity changes. However, since ASTM D1074 was not applied in the current creep test, the impact of the reheating process should be taken into consideration when analyzing the obtained results of the recovered asphalt materials. Overall, the time-dependent deformation properties of the recovered asphalt materials were different. Therefore, AR- IJ and OY– IK demonstrated relatively low accumulated creep deformation, whereas AD-IW had the highest accumulated deformation. IL- IJ had the highest deformation rate. The variations above indicate that the recovered asphalt materials had different responses to the sustained mechanical loading in the controlled laboratory environment at 40 °C.

4.2. Peak-Load and Load-Bearing Response

Peak load and nominal compressive stress were used to characterize the load-bearing compressive response of the recovered asphalt materials. Hence, peak load is the maximum compressive load obtained in the compression test for each specimen, whereas nominal compressive stress is the normalized peak load relative to the nominal cross-sectional area of the specimen.

The use of compression loading in characterizing the response of asphalt mixtures has precedent in laboratory asphalt-mixture testing. The compression testing of compacted bituminous mixtures is described in ASTM D1074 [25] as a method of evaluation of the mixture response under certain conditions of loading and environment, among others. The standard also notes that the reheating may impact the measured compressive properties due to the changes in the binder viscosity. However, the nominal compressive stress obtained in the current study cannot be regarded as a compressive strength value due to the difference in the loading conditions and aims of the current test.

The peak-load and load-bearing responses of the investigated road sections were different. The highest mean peak load was achieved in OY– IK, approximately 69.15 kN, corresponding to the mean nominal compressive stress of approximately 8.53 MPa. The mean peak loads in AD- IW and IL– IJ were 54.25 kN and 52.48 kN, corresponding to the mean nominal compressive stress of approximately 6.69 MPa and 6.47 MPa, respectively. The mean peak load in IF- ID was approximately 48.18 kN, corresponding to the nominal compressive stress of approximately 5.94 MPa.

The lowest mean response was observed in IK– IS, where the mean peak load was approximately 40.03 kN and the nominal compressive stress – 4.94 MPa. The lowest mean peak load was recorded in AR– IJ, approximately 26.63 kN, corresponding to the nominal compressive stress of approximately 3.29 MPa.

The specimen-level results also demonstrated a substantial variability for some road sections. Hence, the nominal compressive stress values varied from 3.29 to 16.16 MPa for OY– IK, from 2.15 to 9.76 MPa for IK– IS, and from 2.01 to 5.82 MPa for AR- IJ. Hence, the mean values should not be treated as universal properties of the whole pavement sections. Instead, they represent the summary measures of the response variability obtained among the recovered specimens.

Therefore, the high peak-load response obtained for OY– IK indicates that its recovered asphalt specimens were capable of sustaining the higher compressive loads before reaching the maximum load during the test. Conversely, the relatively low peak-load response in AR- IJ indicates the comparatively lower peak-load response to the same type of compression loading. The observed variation may be related to the differences in aggregate structure, binder condition, volumetric properties, and previous service exposure of the recovered materials.

The test results should not be assessed in accordance with the universal limits of acceptance for compressive strength since the test was developed primarily for the comparative characterization of the recovered materials. The standard ASTM D1074 [25] notes that the requirements may differ depending on the agency experience and certain test conditions. Therefore, the results obtained during the current study are better compared among the investigated road sections than used for the establishment of the general specification limits for recovered asphalt materials.

4.3. Combined Creep and Load-Bearing Response

The results for creep and peak-load provide complementary information about the mechanical behavior of the recovered asphalt materials. The creep parameters characterize the time-dependent deformation under the sustained loading conditions, whereas peak load and nominal compressive stress characterize the maximum response in terms of compressive load obtained in the separate load-bearing test. Hence, the two sets of parameters characterize different aspects of material behavior and should not be treated as interchangeable indicators. Similarly, the differences between creep behavior and other mechanical properties were reported by Daniel and Lachance [3].

There was no apparent relationship between the creep and load-bearing responses in the tested asphalt samples. Hence, AR- IJ had the lowest mean creep strain (8.70×10^{-5}) and creep compliance (7.07×10^{-5} MPa^{-1}), but the lowest mean peak load. Conversely, OY–IK demonstrated relatively low creep response in combination with the highest mean peak load (69.15 kN) and nominal compressive stress (8.53 MPa). AD–IW had the highest creep strain (0.01646%) and creep compliance (1.33×10^{-4} MPa^{-1}), but still had the relatively high nominal compressive stress of approximately 6.69 MPa. The highest creep rate (9.39×10^{-7} mm/s) was recorded in IL–IJ in combination with the relatively high nominal compressive stress of approximately 6.47 MPa.

