

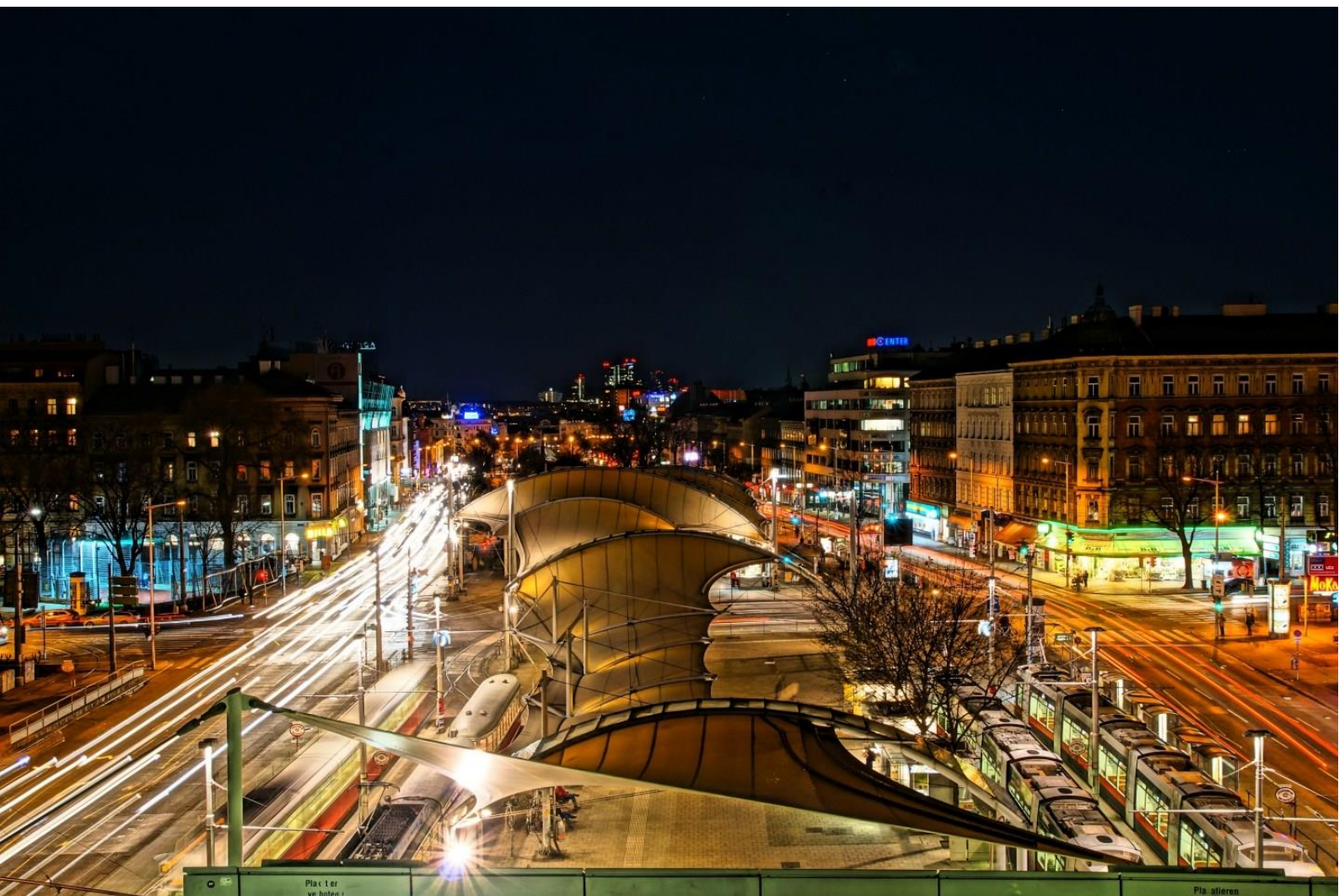
# EATA 2021

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## Book of Abstracts

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Research Center for Road Engineering  
Gusshausstrasse 28/230/3  
1040 Vienna, Austria  
phone: +43 1 58 801/233 01  
fax: +43 1 58 801/233 99  
e-mail: [eata2021@tuwien.ac.at](mailto:eata2021@tuwien.ac.at)  
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## **Change in properties of bitumen using rejuvenators with aromatics and saturates components due to repeatedly recycling**

Kawakami, A. \*; Nitta, H. \*; Kawashima, Y. \*; Tayu, F. \*; Yabu, M. \*

*\*Public Works Research Institute (PWRI)*

The recycling of asphalt pavement has been conducted as a common technology since 1970s in Japan, and the RAP ratio in recycled asphalt mixture has been increasing year by year. Therefore, the number of repeatedly recycling of RAP are also expected to increase. In this study, to investigate the characteristics occurring in repeatedly aged and recycled bitumen, bitumen was aged in a laboratory and then added the rejuvenators with different SARA component (especially aromatics and saturates components were focused) to restore the needle penetration for recycling. This process was repeated five times and material tests of these bitumen were conducted in each stage. In the results, depending on the SARA components of rejuvenator, these characteristics were remarkably different. Especially, the softening point of recycled bitumen increased remarkably when it was repeatedly recycled using a rejuvenator with saturates components. In the sludge amount test, which would be able to evaluate compatibility and homogenous mixing with aged bitumen and rejuvenator, rejuvenator with high aromatics components showed no significant increase in sludge amount compared with rejuvenator with high saturates components. The high temperature cantabro test which the authors expected to be able to evaluate the crack resistance at high temperature, revealed that the recycled bitumen used the rejuvenator with high saturates components had a reduced adhesive strength in the high temperature range.

Keywords: Bitumen; repeated recycling; rejuvenator; SARA component





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## Effect of anti-aging agents on rheological and chemical properties of asphalt binder

Guo, M.\*; Liu, H.\*; Liang, M.\*

*\*The Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education,  
Beijing University of Technology, Beijing*

Aging takes place in asphalt materials during the construction and service life of asphalt pavements and has a significant effect on their performance. In this study, rheological properties and chemical functional groups of asphalts modified by 5 different anti-aging agents were characterized by dynamic shear rheometer and Fourier transform infrared spectroscopy. The results show that 2<sup>#</sup> and 5<sup>#</sup> anti-aging agent have good resistance to increase of complex shear modulus, reduction of viscous flow characteristics and cracking risk caused by aging. It can be attributed to their ability to inhibit the formation of carbonyl and sulfoxide groups in the oxidation reaction of asphalt aging.

**Keywords:** Asphalt binder; aging; anti-aging agent; rheological properties; chemical properties



## Effects of chopped basalt fibres on the rheological properties of high viscosity bitumen (HVB) at high temperatures

Wu, X.\*; Kou, C.\*; Kang, A.\*; Xiao, P.\*; Wu, Z.\*

\*College of Civil Science and Engineering, Yangzhou University, Yangzhou 225127, China

\*\*Centre for Pavement and Transportation Technology, University of Waterloo,  
ON N2L 3G1, Canada

This paper investigates the effect of chopped basalt fibres on the high-temperature rheological properties of high viscosity bitumen (HVB). Basalt fibres (BF) with different lengths (9mm and 12mm) and contents (0%, 3% and 4% by weight of HVB) were added into HVB to prepare testing samples. The viscoelastic indexes and multiple stress creep recovery (MSCR) behaviours of all samples were evaluated by dynamic shear rheometer. The results show that the complex modulus  $G^*$  and the rutting factor  $G^*/\sin \delta$  of HVB were increased while the irrecoverable creep flexibility  $J_{nr0.1}$ ,  $J_{nr3.2}$  were decreased after adding a certain amount of basalt fibres, which indicate that a certain amount of basalt fibre improves the permanent deformation resistance and the elastic recovery ability of HVB. Besides, basalt fibres also reinforce the high temperature PG grade of HVB, the reinforcing effect of which is dependent on the content and the length of basalt fibres. Generally, the length and content of BF have a synergic effect on different test results. Last but not the least, FTIR analysis and a three-dimensional network structure observed through scanning electron microscope (SEM) presents the way how basalt fibres reinforce the rheological properties of HVB.

**Keywords:** High viscosity bitumen; basalt fibre; rheological properties; reinforcing effect; network structure

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## Effects of physical hardening on the rheological property and thermal stress of asphalt binders and their crystallization kinetics analysis

Xu, J.\*; Yang, Q.\*; Lin, J.\*; Wang, D.\*.\*\*

*\*School of Transportation Science and Engineering, Harbin Institute of Technology,  
Harbin 150090, P.R. China*

*\*\*Institute of Highway Engineering, RWTH Aachen University, Mies-van-der-Rohe-Street 1,  
52074 Aachen, Germany*

This paper aims to reasonably evaluate the reversible aging resistance of asphalt binders, and to study the effect of physical hardening on the low temperature performance of asphalt binders. To this end, four different types of asphalt binders were selected for the extended bending beam rheometer (EBBR) test under different conditioning times. The thermal stress was calculated based on the rheological data obtained from the EBBR test and the data was fitted using the generalized Maxwell model to study the effects of low temperature physical hardening on the cracking resistance and rheological properties of the binders, respectively. The Avrami isothermal crystallization kinetics theory was used to analyze the reversible aging process of asphalt binders when the conditioning time was extended under constant temperature. The results show that with the extension of the conditioning time, the low temperature performance of asphalt continues to decline, which is manifested by higher grade loss, relaxation time, thermal stress and critical cracking temperature. The effect of physical hardening on asphalt is not necessarily related to the low-temperature performance of asphalt, but mainly depends on the source of crude oil. Lastly, the Avrami isothermal crystallization kinetic theory can accurately characterize the physical hardening tendency of asphalt binders.