The results above indicate that the lower creep deformation does not necessarily correspond to the higher load-bearing response, whereas the higher load-bearing response does not correspond to the lower creep deformation. Luo et al. [8] reported similar findings with respect to the creep behavior of asphalt mixtures that depended on the loading conditions and time.

The observed differences may be partially explained by the variations in the physical properties of the recovered mixtures. Hence, OY– IK, having the highest load-bearing response, had the highest compacted density (2336.3 kg/m^3) and relatively low air-void content (4.64%), whereas AR- IJ had the lowest compacted density (2258.1 kg/m^3) and the highest air-void content (5.12%).

However, the association does not imply causality since the effects of the density and air-void content were not individually analyzed. The variations in aggregate gradation, asphalt content, binder condition, aging, and previous service exposure may have also contributed to the observed responses, similarly to Daniel and Lachance [3].

The information on the rehabilitation history does not explain the observed mechanical responses either. Hence, AD-IW, which was last rehabilitated in 2021, had the highest creep deformation, whereas OY– IK, which was last rehabilitated in 2012, had the highest load-bearing response. Therefore, the observed behavior may be caused by the joint impact of the rehabilitation history, mixture characteristics, and subsequent service exposure. It should also be noted that the reheating and reconstitution of the recovered materials should be taken into account due to the influence of laboratory preparation procedures on the binder condition and subsequently on the measured response.

Overall, the results indicate that the recovered asphalt materials had different combinations of the time-dependent deformation and compressive load-bearing responses. The creep strain, creep compliance, and creep rate characterize the sustained-load deformation response, whereas the peak load and nominal compressive stress characterize the separate compressive load-bearing response. Therefore, the results should be considered as the comparative laboratory responses rather than predictions of the field pavement performance since the employed creep test included the use of static

sustained-load procedure and not the cyclic compression procedure specified in EN 12697-25. [26]

4.4. Statistical Relationship between Creep and Load-Bearing Response

In order to analyze further the relationship between the creep response and compressive load-bearing response of the reconstituted asphalt specimens, Pearson product-moment correlation analysis was performed. The results presented in Table 6 show that there are very weak linear correlations between the selected creep parameters and peak load.

Hence, there is a very weak negative correlation between the creep strain and peak load ($r = -0.082$, $p = 0.703$). Similarly, the creep compliance demonstrates a very weak negative correlation with peak load ($r = -0.082$, $p = 0.703$). Both correlations are not statistically significant at the 5% significance level. Finally, there is a very weak positive correlation between the creep rate and peak load ($r = 0.083$, $p = 0.700$), which is also not statistically significant.

Therefore, there were no statistically significant linear relationships between the variations in peak-load response and the variations in creep strain, creep compliance, or creep rate in the current tested dataset. Hence, specimens with relatively high creep deformation did not necessarily demonstrate either higher or lower peak-load responses in a consistent manner.

The identical correlation coefficients between the creep strain and creep compliance are not surprising since the creep compliance is calculated by dividing the creep strain by the constant nominal applied stress of approximately 1.23 MPa. Under the constant-stress condition, adopted in the current study, the creep compliance is directly proportional to creep strain and results in the same ranking and correlation coefficient with peak load. The correlation results are presented in Table 6.

The quantitative evidence showing the distinction between the creep behavior and the compressive load-bearing response is provided by the results of Pearson correlation (see Figures 2 and 3). There is no systematic relation between the creep strain and the maximum compressive load attained by the specimens since the corresponding correlation coefficient is very weak ($r = -0.082$). Also, the p-value ($p = 0.703$) indicates that the observed association is not statistically significant at the 5% significance level. Similarly, the very weak correlation between the creep rate and peak load ($r = 0.083$, $p = 0.700$) indicates that the creep deformation rate is not significantly related to the peak-load response.

The finding above is consistent with the mechanical distinction between the two tests. While the peak-load test measures the maximum load reached by a specimen in the separate compression test, the static creep test measures the deformation that develops in time under a certain sustained load. Since the observed linear relations were not statistically significant, the current data set cannot be used to estimate whether the peak-load response can be used to predict the sustained-load deformation response of the recovered asphalt materials under the current laboratory conditions.

The finding above is particularly important for the comparison of the investigated road sections since the specimens with relatively high creep deformation were still capable of sustaining relatively high peak loads, whereas the low creep deformation was not consistently related to either the high or low peak-load values. The correlation results above thus confirm that the creep deformation resistance and compressive load-bearing response are complementary mechanical properties.

It should also be noted that correlation does not imply causality. The weak relationships above may be explained by the joint impact of the mixture composition, aggregate structure, binder condition, aging, air-void characteristics, and the laboratory reheating and reconstitution effects.

Additionally, the relatively small number of specimens limits the ability to generalize the results to other recovered asphalt materials, pavement sections, or test conditions. However, the correlation analysis provides the quantitative evidence supporting the conclusion about the distinction between the creep and load-bearing responses as two different categories of mechanical behavior in the current study.

The correlation results above confirm the decision not to combine the creep and peak-load parameters into one composite performance index. If the index implied the same underlying response, the joint effect would be indicated by the current specimen-level results. Hence, the findings should be reported separately in terms of time-dependent deformation response, characterized by the creep parameters, and compressive load-bearing response, characterized by the peak load and nominal compressive stress.

Table 6. Pearson correlation between creep parameters and peak load

Relationship	Pearson *r*	*p*-value	Interpretation
Creep strain vs. peak load	−0.082	0.703	Very weak negative, not significant
Creep compliance vs. peak load	−0.082	0.703	Very weak negative, not significant
Creep rate vs. peak load	+0.083	0.700	Very weak positive, not significant