**Keywords:** Physical hardening; reversible aging; crystallization kinetics; low-temperature performance; thermal stress; asphalt binder

## Investigation of the GFRP powder reinforced bitumen and its performance

Hong, B.\*; Lin, J.\*; Fan, Z.\*\*; Yang, Q.\*; Li, T.\*; Lu, G.\*\*; Wang, D.\*\*\*

*\*School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin 150090, P.R China*

*\*\*Institute of Highway Engineering, RWTH Aachen University, 52074 Aachen, Germany*

The glass fiber reinforced polymer (GFRP) composites are widely used in various fields, which has produced a lot of waste GFRP composites in the process of producing and using. These waste GFRP composites have led to a great burden on the environment due to their excellent corrosion resistance. Therefore, the recycling of the waste GFRP composites is a concern. In this article, the waste epoxy-based GFRP composites were processed into powder with diameters of less than 0.075 mm to enhance the performance of bitumen used as the binder of pavement materials. For this purpose, the modification method of the waste GFRP reinforced bitumen and its performance were systematically investigated. The results showed that the optimal reinforcement method is to surface treat the GFRP powder first using the silane coupling agent to improve its adhesivity with the bitumen and then add the modified powder by 6 wt.% to the bitumen by mechanical agitation. The addition of the surface treated GFRP (S-GFRP) powder has significantly improved the high- and medium-temperature performance of bitumen. Moreover, the S-GFRP powder has enhanced the elasticity of bitumen as well as reduced the permanent deformation of bitumen. The S-GFRP powder has also enhanced the water resistance of bitumen mixtures. In addition, the above beneficial effects increased with increasing dosage of the S-GFRP powder with the experimental range from 2% to 6%. The present method might resolve the recycling of the waste fiber reinforced polymer (FRP) composites and further promote the new road materials with excellent performance.

**Keywords:** GFRP composites; recycling; bitumen; powder; reinforce





## Natural bitumen Selenizza®SLN – an optimal additive for the implementation of high-performance asphalt mixes

Tartari, E.\*

*\*Selenice Bitumi Sha*

The present paper intends to raise awareness of road construction professionals about the potentiality of natural asphalts used as bitumen modifiers to implement high modulus asphalt mixes characterized by high stiffness, high durability, superior resistance to permanent deformation and good fatigue resistance. Research studies have shown that natural asphalts are totally compatible with straight run bitumen and contribute to increasing the consistence, viscosity and stability of natural asphalt modified binders. Blending natural asphalt with soft bitumen from refineries can successfully contribute to the production of hard binders. In particular, the analysis of road bitumen modified with natural asphaltite Selenizza®, extracted from the deposit located in southeast Albania, showed that the resulting binders are also resistant to aging and relatively efficient at low temperatures. An experimental campaign conducted on natural bitumen-based asphalt mixes, showed that the use of Selenizza® leads to an improvement of mechanical and rheological properties compared to reference asphalt mixes produced with equivalent traditional paving grade bitumen. A Life Cycle Assessment has estimated the environmental impact of the Albanian natural asphalt production process which results in a reduction by approximately 44 % of CO<sub>2</sub> emission compared to the conventional bitumen production from crude oil.

Keywords: Natural bitumen; bitumen modification; high modulus asphalt concrete (HMAC); bitumen aging; CO<sub>2</sub> emission

## Study on the composite reinforcement mechanism of bitumen with combined carbon nanotube and graphene

Yang, Q.\*; Fan, Z.\*\*; Lin, J.\*; Wang, D.\*\*\*; Oeser, M.\*\*

*\*School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin 150090, P.R. China, Institute of Highway Engineering*

*\*\*RWTH Aachen University, Mies-van-der-Rohe-Street 1, 52074 Aachen, Germany*

The poor dispersion of carbon nanomaterial as well as its weak interfacial interaction with bitumen matrix have significantly weakened the reinforcement effect of carbon nanomaterial on bitumen composite. In this study, the hybrid graphene/ carbon nanotube (CNT) composites were used to reinforce the bitumen matrix, and were found to improve the dispersion as well as the interfacial interaction between carbon nanomaterials and the bitumen matrix. Comparing to the control bitumen, a graphene/bitumen composite and a CNT/bitumen composite, the hybrid graphene with CNT, greatly improved the rutting resistance, the creep and recovery behavior, the permanent deformation resistance, the low-temperature cracking resistance and the degree of crosslinking in the bitumen. In particular, bitumen binders with 0.2 wt% graphene and 0.8 wt% CNT composite exhibited the best performance. The improvements can be attributed to synergies and the formation of 1D-2D hybrid structures, which not only increases the contact area, but also provides an effective stress transfer between graphene/CNT and bitumen at the interface.

**Keywords:** Carbon nanotubes; graphene; synergetic effects; rheological property; low-temperature performance



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## Testing conditions for asphalt binder testing using dynamic shear rheometer with 4 mm diameter parallel plate geometry

Büchner, J.\*; Sigwarth, T.\*; Wistuba, M.\*

*\*Braunschweig Pavement Engineering Centre (ISBS), Technische Universität Braunschweig, Beethovenstraße 51b, 38106 Braunschweig, Germany*

No standard procedure is available for low temperature asphalt binder testing in the Dynamic Shear Rheometer. In this study, an overview is given of the necessary equipment to use the 4 mm geometry for asphalt binder testing including an explanation of shear compliance correction. Furthermore, the testing conditions of 4 mm geometry including specimen preparation, specimen conditions and test parameters are evaluated. Additionally, practical tips and screenshots on the implementation of recommended parameters and testing conditions in the software rSpace and RheoCompass are provided. Overall, this paper provides extended information and guidelines on how to use the 4 mm geometry and which testing conditions to consider for testing asphalt binder in the low temperature range.

Keywords: Dynamic shear rheometer (DSR); 4 mm geometry; low-temperature; testing conditions; sample conditioning; shear compliance





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## Effect of activation of polymer modified bitumen in RAP on resistance to permanent deformation

Liphardt, A.\*; Konieczna, K.\*; Król, J.B.\*

*\*The Faculty of Civil Engineering, Warsaw University of Technology, Warsaw, Poland*

The paper presents the test results of SMA mixtures containing RAP derived from selective milling of a ten-year SMA layer. Aggregate blends with a non-continuous gradation and different RAP aggregate content ranging from 0% to 50% were developed. During laboratory mix production, neat bitumen and PMB were used as reference binders. Based on the results obtained for the polymer modified bitumen recovered from RAP, it was determined that its aging level is comparable with reference bitumen after RTFOT. MSCR tests were conducted to evaluate the potential for permanent deformation of the blends of reference and RAP binder. SMA samples were tested for permanent deformation by wheel-tracking test and creep using uniaxial cyclic compression test. Based on the conducted SMA mixture tests, it was confirmed that in the mixtures containing different amounts of RAP, the polymer modified bitumen from RAP could be activated by virgin binder and temperature resulting in the improvement of the mixture's rutting performance. Finally, it was concluded that the SMA resistance to the permanent deformation is not related to its stiffness but modification by the polymer provided by reclaimed binder from RAP.

Keywords: RAP; SMA; recycling; permanent deformation; creep test



## Methodology of an empirical description of filler activity in bituminous mastics

Stoklásek, S.\*; Dašek, O.\*; Všianský, D.\*\*; Varaus, M.\*

*\*Brno University of Technology, Faculty of Civil Engineering, Institute of Road Structures,  
Veverí 331/95, 602 00 Brno, Czech Republic*

*\*\*Masaryk University, Faculty of Science, Department of Geological Sciences,  
Kotlářská 267/2, 611 37 Brno, Czech Republic*

The combination of bitumen and fine aggregate (filler) called “mastic” represents a composite binder of asphalt mixtures. This methodology proposes general parameters of filler which reflect the activity of filler in mastics. The new descriptive classification is based on the determination of various types of critical fractional volumes, which are an authentic reflection of the intrinsic qualities of filler. The fractional volumes were derived from the projection of the rheological properties of the individual points of the mastics concentration series and thus one numerical parameter can characterize the properties of the filler in a wide concentration range. This approach exploits some known procedures and test methods, which allow assessing the type and intensity of the direct interaction of filler with a bituminous binder. A dynamic shear rheometer was applied to study mastic materials over a broad concentration span in two application temperature ranges and two test configurations. The Multiple Stress and Creep Recovery test (MSCRT) covers the medium temperature range (deformation resistance); the high-temperature range of the mastic material is examined by rotational viscosity (processibility). The paper clarifies the nature of the proposed parameters and their relation to the mastic properties and the filler classification system. The system can be used in solving practical problems associated with the rheological behaviour of mastics or asphalt mixtures.