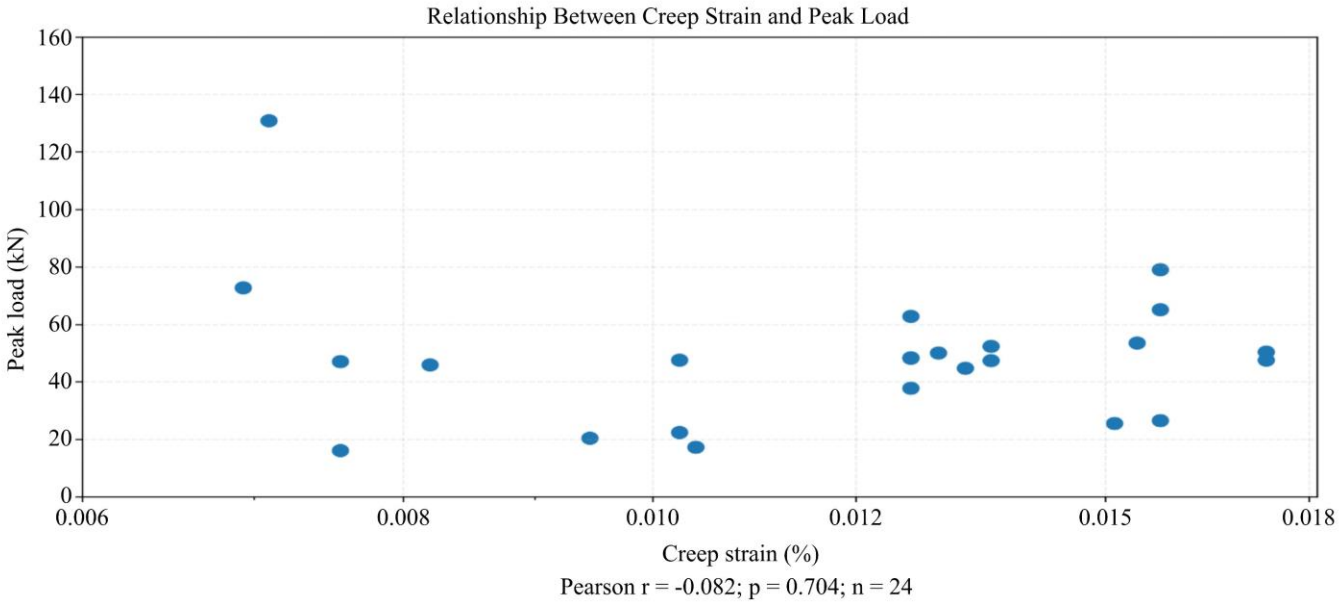


Fig. 2 Graph showing relationship between creep strain and peak load

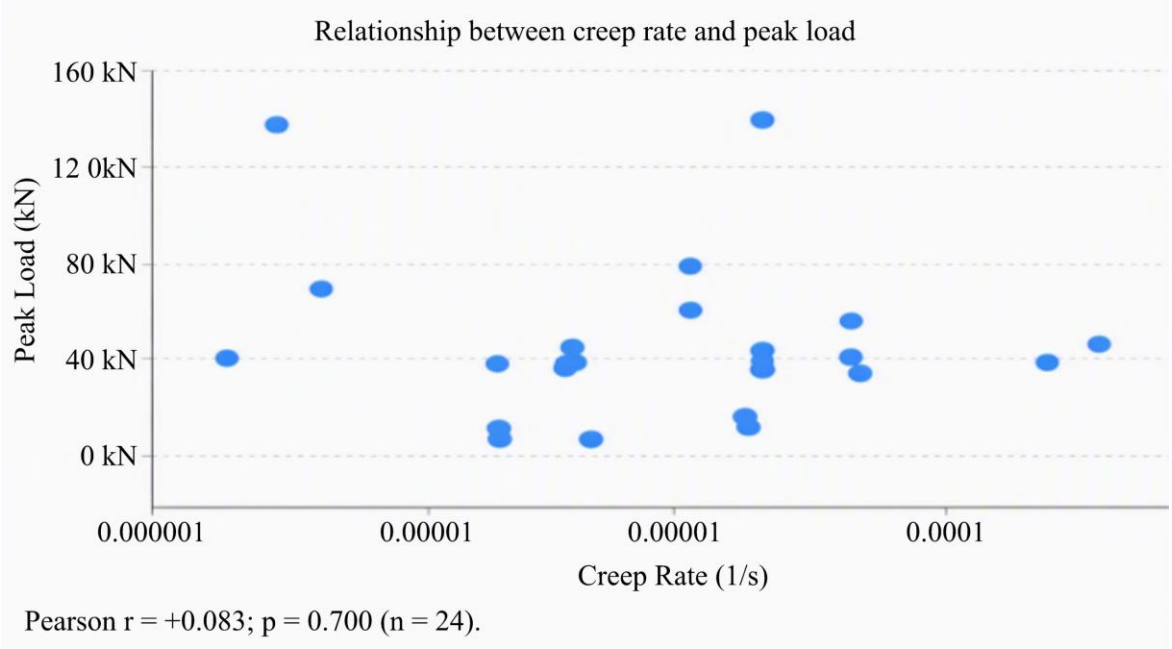


Fig. 3 Graph showing relationship between creep rate and peak load

5. Limitations of the Study

Some limitations are to be considered when interpreting the results of this study. First, the creep test was a static sustained-load compression test conducted at 40 °C and not the cyclic compression test according to EN 12697-25 [26]. The adopted methodology, therefore, cannot be considered as a simulation of cyclic field loading and hence direct prediction of pavement performance in the field.

Second, the recovered materials were reheated and reconstituted in the laboratory before the tests. The laboratory procedure could change the condition of the binder and thus influence the measured mechanical properties. Reheating and reconstitution of materials should, therefore, be considered in interpretation of results.

Third, the available rehabilitation history did not allow the individual effects of traffic exposure, aging, mixture composition and environmental exposure to be separated. Likewise, the effects of density and air voids were not investigated as independent variables. Therefore, the observed relationships between these characteristics and mechanical properties should not be considered as causative relationships.

Fourth, the relatively small sample size and recovery of materials from only six road sections limit the generalizability of the results. The results should, therefore, be considered as laboratory responses of the recovered and reconstituted materials under the specified loading and temperature conditions and not the universal mechanical characteristics of the pavement sections.

6. Conclusion

This study analyzed the creep behavior and compressive load-bearing response of reconstituted asphalt materials from six selected road sections in Ekiti State, Nigeria. The following conclusions were made based on the results and analyses:

- The recovered asphalt materials showed unique time-dependent deformation characteristics under the specified static creep conditions. Variation in creep strain, creep compliance, creep rate and strain rate indicates that the studied road sections did not have uniform response to sustained compressive loading.
- AR-IJ had the lowest accumulated creep response with the lowest mean creep strain and creep compliance of 8.70×10-5 and 7.07×10-5 MPa-1, respectively. OY-IK had also relatively low creep response, with mean creep strain and compliance of 9.49×10-5 and 7.73×10-5 MPa-1, respectively.
- AD-IW had the highest accumulated deformation response with mean creep strain of 1.65×10-4 (0.01646%) and creep compliance of 1.33×10-4MPa-1. These values imply high deformation response of the materials under the specified loading and temperature conditions.
- IL-IJ had the highest mean creep rate of 9.39×10-7mm/s and highest strain rate of 1.48×10-8s-1. It indicates that the highest deformation rate was experienced in IL-IJ specimens under the adopted creep test conditions. The results indicate that creep magnitude and deformation rate are related but different characteristics of time-dependent deformation.
- The peak-load response varied among the investigated road sections in the separate compression test. OY-IK had the highest mean peak load of 69.15kN and corresponding nominal compressive stress of approximately 8.53MPa, whereas AR-IJ had the lowest mean peak load of 26.63kN and corresponding nominal compressive stress of approximately 3.29MPa.
- No consistent response pattern was observed between creep and load-bearing responses. AR-IJ had relatively low creep response together with the lowest peak-load response, whereas OY-IK had relatively low creep response together with the highest peak-load response. AD-IW had the highest accumulated creep response, but still had relatively high peak-load response. This finding shows that creep behavior and peak-load response are different mechanical properties and should not be considered as similar parameters.
- The observed differences may be caused by differences in mixture characteristics, aggregate structure, binder condition, volumetric properties, aging, previous exposure and effects of laboratory reheating and reconstitution. However, these factors were not controlled independently in the current study. The results show the behavior of the recovered and reconstituted materials under the specified laboratory conditions and not the exact in situ behavior of the pavement materials.
- Pearson correlation analysis did not show any statistically significant linear relationship between the creep parameters and compressive load-bearing response in the tested samples. Creep strain and creep compliance showed very weak negative correlation with peak load ($r=-0.082$, $p=0.703$), while creep rate showed very weak positive correlation with peak load ($r=0.083$, $p=0.700$). None of these relationships was statistically significant at the 5% significance level. The results suggest that creep deformation and compressive load-bearing response should be considered as complementary but different measures of the mechanical behavior of the reconstituted asphalt materials.
- Summarily, this study shows that two different dimensions are needed for the description of the mechanical behavior of the recovered asphalt materials: time-dependent deformation response indicated by creep strain, creep compliance and creep rate; and compressive load-bearing response indicated by peak load and nominal compressive stress. Separate consideration of these two different categories provides a better characterization than their combination in a single composite performance index not supported by the observed relationships in specimens.

Recommendations

Creep strain, creep compliance, and creep rate are recommended as comparative indicators of time-dependent deformation under the specified laboratory conditions, while peak load and nominal compressive stress are recommended as complementary indicators of compressive load-bearing response. Until further validation, these parameters should not be considered as universally applicable acceptance limits or used interchangeably as measures of asphalt material performance.

The physical properties and rehabilitation history of recovered materials should be considered as context factors when interpreting laboratory responses, but should not be considered as direct causal predictors without appropriate experimental investigation. For engineering assessment, laboratory characterization should be considered together with field pavement condition, traffic characteristics, structural properties and environmental conditions. Laboratory

responses obtained from recovered materials should not be used in isolation to represent the complete condition or performance of the pavement. Future studies should have a large sample size and more pavement sections to increase statistical robustness and generalizability of the results. Future research should also include field testing and controlled experiments to investigate the individual effects of reheating, aging, material reconstitution, density and air void content on the mechanical response of recovered asphalt materials.