**Keywords:** Mastic; mineral filler; critical concentration volume; MSCRT; viscosity



## **A comparative study of bitumen microscale morphology using atomic force microscopy and laser scanning confocal microscopy**

Blom, J.\*; Hasheminejad, N.\*; Vuye, C.\*

*\*Faculty of Applied Engineering, EMIB research group, University of Antwerp,  
171 Groenenborgerlaan, Antwerp, 2020, Belgium*

Bituminous binders can display a rich microscale morphology, including the so-called bee structures. In literature, a strong relationship has been observed between the presence of paraffin wax crystals and the appearance of bee structures, mainly by using Atomic Force Microscopy (AFM) measurements. The most common AFM testing mode is the tapping mode, and although this is described as a non-contact measuring method accidental collisions between the vibrating cantilever nanotube and the bitumen surface can occur. Additionally, the AFM tapping mode is only applicable when the viscosity of the specimens is high enough, which is highly dependent on the environmental temperature. In this research, a Laser Scanning Confocal Microscope (LSCM) is evaluated for its capability to investigate the microscale morphology of five bitumen, including so-called bee structures, and compared to the observations made with the AFM technique.

Keywords: Bitumen; atomic force microscopy (AFM); laser scanning confocal microscopy (LSCM); micro-scale morphology; bee; artefacts



## **Analysis of cracking mechanisms by the example of a test track using finite element simulation and design life calculation**

Blasl, A.\*; Zeißler, A.\*; Wellner, F.\*

*\*Institute for Pavement and Urban engineering, Technical University of Dresden,  
Dresden, Germany*

In 2008 an undersized test track with only two asphalt layers instead of regular three asphalt layers was realised to provoke an early destruction of the track. The goal was to investigate the influence of a reduced asphalt pavement thickness on service life in just a couple of years and to compare the field data with the predicted service life for the same pavement, especially taking into account fatigue cracks. The case study made it possible to validate and evaluate the applied prediction method, which is currently the only known method of calculating expected service life in terms of years. In 2019 fatigue cracks along the roadway were analysed by cores drilled out from the crack areas. Some cores showed cracks running completely through the entire asphalt construction. Other cores showed cracks that occurred only in the wearing course. To understand the correlation between crack type or crack propagation and stress and strain conditions within the test track the cores, respectively cracks, were secondly analysed by numerical investigations using the finite element method. Therefore the temperature and frequency dependent mechanical performance of the asphalt materials in the different pavement layers was investigated and used along with local traffic and temperature dependent conditions as input data for numerical investigations and design life calculations to determine the damage accumulated during service time. Finally the observations in situ were compared with the results of the numerical analyses of the stress and strain conditions in pavement and of the service life predictions.

**Keywords:** Asphalt pavement; crack mechanism; finite element simulation; service life predictions; case study

## **Influence of ultraviolet radiation on the rheological properties and the structure of non-modified bitumen**

Schwettmann, K.\*; Nytus, N.\*\*; Stephan, D.\*; Radenberg, M.\*\*

*\*Group of Building Materials and Construction Chemistry, Technische Universität Berlin*

*\*\*Field of Road Construction, Ruhr-Universität Bochum*

The ageing process during asphalt mix production, transportation and service life leads to changes in chemical and physical properties of bitumen. The long-term ageing commonly is simulated in the laboratory by the PAV method, however there are differences between the effects of the ageing simulation and the ageing in-situ. Oxidative ageing is also intensified by exposure to ultraviolet (UV) radiation. For this reason, the influence of UV light on the rheological properties and the structure of bitumen was analysed, measured with the Dynamic shear rheometer (DSR) and Fourier transform infrared (FTIR) spectroscopy. Three different kinds of UV exposure were used and the results were compared with conventional ageing methods. The average intensities of the UV lamps ranged from 1,000 W/m<sup>2</sup> to 10,555 W/m<sup>2</sup>. The used materials were three non-modified bitumen samples, paving grade 50/70, from three different sources. The samples were available in six different artificially produced ageing states, on which the influence of UV radiation was examined. During the test series, the layer thicknesses of the samples were changed and the distance between the samples and lamps was varied. The results show that the increase in the stiffness of the binder, when simulated with the conventional ageing methods, cannot be achieved with pure UV exposure. This study is part of the research project "Post carbon road – The endless cycle of bitumen reuse" funded by the German Research Foundation (DFG). The purpose of this project is to investigate a cyclical reuse of bitumen using different rejuvenators.

Keywords: Ultraviolet radiation; ageing; bitumen; rheology; DSR; FTIR spectroscopy



## Field aged and laboratory aged polymer-modified asphalt binder –investigation with fluorescence spectroscopy

Koyun, A.\*; Büchner, J.\*\*; Wistuba, M.\*\*; Grothe, H.\*

*\*Institute of Materials Chemistry, TU Wien, Getreidemarkt 9/BC, A – 1060 Vienna, Austria*

*\*\*Braunschweig Pavement Engineering Centre (ISBS), Technische Universität Braunschweig, Beethovenstraße 51b, D - 38106 Braunschweig, Germany*

Numerous factors affect the lifespan of asphalt roads, such as the climate, traffic and whether or not the owner performs routine maintenance. Ageing is caused by mechanical stress (steric or physical hardening), through rain water including oxidizing agents, thermal oxidation, solar radiation and reactive oxygen species (ROS) in the atmosphere. While mechanical stress also plays a crucial part in this study we are focusing on the oxidants from the atmosphere. Standardized binder tests such as rolling thin film oven test (RTFOT) and pressure ageing vessel (PAV) address mechanical and thermal oxidation, while UV radiation and ROS are neglected. The interaction of ozone and UV light with volatile organic compounds (VOCs) in the atmosphere leads to the formation of OH radicals and many other oxidants such as HONO. These compounds are key species in photochemical cycles, which are responsible for the so called "photochemical smog". With OH radicals known to be as very powerful oxidizing agents for organic compounds, they are neglected in PAV and RTFOT testing methods. Here we demonstrate the power of UV and ROS ageing and highlight the importance of implementing these factors to the existing standardized testing methods. Last but not least, the penetration depth of oxidants into the binder is demonstrated with fluorescence spectroscopy. Characteristic chemical shifts which are unique for UV ageing have been found with progressive ageing that are missing in PAV and RTFOT ageing methods.

Keywords: Photochemical ageing; UV; reactive oxygen species; fluorescence spectroscopy

## Swelling and absorption of crumb rubber aggregates incorporated in bituminous mixtures

Mahmoudi, Y.\*; Mangiafico, S.\*; Sauzéat, C.\*; Di Benedetto, H.\*; Pouget, S.\*\*;  
Loup, F.\*\*; Faure, J.-P.\*\*\*

*\*University of Lyon / ENTPE, Lyon, France*

*\*\*Eiffage Infrastructures, France; \*\*\*Aliapur, France*

When it comes to bituminous mixtures produced with incorporation of Crumb Rubber (CR) aggregates, it is vital to understand the bitumen-rubber interactions occurring, in the case of both wet and the dry processes. If adequate contact time and temperature are maintained, these phenomena allow the modification of bitumen by crumb rubber in the wet process. However, even in limited extent, their effects are not negligible in the dry process as well. In order to evaluate swelling and absorption of crumb rubber aggregates incorporated by dry process in bituminous mixtures, several experimentations were conducted. CR aggregates with a continuous 4/8 mm grain size distribution were immersed during 2 and 7 days in an aromatic oil bath and oil absorption and swelling ratios were determined by the pycnometer method. Identical CR aggregates batches were mixed with bitumen using different procedures and grading curves of CR aggregates coated with bitumen were determined. The swelling of a slab made of a bituminous mixture with 2% of CR incorporated by dry process was finally investigated during 7 days.

Keywords: Crumb rubber; swelling; absorption; bituminous mixtures; aromatic oil; bitumen



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## Thermodynamic sorption and kinetic transport of water in bitumen

Ma, L.\*; Varveri, A.\*; Jing, R.\*; Erkens, S.\*

*\*Faculty of Civil Engineering and Geosciences, Delft University of Technology,  
Delft, Netherlands*

Moisture can be detrimental to the mechanical performance of pavement by interacting with bitumen and aggregates. The presence of moisture in bitumen and at the bitumen-aggregate interface influences the cohesive and adhesive properties, respectively, which are critical for long-term performance and pavement durability. This paper aims to investigate the kinetic transport and thermodynamic sorption of moisture in bitumen. The non-Fickian sorption behavior is discussed and three models, two separated surface-bulk transport models and an integrated transport model, were introduced to describe the moisture transport kinetics in bitumen. Moisture clustering behavior was also discussed to explain the high water sorption amount in bitumen at high relative humidity. The finite element method was used to solve the moisture transport models and the optimized transport parameters were derived on the basis of gravimetric experimental data. The kinetics models show a good fitting over the entire range of relative humidity and provide a mechanistic interpretation of the transport process. The transport models are expected to be able of predicting the moisture behavior of bitumen.

Keywords: Moisture; transport; sorption; clustering; bitumen

## **Influence of temperature on global and local elastic and strength properties of bituminous stabilized material**

Preti, F.\*\*\*; Dave, E.V.\*; Sias, J.E.\*; Romeo, E.\*\*; Tebaldi, G.\*\*

*\*Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH*

*\*\*Department of Architecture and Engineering, Università di Parma, Parma, Italy*

Bituminous stabilized materials (BSM) are often defined as partially bounded materials since the bitumen content is usually limited to 2% by weight of mix. Nonetheless, temperature susceptibility cannot be neglected when dealing with a material containing bitumen. Therefore, the purpose of this research study was to analyse the influence of test temperatures on mechanical properties of a BSM prepared with bituminous emulsion and hydrated lime. Triaxial shear strength tests were performed at different temperatures and subjecting the material to different confining pressures to obtain the force-displacement curves of BSM (global response). Finite element simulation models were developed for the triaxial shear strength tests, the global responses from laboratory tests were used as objective functions in finite element models to extract stress-state and temperature dependent local elastic and strength mechanical properties. It was found that both cohesion values in BSM decreases when the test temperature is increased; in addition, the finite element simulation showed that local cohesion is not a constant parameter, but it is closely related to the intensity of the applied lateral confining pressure stress. As expected, internal friction angle was minimally affected by testing temperature for the range of temperatures considered in the study.