Funding Statement

The authors received no financial support for the research, authorship, and publication for this article.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

References

[1] Ali Behnood, "Application of Rejuvenators to Improve the Rheological and Mechanical Properties of Asphalt Binders and Mixtures: A Review," *Journal of Cleaner Production*, vol. 231, pp. 171-182, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[2] Yuetan Ma et al., "Binder Availability and Blending Efficiency of Reclaimed Asphalt: A State-of-the-art Review," *Construction and Building Materials*, vol. 357, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[3] Jo Sias Daniel, and Aaron Lachance, "Mechanistic and Volumetric Properties of Asphalt Mixtures with Recycled Asphalt Pavement," *Transportation Research Record*, vol. 1929, no. 1, pp. 28-36, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[4] Giulia Tarsi, Piergiorgio Tataranni, and Cesare Sangiorg, "The Challenges of using Reclaimed Asphalt Pavement for New Asphalt Mixtures: A Review," *Materials*, vol. 13, no. 18, pp. 1-26, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[5] Fan Bai, Xinhua Yang, and Guowei Zeng, "Creep and Recovery Behavior Characterization of Asphalt Mixture in Compression," *Construction and Building Materials*, vol. 54, pp. 504-511, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] Fazal R. Safi et al., "A Model to Predict Creep Compliance of Asphalt Mixtures Containing Recycled Materials," *Construction and Building Materials*, vol. 184, pp. 374-381, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] John F. Rushing john, and Dallas N. Little, "Static Creep and Repeated Load as Rutting Performance Tests for Airport HMA Mix Design," *Journal of Materials in Civil Engineering*, vol. 26, no. 9, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[8] Wenbo Luo et al., "A Creep Model of Asphalt Mixture Based on Variable Order Fractional Derivative," *Applied Sciences*, vol. 10, no. 11, pp. 1-12, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Matthew W. Witczak, *Simple Performance Test for Superpave Mix Design*, National Academy Press, pp. 1-105, 2002. [Google Scholar] [Publisher Link]

[10] Paul J. Cosentino et al., "Evaluating Laboratory Compaction Techniques of Reclaimed Asphalt Pavement," *Transportation Research Record*, vol. 2335, no. 1, pp. 89-98, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[11] He Gui-ping, and Wong Wing-gun, "Laboratory Study on Permanent Deformation of Foamed Asphalt Mix Incorporating Reclaimed Asphalt Pavement Materials," *Construction and Building Materials*, vol. 21, no. 8, pp. 1809-1819, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[12] Ki Hoon Moon, Augusto Cannone Falchetto, and Mihai O. Marasteanu, "Performance of Reclaimed Asphalt Pavement Mixtures under Static and Oscillatory Loading Available to Purchase," *Proceedings of the Institution of Civil Engineers—Transport*, vol. 168, no. 1, pp. 71-82, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[13] Jie Yin et al., *Creep Behavior of Recycled Asphalt Pavement Compacted at Elevated Temperatures*, Proceedings of the Geotechnical and Structural Engineering Congress 2016, ASCE, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] Mequanent Mulugeta Alamnie, Ephrem Taddesse, and Inge Hoff, "Advances in Permanent Deformation Modeling of Asphalt Concrete—A Review," *Materials*, vol. 15, no. 10, pp. 1-27, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Andrew Drescher, Jong R. Kim, and David E. Newcomb, "Permanent Deformation in Asphalt Concrete," *Journal of Materials in Civil Engineering*, vol. 5, no. 1, pp. 112-128, 1993. [CrossRef] [Google Scholar] [Publisher Link]

[16] A. Copeland, "*Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice*," Rep. FHWA-HRT-11-021, Federal Highway Administration, pp. 1-60, 2011. [Google Scholar] [Publisher Link]

[17] Jie Yin et al., "Effects of Temperature on Creep Behavior of Compacted Recycled Asphalt Pavement," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 143, no. 4, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] E. A. Oluwasola, Abayomi Afolayan, and Damilola Ayodele Ogundare, "The Performance of Hot Mix Asphalt Mixtures Incorporating Reclaimed Asphalt Pavement," *8th International Conferences of Science, Engineering and Environmental Technology*, Federal Polytechnic Ede, pp. 1-12, 2016. [Google Scholar]