**Keywords:** Bituminous stabilized materials; triaxial shear strength test; finite element modeling; Mohr-Coulomb theory; cohesion; confining pressure



## Modelling asphalt binder fatigue at multiple temperatures using complex modulus and the LAS test

Chen, H.\*; Bahia, H.\*

*\*Department of Civil and Environmental Engineering, University of Wisconsin-Madison, Madison, USA*

The linear amplitude sweep (LAS) test is considered a useful tool for evaluating the fatigue of asphalt binders, and its correlation with mixture fatigue performance has been confirmed in a few studies. While effects of load or strain level is well studied and modeled, the effects of temperatures remain difficult to explain or to model in a simple format. In this paper, the combined effects of strain and temperature are investigated and a method for estimating binder fatigue behavior at different temperatures from limited measurements is introduced. LAS tests were conducted on several different PG grade binders at four different temperatures. It is found that binder fatigue damage parameters  $C_1$  and  $C_2$  have a good linear relationship with temperature when using the dissipated pseudo-strain energy approach. The results also show that LAS parameters A and B at different temperatures maintain a linear relationship with the binder complex modulus ( $G^*$ ) measured at corresponding temperatures. Therefore, a new fatigue life model accounting for strain level and temperature is proposed using a power function of the binder  $G^*$ , which can account for temperature effects. To verify the model, its parameters are fitted using test data at two temperatures and used to predict the fatigue life at additional temperatures. This study findings offer a simpler and reliable method to predicted values of fatigue life at new temperatures using both 35% damage level and maximum stress failure criteria that are recommended in AASHTO TP101-12 and AASHTO TP101-14, respectively. The new prediction method will allow wider use of the LAS procedure in regard to effects of temperature and strain level for which binders are subjected to in the pavement.

**Keywords:** Linear amplitude sweep; pseudo-strain energy; strain level; failure criterion; fatigue prediction; temperature



## Phase-compatibility of bitumen defined through deconvolution of modulated differential scanning calorimetry response

Tabatabaee, H.A.\*; Sylvester, T.\*; Calcanas, C.\*

*\*Cargill, Incorporated – BioIndustrial Business, Minneapolis, USA*

With increasing use of complex binders from various manufacturing processes, higher recycled bitumen contents, and use of various additives and recycling agents, the ability to assess bitumen compatibility is more important than ever. Continuum rheological parameters and solvent-extracted fractional ratios have been used as empirical indices for bitumen compatibility, however direct analytical measures of bitumen phase compatibilization and sol/gel morphology without the complication of solvent disturbance continues to be elusive. The present study investigates bitumen compatibility through use of miscibility principles based on the number of discernible glass transition occurrences in the blend. A quantification method was devised through the deconvolution of the modulated differential scanning calorimetry (MDSC) response. Analysis of virgin, recycled, and rejuvenated binders at various aging levels demonstrates the promise of the proposed parameters and analysis framework as a quantified analytical measure of the compatibility of complex bitumen that may be used for validation of future relevant specifications.

Keywords: Bitumen compatibility; aging; rejuvenation; glass transition



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## Preliminary assessment of linear amplitude sweep (LAS) testing using automated digital image analysis

Aurilio, R.\*; Aurilio, M.\*\*; Baaj, H.\*

*\*Centre for Pavement and Transportation Technology (CPATT), University of Waterloo,  
Waterloo, Canada*

*\*\*Yellowline Asphalt Products Ltd., Hamilton, Canada*

Fatigue cracking is caused by repetitive traffic loading by heavy or multiple axle vehicles at intermediate temperatures. Using the dynamic shear rheometer (DSR), fatigue resistance of bituminous binders was initially characterized by conducting time sweep tests at low strain amplitudes. Over the past decade, the linear amplitude sweep (LAS) test has become accepted as a viable alternative to the more traditional time sweeps. Instability flow, or “necking”, occurs due to increasing normal forces during continuous shearing. This results in a change in geometry which leads to an artificial decrease in stiffness. This decrease in stiffness may be misinterpreted as the accumulation of fatigue damage. In this study, instability flow was characterized using automated digital image analysis techniques to determine the flow strain amplitude (FSA) of a locally-sourced PG 58-28 binder at three ageing conditions (unaged, RTFO, and RTFO+PAV) during the LAS test. The FSAs for each ageing level were then compared against four LAS failure criteria (peak pseudostrain energy, peak shear stress, peak CN and peak  $C^2N(1-C)$ ). Results indicate that less aged binders experience flow at smaller FSAs, while minimal flow is observed for the long-term RTFO+PAV aged samples. Similarly, the first observable flow occurs at strain amplitudes significantly lower than all failure criteria for unaged and short-term aged binders while long-term aged samples exhibit flow at strain amplitudes beyond the most conservative failure criteria. Consequently, it can be concluded that the existing failure criteria may not capture the flow behaviour of less aged bitumen samples.

Keywords: Linear amplitude sweep (LAS); fatigue; instability flow; failure criterion



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## The unexpected addition of materials to bitumen in the Netherlands

Besamusca, J.\*; Poeran, N.\*\*; Sluer, B.\*\*

*\*Kuwait Petroleum R&T, Europoort, the Netherlands*

*\*\*Boskalis Nederland QRS, Nieuw-Vennep, the Netherlands*

The global transition to a sustainable future has led to the development of all types of binders, binder additives and to the extended use of waste products such as REOB/VTAE, roofing shingles and waste tires. Bitumen used for road construction is limited by European or US Superpave specifications. Additional material, like waste tires, shingles or REOB, is not bound to any specification and will therefore, not perform in a consistent way. Type testing might show good results but asphalt production can differ due to change in additional materials. This paper shows an example of premature failure, most probably due to the addition of REOB/VTAE without informing the contractor. It also shows the limitation of current test methods in specifications and the use of the promising  $\Delta T_c$  method.

Keywords: Bitumen; waste; asphalt failure



## **Durability assessment of RAP asphalt mixture using SATS conditioning procedure**

Iwama, M.\*; Hayano, K.\*

*\*Yokohama National University, Institution of Urban Innovation*

Recent trends in construction have placed a greater emphasis on infrastructural durability and performance during service. Generally, the characteristics of infrastructural asset are assessed in laboratories and on-site experimentation before construction. This applies to asphalt pavement construction, which is subject to accelerated traffic loads over long periods. However, despite assessments to select better materials, asphalt pavements are observed on site to suffer distress relatively quickly. This issue appears to be exacerbated when subject to the rising temperatures and torrential rain due to recent environmental issues, such as global warming and climate change. Also, it is important to ensure the long-term performance of asphalt mixtures to conserve natural resources. This requires durability assessments with due consideration for these recent issues focused on stiffness, fatigue and aging. This study examines the durability assessment of reclaimed asphalt mixtures using the Saturation Aging Tensile Stiffness (SATS) conditioning procedure. In this research, the effects of the binders used for three types of asphalt mixtures – conventional asphalt mixture, reclaimed asphalt mixture, and warm-mix asphalt mixture – were studied experimentally. This required the binder properties to be tested before and after SATS conditioning as per the test devised by the University of Nottingham. Furthermore, stripping resistance of the test samples was also assessed. The study concludes with an assessment of the relationships between the various parameters tested and their effects on the characteristics of the asphalt mixtures.

Keywords: Reclaimed asphalt mixture; warm-mix asphalt; moisture sensitivity; rejuvenator; mechanical properties



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## Study on test parameters and design optimization of high modulus asphalt mixture

Gong, Y.\*; Chang, R.\*; Yan, E.\*; Zhou, Z.\*; Luo, K.\*

*\*Research Institute of Highway, Ministry of Transport, Beijing 100088, China*

According to the high modulus asphalt mixture Marshall tests, the effects of four parameter, modifier dry mixing time, mixing temperature, asphalt mixture mixing time and compaction temperature on the performance of asphalt mixture were studied. The parameters optimization suggestions for the high modulus asphalt concrete Marshall tests were put forward. The dry mixing time of modifier and aggregate should be controlled in 15 s, the mixing temperature should be controlled in about 170 ~ 175 °C, asphalt and aggregates mixing time is 150 ~ 210 s, compaction temperature should be controlled in 160 ~ 165 °C. Through the research of the design for high modulus asphalt mixture, the improved high modulus asphalt mixture Marshall design method and process were put forward. The study provides a reference for the field construction and application of high modulus asphalt mixture.

Keywords: Road engineering; high modulus asphalt concrete; Marshall test; parameter correction.





## Effect of short term oven conditioning and incorporation of 60% reclaimed asphalt on performance of warm mix asphalt

Rathore, M.\*; Haritonovs, V.\*\*; Zaumanis, M.\*\*\*

\**Celū Eksperts, Apeņu iela 1, Ikšķile, Ikšķiles novads, LV-5052, Latvia*

\*\**Faculty of Civil Engineering, Riga Technical University, Riga, Latvia*

\*\*\**Empa Swiss Federal Laboratories for Materials Science and Technology, Überlandstrasse 129, CH-8600, Dübendorf, Switzerland*

Incorporation of high content of reclaimed asphalt (RA) material into warm mix asphalt (WMA) is known to provide synergetic benefits. The main objective of this study is to compare the performance of WMA mixtures containing 0% and 60% RA material to conventional hot mix asphalt (HMA). In addition, impact of short term oven conditioning of mixture on mixture performance was also determined. The performance of mixtures in terms of rutting, low temperature cracking and moisture susceptibility was evaluated. Based on the test results, a mixing temperature of 125°C was found to be suitable for producing WMA mixture with performance comparable to HMA mixtures. The incorporation of 60% RA material reduced both the high temperature and low temperature performance of the mixtures. Finally, the short term conditioning of mixtures had a significant effect on rutting and low temperature cracking performance.

Keywords: WMA; RA; RAP; rutting; TSRST; additive

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## **A preliminary experimental application of cigarette filters as stabilizing fibres for asphalt concretes**

Tataranni, P.\*; Sangiorgi, C.\*

*\*University of Bologna, Department of Civil, Chemical, Environmental and Material Engineering*

The massive consumption of cigarettes all over the world made the cigarette butts one of the most common waste, which is generally landfilled and incinerated. In the last years, different recycling methods and applications have been tested in order to find solutions in line with the circular economy principles. In this paper, the use of grinded cigarette filters is proposed as sustainable alternative to the addition of fibres within Asphalt Concretes (ACs). The use of fibres is a common practice for the production of high bitumen content mixtures such as Splittmastix Asphalt (SMA) and Porous Asphalt. The fibres has the double function of stabilizing agent, avoiding the separation between the aggregates and the bitumen during the storage and transport operations, and improve the mechanical performances of the final AC. In order to evaluate the effects given by the addition of the grinded cigarette filters in the bituminous mixture, two different SMAs were produced in lab and tested. The first, named SMA0, with traditional cellulose fibres was taken as reference mixture. The latter was the experimental mixture (SMAF), produced with grinded cigarette filters. Tests show interesting and promising results, making the use of cigarette filters a viable potential alternative to common cellulose fiber for ACs.

Keywords: Cigarette filters; cigarette butts; asphalt concrete; SMA; fibres

## Fatigue laboratory test on asphalt reinforcement systems

Mannsbart, G.\*; Ruiz, A.\*\*

\*TenCate Geosynthetics, Linz, Austria

\*\*Ciesm INTEVIA, Madrid, Spain

Fatigue behaviour of asphalt reinforcement and the improvement of lifetime has been studied by execution of various laboratory tests. A series of bending beam tests was carried out for different asphalt interlayer systems, comparing different raw materials for the filaments used. Fatigue strength is tested by repeated loading below rupture strength. Both reinforced and unreinforced samples have been tested. Fatigue failure is defined by the number of cycles necessary to reduce the stiffness of the test piece in half – to a percentage of 50% of its initial value. Test configuration consists of a three-point bending test on prismatic shaped specimens, supported at its ends and held in the centre, which is loaded to a displacement of this centre according to a sinusoidal function. Usually the tests are carried out at 20 °C and 10 Hz, but any temperature between (-20 and +30°C) and any frequency up until 40 Hz, depending on the material tested could be applied. To keep the results simple one standard configuration of frequency and temperature was studied.

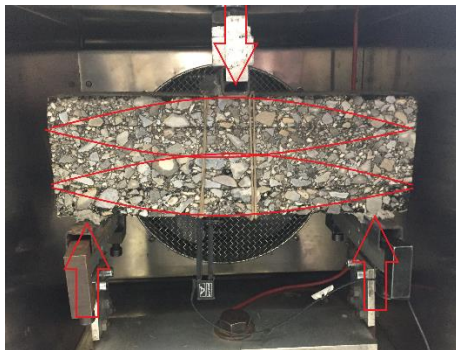


Fig. 1 Loading and deformation scheme

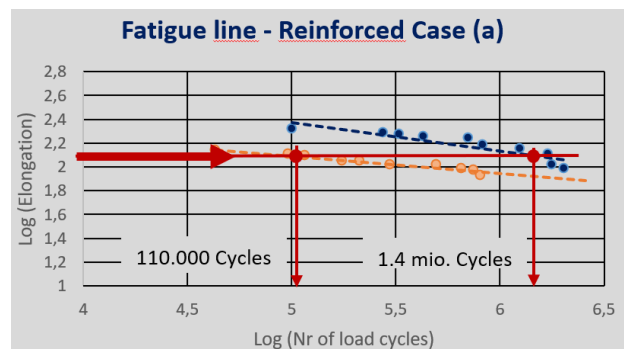


Fig. 2 Fatigue line for multi-functional composite

The results are presented as number of load cycles for a deformation of 100 Microstrain. For a multi-functional composite material, the number of load cycles was improved from 400.000 to 3,5 mio. This may be interpreted as an increase in lifetime by a factor of 8. The test results show a considerable improvement of fatigue strength for a continuous filament nonwoven with glass fibre reinforcement. Thus, the application of a geosynthetic is certainly beneficial to pavement performance.

**Keywords:** Road rehabilitation; asphalt reinforcement; fatigue strength; reflective cracking; pavement repair; asphalt interlayer system

## Effects of recycled concrete aggregate (RCA) fraction replacement on cracking, rutting and surface texture of semi-dense asphalt (SDA)

Mikhailenko, P.\*; Piao, Z.\*\*\*; Kakar, R.\*\*\*\*\*; Bueno, M.\*; Poulikakos, L.\*

*\*Empa, Swiss Federal Laboratories for Material Science and Technology, Dübendorf, Switzerland*

*\*\*ETH Zurich, Swiss Federal Institute of Technology Zurich, Institute of Environmental Engineering, Ecological Systems Design, Zurich, Switzerland*

*\*\*\*Bern University of Applied Sciences, Department of Architecture, Wood and Civil Engineering, Bern, Switzerland*

In order to improve the sustainability of the low-noise Semi-Dense Asphalt (SDA) surface layer, the aggregate fractions were replaced by recycled concrete aggregates (RCA), a waste material with a very high production volume. The aggregate replacement was conducted by fractions of 2/4 and 0.125/2 mm corresponding to the 2/4 mm (coarse), 0.063/4 mm (sand) fractions of the control aggregates, at about 15% replacement by volume of the control mixture for each fraction. Additionally, RCA filler was replaced at 100% of the control filler, bringing the replacement level to over 20% of the total mixture. The binder was added at the same amount as of the control binder and +0.5%, with additional binder compensating for the estimated increase in binder absorption in RCA aggregates. The wheel track rutting test indicated marginally improved performance with RCA sand replacement. However, low temperature semi-circular bending (SCB) test at 0°C showed that there is a 10% reduction in cracking resistance using RCA course and 20% for RCA sand. The laser texture scanning indicated a small reduction in the texture level before wheel tracking, and very similar texture profiles after the wearing of the samples. This study suggests that the use of RCA fractions in porous SDA surface mixtures should be moderated.

**Keywords:** Recycled concrete aggregates (RCA); semi-dense asphalt (SDA); semi-circular bending (SCB); rutting; surface texture





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## **Modelling self-heating of asphalt concrete under mechanical fatigue loading with heterogeneous microstructure**

Benaboud, S.\*; Allou, F.\*; Dubois, F.\*; Takarli, M.\*

*\*Laboratoire GC2D, Université de Limoges, 17 Bd J. Derche, 19300 Egletons, France*

Asphalt concrete (AC) is a heterogeneous material containing bituminous matrix and aggregates characterized by viscoelastic and elastic behaviours, respectively. The dependent time mechanical behaviour of AC is strongly dependent to the matrix behaviour characterized by a thermo-sensibility. Simulations are performed on cylindrical tension-compression tests assuming a radial heat transfer with axisymmetric description. Both thermal and mechanical aspects and their coupling are taken into account leading to a complete constitutive modelling. During the fatigue test, cyclic loading induces dissipated energy which is the source of self-heating of material and consequently the decrease of the bituminous matrix rigidity. An electro-mechanical analogy is proposed to determine the dissipated energy. Based on image processing approach, a heterogeneous microstructure is used to model the AC. Therefore, simulations are carried out on a regular mesh based on heterogeneous thermomechanical properties fields.

**Keywords:** Asphalt concrete; self-heating; viscoelasticity; heterogeneous simulation; fatigue



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## Laboratory study on warm mix asphalt based on binder, mastic and mixture testing

Cheraghian, G.\*; Klüter, I.\*; Büchner, J.\*; Büchler, S.\*; Wistuba, M.\*

*\*Braunschweig Pavement Engineering Centre (ISBS), Technische Universität Braunschweig, Braunschweig, Germany*

The objective of this laboratory study was to investigate a set of asphalt binders, asphalt mastics, and asphalt mixtures by different types of warm mix additives (chemical and organic). Performance of asphalt binders, asphalt mastics, and asphalt mixtures was evaluated using different types of binders, and aggregates. The laboratory performance tests included rheological tests for asphalt binder and mastic samples and Marshall test for asphalt mixture samples. The experimental results indicated that organic additives had a positive effect on the viscoelastic properties of the binder and mastic samples. In the asphalt mixture scale, the addition of chemical and organic had a negative effect on the deformation resistance. Moreover, the results indicated that organic warm mix additives can reduce 50 °C temperature in asphalt mixtures.