[19] Idorenyin Ndarake Usanga, Enobong Okon Inyang, and Chijioke Christopher Ikeagwuani, "Investigation of Deformation Characteristics of Asphalt Mixtures Containing Reclaimed Asphalt Pavement (RAP) Binders using Laboratory Simulations," *Hybrid Advances*, vol. 10, pp. 1-12, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[20] Deyu Zhang et al., "Effects of Internal Structure on Anisotropic Creep Behavior of Asphalt Mixture based on User-Defined Three-Dimensional Discrete Element Method," *Journal of Testing and Evaluation*, vol. 46, no. 4, pp. 1355-1365, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[21] Xiangbing Gong et al., "Rheological Characterization of Asphalt Fine Aggregate Matrix Using Dynamic Shear Rheometer," *Polymers*, vol. 11, no. 8, pp. 1-15, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[22] *ASTM D6926-20: Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus*, ASTM International, pp. 1-8, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Davide Lo Presti et al., "Laboratory Mix Design of Asphalt Mixture Containing Reclaimed Material," *Advances in Materials Science and Engineering*, vol. 2014, pp. 1-11, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[24] D. Lo Presti et al., "Reclaimed Asphalt Test Specimen Preparation Assisted by Image Analysis," *Journal of Materials in Civil Engineering*, vol. 27, no. 8, pp. 1-5, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[25] *ASTM D1074-09: Standard Test Method for Compressive Strength of Bituminous Mixtures*, ASTM International, pp. 1-5, 2009. [CrossRef] [Publisher Link]

[26] *EN 12697-25:2016: Bituminous Mixtures - Test Methods - Part 25: Cyclic Compression Test*, European Committee for Standardization, pp. 1-8, 2016. [Publisher Link]

Appendix

Table 3. Combined creep and compressive load-bearing response for the reconstituted asphalt specimens

Creep Response							Compressive Load Bearing Response		
Sample Location	**Creep Strain**	**Creep Deformation (mm)**	**Creep strain (%)**	**Creep compliance (MPa^{-1})**	**Creep rate (mm/s)**	**Creep Strain rate (s^{-1})**	**Peak load (kN)**	**Nominal compressive stress (MPa)**	**Comparative load-bearing response**
IF-ID1	1.3543×10^{-4}	0.0086	0.01354	1.098×10^{-4}	7.26×10^{-7}	1.143×10^{-8}	52.5	6.48	High
IF-ID2	1.3543×10^{-4}	0.0086	0.01354	1.098×10^{-4}	7.26×10^{-7}	1.143×10^{-8}	47.6	5.87	High
IF-ID3	1.0236×10^{-4}	0.0065	0.01024	8.299×10^{-5}	1.00×10^{-6}	1.575×10^{-8}	47.7	5.88	High
IF-ID4	1.3228×10^{-4}	0.0084	0.01323	1.072×10^{-4}	5.11×10^{-7}	8.047×10^{-9}	44.9	5.54	High
AR-IJ1	9.4488×10^{-5}	0.0060	0.00945	7.660×10^{-5}	6.82×10^{-7}	1.074×10^{-8}	20.5	2.53	Low
AR-IJ 2	1.0236×10^{-4}	0.0065	0.01024	8.299×10^{-5}	8.33×10^{-7}	1.312×10^{-8}	22.5	2.78	Low
AR-IJ 3	7.5591×10^{-5}	0.0048	0.00756	6.128×10^{-5}	6.82×10^{-7}	1.074×10^{-8}	16.3	2.01	Very low
AR-IJ 4	7.5591×10^{-5}	0.0048	0.00756	6.128×10^{-5}	6.82×10^{-7}	1.074×10^{-8}	47.2	5.82	High
OY-IK1	7.0866×10^{-5}	0.0045	0.00709	5.744×10^{-5}	8.33×10^{-7}	1.312×10^{-8}	131.0	16.16	Very high
OY-IK2	1.5748×10^{-4}	0.0100	0.01575	1.277×10^{-4}	8.33×10^{-7}	1.312×10^{-8}	26.7	3.29	Low
OY-IK 3	8.1890×10^{-5}	0.0052	0.00819	6.640×10^{-5}	7.22×10^{-7}	1.137×10^{-8}	46.1	5.69	High
OY-IK 4	6.9291×10^{-5}	0.0044	0.00693	5.618×10^{-5}	5.65×10^{-7}	8.713×10^{-9}	72.8	8.98	Very high
IK-IS 1	1.5748×10^{-4}	0.0100	0.01575	1.277×10^{-4}	7.94×10^{-7}	1.285×10^{-8}	79.1	9.76	Very high
IK-IS 2	1.0394×10^{-4}	0.0066	0.01039	8.428×10^{-5}	7.29×10^{-7}	1.148×10^{-8}	17.4	2.15	Very low
IK-IS 3	1.2598×10^{-4}	0.0080	0.01260	1.021×10^{-4}	8.89×10^{-7}	1.400×10^{-8}	37.9	4.67	Moderate
IK-IS 4	1.5118×10^{-4}	0.0096	0.01512	1.226×10^{-4}	8.30×10^{-7}	1.307×10^{-8}	25.7	3.17	Low
AD-IW1	1.5748×10^{-4}	0.0100	0.01575	1.277×10^{-4}	7.94×10^{-7}	1.250×10^{-8}	65.2	8.04	Very high
AD-IW2	1.5433×10^{-4}	0.0098	0.01543	1.251×10^{-4}	1.03×10^{-6}	1.622×10^{-8}	53.6	6.61	High
AD-IW3	1.7323×10^{-4}	0.0110	0.01732	1.404×10^{-4}	8.33×10^{-7}	1.312×10^{-8}	50.5	6.23	High
AD-IW4	1.7323×10^{-4}	0.0110	0.01732	1.404×10^{-4}	8.33×10^{-7}	1.312×10^{-8}	47.7	5.88	High
IL-IJ 1	1.2598×10^{-4}	0.0080	0.01260	1.021×10^{-4}	1.11×10^{-6}	1.748×10^{-8}	48.3	5.96	High
IL-IJ 2	1.2913×10^{-4}	0.0082	0.01291	1.047×10^{-4}	8.81×10^{-7}	1.387×10^{-8}	50.1	6.18	High
IL-IJ 3	1.2598×10^{-4}	0.0080	0.01260	1.021×10^{-4}	8.83×10^{-7}	1.391×10^{-8}	48.6	5.99	High
IL-IJ 4	1.2598×10^{-4}	0.0065	0.01260	1.021×10^{-4}	8.81×10^{-7}	1.387×10^{-8}	62.9	7.76	Very high