**Keywords:** Warm mix asphalt; rheological properties; asphalt binders; organic additive; asphalt mixtures

## Determination of dynamic modulus of cylindrical asphalt specimens using resonant acoustic spectroscopy

Kollmus, F.A.\*; Trifunović, S.\*; Grönniger, J.\*; Wistuba, M.P.\*

*\*Department of Civil Engineering – ISBS, Technische Universität Braunschweig,  
Braunschweig, 38106, Germany*

Conventional methods for determination of the dynamic modulus of asphalt mixtures are elaborate in terms of testing setup and analysis. A less time consuming alternative is studied in this paper, which is simple, fast and cheap, and applicable for day-to-day routine testing. The main objective of this study is to check the possibility of applying the resonant acoustic spectroscopy (RAS) for the determination of dynamic modulus of asphalt mixture. This paper contains the results of the dynamic modulus and the phase angle, determined by RAS. In addition, the influence of the measurement position on the results is investigated. An asphalt mixture of the type AC 11 is produced and compacted in the Marshall compactor according to EN 12697-30. Specimens with different air void contents are produced by variation of the number of blows (35, 50, 75 blows) applied to each side of the specimen. The RAS is performed for each specimen (12 in total) at 13 temperatures, starting at 40 °C and decreasing in 5 °C steps to -20 °C. Results show that the dynamic modulus of an asphalt concrete mixture can be determined by RAS and also the influence of different air voids content on the stiffness can be obtained by this test method. Furthermore, the results show advantages of this test method such as simplicity and repeatability. The main advantage over conventional dynamic modulus testing is that it is much faster and requires less expensive testing equipment and setup. The results of this research provide a good base for further application of this test method in situ.

Keywords: Resonant acoustic spectroscopy (RAS); impact resonance test (IRT); dynamic modulus; phase angle; asphalt mixture; asphalt concrete



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## Temperature controlled asphalt pavement to improve the permanent deformation resistance

Inestroza Mercado, A.I.\*; Hess, R.\*

*\*Durth Roos Consulting GmbH, Siegfriedstrasse 28, 53179 Bonn, Germany*

Permanent deformation is one of the main difficulties suffered by asphalt pavements due in part to the high temperatures occurring. The use of a network of pipes embedded in the pavement has been studied, which will allow reducing and controlling the temperature in the pavement and thus contribute to the resistance against permanent deformations. A finite element analysis was performed to investigate the temperature distribution in the pavement and evaluate the temperature reduction in the asphalt layers. The results show that the temperature of the asphalt pavement can be reduced and can be kept within a certain range taking into account the climatic variables. Furthermore, the reduction at the surface obtained is above 20%. The proposed numerical model can be used later for the selection of variables and parameters necessary for the implementation of the concept.

Keywords: Temperature distributions; permanent deformations; heat balance; surface temperature; finite element analysis





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## **How to avoid road damage with the help of modern transport technology - can it be an effective means for reaching our climate goals?**

Fliegl, M.\*

*\*Fliegl Bau- und Kommunaltechnik GmbH*

The European Union has decided to become the first climate-neutral continent in the world. In order to achieve this goal, greenhouse gas emissions must be reduced by 55% (compared to 1990) by 2030. Currently, up to 51 kg carbon emissions (CO<sub>2</sub>) are generated per ton of asphalt mixture. In addition to the effects of road construction on climate change, most countries allocate large portions of their budget into the development and maintenance of roads and highways. Sustainable and low-carbon road construction could therefore contribute both to economic welfare and climate protection. The reduction of production temperature of asphalt mixtures holds great potential in order to reduce greenhouse gas emissions, however beside economic, ecologic and occupational health benefits, there are challenges that must and can be solved when asphalt temperature is reduced. One of the challenges is temperature management to reduce temperature segregation. The presentation will show you how temperature management can be improved with the help of push-off technology as it effectively minimizes the risks of temperature segregation, and as a result, prevents road damages. Push-off technology could therefore be an important and contributing factor in building sustainable roads. Since push-off technology delivers asphalt mixtures with low temperature differences, it creates the opportunity to reduce the asphalt production temperature in order to build low carbon roads.

Keywords: Temperature management; carbon emissions; push-off technology

## Hot mix asphalts modifiers: SBS-copolymer, plastomeric compound, and graphene-enhanced asphalt modifier

Viscione, N.\*; Eskandarsefat, S.\*\*; Veropalumbo, R.\*; Venturini, L.\*\*; Russo, F.\*

*\*Department of Civil, Construction and Environmental Engineering, Federico II University of Naples, Via Claudio 21, 80125, Naples, Italy*

*\*\*Iterchimica S.r.l. Via Guglielmo Marconi, 21, 24040 Suisio (BG), Italy*

Soon after the road authorities and engineers understood the needs for high-performance asphalt pavements, different solutions have been introduced to reduce distresses. So, many asphalt modifiers have been introduced and projected, however, it should be considered that they are different in function and performance. In this research work, three different types of asphalt modifiers have been studied and compared, providing a comprehensive understanding of the mechanism of modification and the way they alter the asphalt mixture's properties. For this purpose, a series of dense-graded binder layer Hot Mix Asphalt (HMA) has been manufactured and tested after a mix design process, comparing the performance properties of commonly-used SBS Polymer modified Bitumen (PmB) mixtures with two polymeric compounds, one of which enhanced with Nano-graphene platelets, both added to the mixture, using dry method. According to the tests' results, the mixtures modified with graphene-enhanced asphalt modifier outperformed the other two mixtures. In detail, the eco-friendly HMA displayed both higher mechanical properties in terms of Indirect Tensile Strength (ITS) when compared to PMB mixture (+48%). In terms of water sensitivity, all the investigated alternatives exhibited good results however, the PMA mixtures showed an increment, compared to HMA containing neat bitumen and HMA with PMB mixture. the ITSM test results, confirmed that the outcomes of the conventional performance test (ITS), for both of the PMA mixtures show a higher ITSM values compared to the NB\_HMA and PMB\_HMA at 10°C and 20°C, while at 40°C the PMB\_HMA solution returns the highest value.

**Keywords:** Asphalt modifiers; hot mix asphalt (HMA); SBS polymer modified bitumen (PmB); polymeric compounds; nano-graphene platelets; dry method



## Study on sustainable road structure: mechanical and environmental approach

Król, J.B.\*; Bańkowski, W.\*\*; Kowalski, K.J.\*; Holt Andersen, B.\*\*\*; Komkova, A.\*\*\*;  
Casado Barrasa, R.\*\*\*\*

*\*The Faculty of Civil Engineering, Warsaw University of Technology, Warsaw, Poland*

*\*\*The Road and Bridge Research Institute, Warsaw, Poland*

*\*\*\*CWare, Waterloo, Belgium; \*\*\*\*Acciona Construcción Technology Centre, Madrid, Spain*

The principles of the circular economy are the basic determinants of the sustainable development of road construction. This paper presents a new concept of asphalt pavement structure with ecologically oriented attributes, significantly reducing the asphalt pavement carbon footprint while achieving a level of long term performance comparable or greater than that of conventional pavement structures. The sustainable pavement consist of the introduction of a BIO-additive that allows for the integration of higher percentage of RAP as an alternative to the traditional asphalt mixtures. In the sub-base the use of construction and demolition waste was adopted. The results were obtained from a full-size test sections of the road structure divided for reference and eco-innovative cases. Mechanistic analysis were performed for materials and pavement structure based on durability laboratory tests and on-site assessment. The new eco-design solution was subjected to a comprehensive LCA and LCCA analysis and summarised by SWOT assessment.

**Keywords:** Sustainable; road structure; RAP; bio-additive; LCA; LCCA; SWOT

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## Effect of aramid fibers on the mechanical characteristics of porous asphalt mixtures

Gupta, A.\*; Lastra-Gonzalez, P.\*; Castro-Fresno, D.\*; Rodriguez-Hernandez, J.\*

*\*GITECO Research Group, University of Cantabria, 39005 Santander, Spain*

The porous asphalt (PA) mixtures are known to be more sustainable due to its innumerable benefits of reducing the surface runoff and managing the stormwater. Moreover, PA mixtures provide a safe pavement surface for the vehicles by reducing the skidding and water splashing. The concerns of low durability due to high air voids ratio and continual presence of moisture in the surface course has led to its limited use. In this study, fibers were incorporated to improve the performance of the PA mixtures. Fibers included were: Regular aramid fibers of 6mm; 12mm length; aramid fiber with latex and polyurethane coating were added in open graded mixtures. The functional performance was evaluated using the permeability tests and the mechanical resistance was evaluated by indirect tensile tests. The parameters such as fracture energy, post cracking energy and toughness were obtained from the stress-strain plots. It was concluded that the addition of fibers did not significantly reduce the permeability of PA mixtures. Addition of aramid fibers improved the abrasion resistance of PA mixtures. In terms of ITS, a negligible influence under dry conditions was observed. Meanwhile, the fibers had adverse effects on the moisture susceptibility of PA mixtures. Aramid fibers were found to have no effect on the fracture energy, post cracking energy and toughness of the PA mixtures. More research to analyse their effect on fatigue resistance and low temperature cracking after freeze and thaw cycles are required to be conducted in the future.

**Keywords:** Aramid fibers; porous asphalt mixtures; fracture energy; toughness; open-graded mixtures; durability





## Long-term structural performance of crumb rubber modified asphalt layers

Moreno-Navarro, F.\*; Sol-Sánchez, M.\*; Tauste, R.\*; Rubio-Gámez, M.C.\*

*\*Laboratory of Construction Engineering (LabIC.UGR), School of Civil Engineering (ETSICCP), University of Granada, Dr. Severo Ochoa St., Granada 18071, Spain*

Nowadays, sustainability has become one of the most important factors when designing road infrastructures, however it is still a challenge when constructing them. Among the solutions found for increasing road pavement sustainability, the use of crumb rubber from end-of-use tyres as a modifier to improve the performance and increase the service life of asphalt materials has taken special relevance in the last decades. Nonetheless, the use of crumb rubber modified road pavements in construction is still very limited all over the world. One of the main reasons is because the tools used to design pavement structures fail to consider their potential advantages in the long-term and therefore their economic viability is very difficult to justify; given they provide an increase in the initial construction costs. Based on these considerations, the present paper is focused on the evaluation of the long-term structural performance of crumb rubber modified asphalt layers in comparison to traditional ones by using the UGR-FACT method. The results indicate that the use of crumb rubber modified asphalt materials (using the wet or dry process) could be a viable solution to construct more durable and sustainable road pavements.

**Keywords:** Crumb rubber; structural performance; sustainability; road pavement; asphalt; UGR-FACT; bituminous mixtures

## **Experimental investigation on fatigue life performance of asphalt-rubber and reacted and activated rubber modified mixtures using dissipated energy approach**

Boudnani, Z.E.\*; Glaoui, B.\*; Merbough, M.\*; Silva, F.\*\*; Sousa, J.B.\*\*

*\*Laboratoire de -FIMAS-, UTMBéchar, Bechar, Algeria*

*\*\*CONSULPAV, Consultores e Projectistas de Pavimentos, Lda., Mafra, Portugal*

The paper investigates the findings of a four-point bending test, measured at 500 microstrains, 20 ° C and 10 Hz, concerning fatigue efficiency of “Asphalt Rubber” (AR) and “Reacted and Activated Rubber” (RAR) bituminous mixtures. Five various bituminous mixtures with 2 AR compositions as well as 2 RAR materials and control mixture as reference have been used in the laboratory research. The fatigue experiments were conducted in strain control mode for explaining the mixture’s fatigue properties as well as for defining the impact of the modifier type on the mix fatigue. An energy dissipation approach has been utilized for the fatigue study based on internal damage caused by bituminous mixture loading. For unifying fatigue evaluation, damage curves stated in Plateau Values have been formed and analyzed for Dissipated Energy Change Ratio. Results showed as compared to control bituminous mixture, mixtures prepared totally with AR and RAR have improved fatigue performance showing lower ratio of dissipated energy change (RDEC) and plateau value, the mixes with RAR have resulted in better fatigue life as compared to AR mixes.

**Keywords:** Asphalt-rubber (AR); reacted and activated rubber (RAR); ratio of dissipated energy change (RDEC); plateau value (PV); fatigue

## Effectiveness rejuvenation in porous asphalt

Moenielal, M.\*; van Vliet, D.\*; van Aalst, W.\*\*; van der Kemp, J.W.F.\*\*; Varveri, A.\*\*\*  
The, P.\*\*\*\*

*\*TNO Structural Reliability; \*\*TNO Intelligent Imaging*

*\*\*\*Delft University of Technology; \*\*\*\*Rijkswaterstaat GPO*

Lifetime extension of porous asphalt (PA) by rejuvenation is quite some years under investigation by Rijkswaterstaat (RWS), the Dutch road authority for highways. Prior to pilots detailed research was carried out to determine the effectiveness of rejuvenation of PA. It appeared that rejuvenation was a sound technology, cost-effective and sustainable without loss of the functional properties of PA to delay the degradation of asphalt in terms of stone loss. RWS has constructed several test sections and monitors the development of stone loss by using the DOS/LCMS system (Laser Crack Measurement System). The monitoring runs now for 8 years and shows that in sections treated with rejuvenation products the development of raveling of PA16 is delayed for at least 3 years compared to non-treated sections. For 2-layered PA (2LPA8) no raveling has been seen, thus no delay has been (yet) observed. Samples have been retrieved from drilled cores, which have been investigated by RSAT for stone loss, aging and erosion of the mortar. The observed lifetime extension of 3 years for PA16 from DOS/LCMS data by using rejuvenated products has been confirmed by RSAT results. It is concluded that the method of investigation by taking cores arbitrarily on project level poorly reflects the average stone loss in a 100 m section. By adding detailed damage inspection data of the (targeted) drilling locations in the analysis better or correct correlation between the raveling in DOS/LCMS -measurements and stone loss of cores as tested by RSAT have been found for two test sections.

Keywords: Porous asphalt; rejuvenation; raveling; LCMS; RSAT



## Engineered crumb rubber technology for “dry-process” rubberized asphalt pavement

Schüwer, N.\*; de León, L.A.\*; Martin, J.\*; Megert, S.\*

*\*Tyre Recycling Solutions, Z.I. Trési 9A, 1028 Préverenges, Switzerland*

The problems associated with the recycling and the valorization of end-of-life tyres (ELT) have been and still are burdens for societies and serious environmental concerns. Rubberized modified asphalt is a great way to valorize waste tyres and this approach allows for pavement performance improvement while providing economical benefits. As proven by laboratory tests and field data, high performance rubberized asphalt pavements can be obtained using engineered rubber crumb (ECR) specifically design for the dry process production method. The ECR additive allows for a performance increase as compared with traditional pavements and the roads produced with this technology have comparable high-performance properties than the one made from polymer modified bitumen but come at a reduced price and lower carbon footprint. The ECR technology has been used successfully for more than 15 years in the USA and it is well documented. Extensive laboratory studies have demonstrated that the ECR technology is able to produce pavement materials of high performances and in compliance with technical requirements. Recently several test sections have been realized in Switzerland and the quality of the pavement laid in the field matched the positive results obtained at the laboratory scale. Long-term assessment and monitoring of those ECR based pavements is currently ongoing.

Keywords: Rubberized asphalt; dry process; engineered crumb rubber



## Characterization of bituminous mortar as input to multiscale modeling of asphalt

Canon Falla, G.\*; Leischner, S.\*; Wellner, F.\*

*\*Institute of Pavement Engineering, Technische Universität Dresden, Germany*

The ability to predict asphalt performance using multiscale modeling techniques would enhance the design of flexible pavements. It would be advantageous if road engineers could account for the effect of the asphalt constituents and bring out tailored mechanical responses by optimizing specific parameters at the microscopic level, such as the bitumen in the mortar or the shape/gradation of the aggregates. For adequate characterization at the micro level, it is necessary to carry out laboratory tests on the mortar that binds the coarse aggregates of the asphalt mixture. Testing the mechanical properties of bituminous mortar is a crucial element within multiscale modelling techniques. On this context, a novel shear tester, known as Dresden Dynamic Shear Tester (DDST), was created to characterize the shear response of mortar under different temperature and frequency conditions. The DDST is a direct dynamic shear box with normal stress applied. It consists of two stacked rings separated by a gap of 1 mm thickness to allow free relative movement between them. The DDST was designed to be driven by a Universal Testing Machine (UTM) with temperature and relative humidity control. The load cell based piston of the UTM provides movement in the shear direction, and an in-built pneumatic pressure actuator applies load in the axial direction. Shear and axial displacements are measured by four external linear vertical displacement transducers. The results of the DDST were used within a multiscale approach aiming to determine effective asphalt properties.

**Keywords:** Asphalt mortar; Dresden dynamic shear tester; representative volume element; multiscale



## Effects of surfactants on formulation, cohesion build-up and moisture resistance of cold mix asphalt in relationship with emulsion breakup and mineral substrates chemical reactivity

Konaté Y.\*\*\*; Ziyani, L.\*\*; Dony, A.\*\*; Poirier, J-P.\*\*\*; Château, X.\*\*\*\*; Konin, A.\*

\**Institut National Polytechnique, Boulevard Mamie Adjoua, 1093 Yamoussoukro, Ivory Coast*

\*\**Université Paris-Est, Institut de Recherche en Constructibilité, Ecole Spéciale des Travaux Publics, 28 avenue du Président Wilson, 94234 Cachan Cedex, France*

\*\*\**PQSERENDI, 2 allée de l'Hermine, 78180 Montigny-le-Bretonneux, France*

\*\*\*\**Laboratoire Navier (UMR 8205), CNRS, Ecole des Ponts ParisTech, Université Gustave Eiffel, 14-20 Boulevard Newton Cité Descartes, Champs-sur-Marne F-77447 Marne-la-Vallée Cedex 2, France*

The objective of this research work is to investigate the influence of parameters related to bitumen emulsion and asphalt mixture compositions on the formulation of virgin and recycled cold mix asphalt (CMA), as well as their properties in terms of cohesion build-up and resistance to moisture damage. The study focused on diorite and granite-based CMA in which 50 % of reclaimed asphalt pavement (RAP) were incorporated. Several emulsions, differing from their emulsifier chemical nature and content were formulated. The results showed at virgin and recycled asphalt mixes scale that total water content varies with the surfactant type and decreases when surfactant content increases, whatever its composition. Likewise, kinetics of cohesion build-up of mixtures is influenced both by the quantity of added water and emulsifier content. The moisture resistance of mixes depends on each emulsifier-substrate couple used and has an optimal surfactant content that guarantees a better durability with respect to water effect. Finally, recycled asphalt mixes present better compaction properties and high mechanical strength comparatively to virgin asphalt mixes and with best moisture resistance depending on nature of the aggregate.