Table 4. Statistical summary of creep parameters for the reconstituted asphalt specimens

Road section	Creep Deformation (mm)			Creep strain (%)			Creep compliance (MPa^{-1})		
	Mean	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**
IF-ID	0.00803	0.00102	12.72	0.01264	0.00161	12.70	1.020×10^{-4}	1.30×10^{-5}	12.72
AR-IJ	0.00553	0.00086	15.60	0.00870	0.00136	15.61	7.054×10^{-5}	1.10×10^{-5}	15.60
OY-IK	0.00603	0.00267	44.38	0.00949	0.00421	44.37	7.685×10^{-5}	3.41×10^{-5}	44.39
IK-IS	0.00855	0.00156	18.26	0.01347	0.00246	18.27	1.098×10^{-4}	2.01×10^{-5}	18.27
AD-IW	0.01045	0.00064	6.13	0.01646	0.00101	6.12	1.333×10^{-4}	8.15×10^{-6}	6.11
IL-IJ	0.00768	0.00079	10.28	0.01268	0.00016	1.22	1.026×10^{-4}	1.30×10^{-6}	1.27

Table 5. Statistical summary of creep parameters compressive loading for the reconstituted asphalt samples

Road section	Static Creep						Compressive Load Bearing Response			
	Creep rate (mm/s)			Creep Strain Rate (s^{-1})			Peak load (kN)		Nominal compressive stress (MPa)	
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	Mean	SD
IF–ID	7.408×10^{-7}	2.004×10^{-7}	27.05	1.166×10^{-8}	3.156×10^{-9}	27.06	48.18	3.16	5.94	0.39
AR–IJ	7.198×10^{-7}	7.550×10^{-8}	10.49	1.134×10^{-8}	1.190×10^{-9}	10.50	26.62	13.96	3.28	1.72
OY–IK	7.383×10^{-7}	1.268×10^{-7}	17.18	1.158×10^{-8}	2.082×10^{-9}	17.98	69.15	45.36	8.53	5.59
IK–IS	8.105×10^{-7}	6.698×10^{-8}	8.26	1.285×10^{-8}	1.040×10^{-9}	8.10	40.02	27.38	4.94	3.38
AD–IW	8.725×10^{-7}	1.066×10^{-7}	12.22	1.374×10^{-8}	1.679×10^{-9}	12.22	54.25	7.69	6.69	0.95
IL–IJ	9.388×10^{-7}	1.142×10^{-7}	12.16	1.478×10^{-8}	1.798×10^{-9}	12.17	52.48	6.99	6.47	0.86