**Keywords:** Cold mix asphalt; bitumen emulsion; chemical reactivity; recycling; durability



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## **Reflective cracking and serviceability performance of asphalt overlays on distressed concrete pavements through field test sections**

Haslett, K.E.\*; Dave, E.V.\*; Sias, J.E.\*

*\*Department of Civil and Environmental Engineering, University of New Hampshire, Durham, USA*

Asphalt concrete (AC) overlays on Portland Cement Concrete (PCC) are a common maintenance and rehabilitation technique used to extend the service life of a roadway. However, composite pavement structures are often subjected to high stress concentrations at joint locations from traffic and thermal driven movements leading to the formation of reflective cracks. This study examines field performance data from 12 full-scale test sections located at the MnROAD test facility in terms of cracking reported at joint locations and serviceability (International Roughness Index) measured using two different methods. Based on the field performance data, recommendations are provided on overlay structure, material selection, and impact of the use of interlayers mixtures. In general, thicker pavement sections are performing better, with test sections containing a regressed air void (3% AV) or Superpave5 (5% AV) design mixtures showing lower amounts of joint cracking after 30 months of service. There exists some discrepancy in test section ranking when considering reflective cracking performance versus IRI performance, irrespective of the IRI measurement collection method.

**Keywords:** Asphalt concrete overlay; field performance; reflective cracking; serviceability; international roughness index; in-situ density



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## **An initiative to make the U.S. asphalt pavements greener and safer**

Arabzadeh, A.\*; Podolsky, J.H.\*; Staver, M.D.\*; Williams, R.C.\*; Hohmann, A.D.\*;  
Hernández, N.\*; Cochran, E.W.\*

*\*Iowa State University, Ames, Iowa, USA*

An asphalt binder was modified with bio-renewable modifiers formulated from epoxidized soybean oil derivatives. In this study, the combination of these modifiers is referred to as BioMAG. The binder modification occurred in an asphalt terminal, and the resulting binder was transferred to an asphalt plant to produce an asphalt mixture containing reclaimed asphalt pavement aggregate (RAP). The reason for the modification of asphalt binder with the BioMAG was for reversing the undesired effects of RAP used in a pavement demonstration project in Iowa, U.S. According to comprehensive binder rheology test results, the undesired effects of RAP binder were mitigated significantly, and the temperature grade of the mixture binder was maintained in presence of the BioMAG. Mechanical performance tests such as disk-shaped compact tension (DCT), push-pull fatigue, and Hamburg wheel tracking (HWT) revealed that the BioMAG significantly improved the low, intermediate, and high-temperature performance of the asphalt mixture.

Keywords: Bio-renewable modifiers; soybean oil derivatives; asphalt; binder rheology; mixture performance





## **Preliminary field and laboratory investigation on the use of non-contact digital ski sensor as pavement-smoothing technology in the South Korea expressway network**

Moon, K.H.\*; Cannone Falchetto, A.\*\*; Cho, J.W.\*

*\* Korea Expressway Corporation*

*\*\*Aalto University*

In this study, the effect of using next-generation equipment for pavement smoothness leveling, known as Non-Contact Digital Ski (NCDS), on the smoothness of asphalt pavements and its impact on the low temperature behavior of the paved mixture is evaluated. For this purpose, the International Roughness Index (IRI m/km) was measured on sections paved with and without NCDS. Asphalt mixture cores were then taken from the pavement to be tested with the Bending Beam Rheometer (BBR) and determine the evolution of thermal stress. Based on simple graphical and statistical comparisons, it was found that the NCDS paving method results in considerably lower IRI coupled with a moderate reduction in thermal stress, suggesting a potential benefit of this technology also on the low temperature behavior of the mixture.

**Keywords:** Smoothness; long-range surface contact ski (LSCS); non-contact digital ski (NCDS); international roughness index (IRI); bending beam rheometer (BBR) test



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## **An investigation on the mechanistic-empirical design of asphalt overlay on concrete pavement based on different rheological models**

Moon, K.H.\*; Cannone Falchetto, A.\*\*; Cho, J.W.\*

*\* Korea Expressway Corporation*

*\*\*Aalto University*

This research presents a combined experimental and design study to evaluate the effect of five rheological models used to characterize the dynamic modulus of asphalt mixture on the predicted performance of composite pavement (asphalt overlay on concrete base) currently adopted in the South Korean Expressway network. For this purpose, different models, including a newly modified Christensen Anderson and Marasteanu (CAM) model, are selected and used to describe the experimental measurements on three different types of asphalt mixtures. The models' output is then incorporated into the mechanistic-empirical pavement design procedure and distresses such as roughness, rutting, and reflective cracking are evaluated. Based on dynamic modulus data and pavement design results it appears that the newer modified CAM model might result in pavements with moderately longer service life.

Keywords: Asphalt overlay; composite pavement; dynamic modulus; mechanistic-empirical pavement design

## **Recycled concrete aggregates in varied proportion for black cotton soil stabilization**

Nabeel Muhamed, N.K.\*; Jaya, R.S.\*

*\*RASTA-Centre for Road Technology, Bangalore, India*

Soil sub grade is the bottom most layer in the pavement structure. It bears the total load transferred from the top and hence it contributes to the strength and stability of pavements. If the in situ soil does not possess the deserved properties, it has to be improved by technical methods because replacing the native soil is uneconomical. This method is referred as soil stabilization. Improved sub grade material reduces the pavement thickness and the cost of construction. Black cotton soil is the major soil deposits in Indian sub continental belt. Due to its poor engineering properties, it is not suitable as a pavement material. The objective of this study is to improve the existing Black cotton soil properties using a construction waste material in the form of Recycled Concrete Aggregate (RCA). RCA is processed from Construction and Demolition wastes, which is accumulated in huge quantities due to the modernization of buildings and rapid development in the urban centers. According to Indian Road Congress (IRC) Guidelines on Use of Recycled Construction and Demolition Waste in Road Works, Construction and Demolition waste makes up about 25 % of the Municipal Solid Waste generated annually. This poses a threat to the environment in terms of finding suitable landfills to dispose it. Conventionally naturally occurring graded aggregates are used for mechanically stabilizing the poor soil sub grades. However, projections for construction material requirement by the infrastructure sector indicate a shortage of about 55,000 million m<sup>3</sup> aggregates. An additional 750 million m<sup>3</sup> of aggregates would be required to achieve the targets of the highway sector. The concept of mechanical stabilization has been used in the present study, with the use of RCA instead of virgin aggregates. Trial ratios of Soil: RCA Ratio: 3:1, 2:1 and 1:1 have been mixed and tested for improvement in engineering properties. Based on the results obtained, all the three proportions have shown considerable strength improvement to use it as a sub grade material and can be recommended as an effective option for stabilization.

**Keywords:** Mechanical stabilization; black cotton soil improvement; recycled concrete aggregates

## Utilization of recycled concrete aggregates and mortar wastes in stabilization of clayey soil subgrade

Nabeel Muhamed, N.K.\*; Mohammed Sayeed\*; Jaya, R.S.\*

*\*RASTA-Centre for Road Technology, Bangalore, India*

Sub-grade being the most important layer in the pavement structure takes the final load transferred from the top layers and contributes for the stability of pavement structure. It plays a major role in determining the performance of pavement. Soil used for sub-grade construction should possess certain desirable properties such as grain size, consistency limits, CBR Strength, UC Strength and Durability. If the soil does not possess such properties, it should be improved because the option of replacing the soil by a good soil may not be economical all the time. This can be considered as soil stabilization. After stabilization, strength and durability of the in-situ soil is assessed. This renders it to be suitable as a sub-grade material. Improved sub-grade material not only reduces the pavement thickness but also the cost of replacing weak soil with good borrow soil. The objective of this study is to improve the existing soil properties using a constructional waste material in the form of Recycled Concrete Aggregates (RCA) and construction waste generated from the high rise building known as Mortar Waste (MW). The concept of mechanical stabilization has been used in the present study, with the use of RCA and MW with soil. Mainly four sizes of RCA i.e. 12.5 mm down, 4.75 mm down, 2.36 mm down and 600  $\mu$  down are used and MW generated from the building construction is replaced in 600  $\mu$  RCA which is used for this study. Blending of different sizes of RCA are done by Rothfutch method in proportion i.e. 3:1 (Soil : RCA) and also mixing the blended RCA with MW is done in same proportion i.e. 3:1 (Soil : RCA+MW). Tests are done on both un-stabilized and stabilized soil samples for basic properties, strength parameters and durability. Based on the results obtained, the ratio 3:1 (Soil : RCA) and (Soil : RCA+MW) have shown considerable strength improvement to use it as a sub-grade material. Optimum dosage of RCA and MW to be added to soil to get the best output which is based on the result obtained along with considering the cost comparison with the help of IRC 37: 2012.

**Keywords:** Recycled concrete aggregates; mortar waste; stabilization





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