

Aging of Bitumen and Asphalt Concrete

Comparing State of the Practice and Ongoing Developments in the United States and Europe

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1 **REVIEW OF ASPHALT (CONCRETE) AGING TESTS IN THE US AND EUROPE**

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52 **ABSTRACT**

53 Aging is a crucial factor in pavement performance and being able to determine its effect on a
54 mixture is necessary to link its initial properties to the properties over time in order to ensure
55 the intended service life. This is becoming more important now that climate change leads to
56 increased variation in weather conditions, while environmental considerations cause changes
57 in the constituent materials that are used. As a result, past experience is becoming less
58 reliable. In this paper, the USA and EU approaches to aging are compared, showing that those
59 contain the same test equipment and almost identical conditions for aging. This allows the
60 exchange of data and experience.

61
62 The current tests are suitable for binders and give an indication of the sensitivity to aging. For
63 short term aging RTFOT conditioning gives a reasonable indication of bitumen aging during
64 asphalt concrete production and construction. This only holds for penetration grade binders
65 during hot mix production and construction.

66
67 For long term aging, because of the many variables involved, developing a single test method
68 to characterize aging sensitivity, seems impossible. However, using more elaborate protocols
69 in existing, practical tests, can provide more information and the necessary input for kinetic
70 aging expressions. A PAV protocol for testing at two temperatures and time intervals,
71 specifically at 90 and 100 degrees Celsius and for 20 and 40 hours respectively, is suggested.
72 Using the same conditioning in characterizing materials for pavement construction and
73 research will facilitate the exchange of data and enable faster developments.

74
75 Keywords: aging tests review, oxidation, PAV protocol, kinetic expressions

76 INTRODUCTION

77 Aging of asphalt concrete is an important aspect of pavement performance, because most
78 pavement damage in well-constructed pavements occurs only after a considerable service life.
79 In the Netherlands and most other west European countries, service life ranges from 10 to 20
80 years for surface layers to considerably longer times for binder and base layers. Aging causes
81 the material properties to change during this time, especially for surface layers which are
82 exposed to moisture, large temperature changes, oxygen and UV light. This means that to
83 assess the suitability of a material for a given application, not just its original properties, but
84 also some indication of how these properties change over time is needed. Unfortunately, aging
85 is a complex process that is not only influenced by the material characteristics, but also by the
86 conditions during production and construction and the local environmental conditions. This
87 makes it difficult to define a test that covers aging for all materials and climatic conditions.

88 This is especially true in the current situation, where various changes occur simultaneously.
89 On the one hand environmental and financial considerations lead to changes in the constituent
90 materials that are used. Examples are the increase in recycling and the use of alternative
91 materials like bio-binders, RAS and different additives. On the other hand, climate change
92 causes changes in environmental conditions, which affect the way asphalt concrete properties
93 change over time. These developments lead to an increased variation in material properties
94 and pavement performance.

95 At the same time decreasing maintenance budgets result in an increased use of asset
96 management systems. For most road authorities, pavement maintenance is a large part of their
97 yearly costs, so a reliable prediction of the average life span of a pavement is crucial and this
98 requires some method of determining the properties of pavement materials over time.

99
100 In Europe the Centre European de Normalisation (CEN, European centre for
101 normalization/standards) technical committee on Asphalt Concrete is looking into the
102 possibility to include requirements for aged asphalt concrete in the standards. In order to
103 provide input for that attempt, the Dutch road authority (Rijkswaterstaat) and the Delft
104 University of Technology organized a symposium to obtain an overview of the current
105 practice regarding aging of asphalt concrete as well as the developments in research. This
106 contribution is based on the results from that symposium (1) and aims to provide both an
107 overview of the current practice in the USA and Europe and propose a next step that will give
108 more fundamental insight in aging and allow the exchange of aging data. The first part of this
109 paper summarizes the current approach to aging in the standards in the USA and Europe. The
110 second part summarizes the discussion during the symposium, which results in a
111 recommendation for a testing protocol that can be carried out with existing equipment but will
112 provide an overall indication of aging sensitivity as well as input for fundamental aging
113 research.

114 115 SUMMARY CURRENT AGING PROCEDURES IN USA AND EU STANDARDS

116 Aging tests: bitumen

117 *Short term aging: RTFOT*

118 Aging tests can be separated into tests on bitumen and tests on the asphalt mixture. For
119 bitumen a common test to represent the short term aging of bitumen that takes place during
120 mixing, transport and placement is the Rolling Thin Film Oven Test (RTFOT, AASHTO
121 T240 (2), ASTM D2872 (3) and EN12607-1 (4)). Besides in the actual standards, descriptions
122 of this test can be found in (5) and (6).

123

124 In this test bitumen is placed in glass bottles in a circular rack in a strictly specified oven. The
125 rack contains eight bottles in total with 35 grams of bitumen per bottle. The oven is heated to
126 163°C before placing the bottles in the rack and they are left in the oven for 75 (4) or 85 (2, 3)
127 minutes of testing. The rack rotates the bottles at a rate of 15 revolutions per minute while the
128 oven is kept at 163°C. During the test air is being blown into the oven at 4000 ml/minute.
129 After testing the mass loss, or more specifically the mass change (since some bitumen may
130 increase in density due to oxidation), is determined. In the USA the material from the other
131 bottles is used for DSR testing (T315 (8)) to obtain the $G^*/\sin\delta$ after short term aging which is
132 used in AASHTO M320-10 (7), as part of the requirements for binders. Alternatively, the
133 material can also be aged further using the pressure aging vessel. In Europe the remaining
134 material is used to determine the change in penetration, ring and ball temperature and
135 viscosity at 60°C. The standards for penetration bitumen (EN12591), polymer modified
136 bitumen (EN14023) and hard paving grade bitumen (EN13924) specify the allowed changes
137 in mass, penetration and/or ring and ball temperature.

138

139 *Long term aging: PAV*

140 The pressure aging vessel (PAV, AASHTO R28 (9), EN 14769 (10)) is meant to simulate
141 long term aging, the aging that occurs during the pavement service life. The current PAV test
142 was developed during the SHRP program in the USA. In the test, previously RTFOT aged
143 bitumen is aged further in a pressure vessel which is placed in an oven, both increased
144 temperature and increased pressure to accelerate aging. The aim is to achieve an amount of
145 aging that is comparable to several years of service life in a pavement. In developing the test,
146 bitumen reclaimed from field cores was used as a reference, using the bitumen from the whole
147 core. More recent results indicate that the top part of field cores is aged much more than lower
148 parts (11, 12). This indicates that assessing the aging effect based on bitumen reclaimed from
149 whole cores rather than only the top 1 or 2 centimetres underestimates the aging effect. As
150 such, PAV conditions are now thought to represent only limited aging times for the material
151 at the top of a pavement.

152

153 **USA** In the USA, the PAV procedure uses samples of 50 g of bitumen in a 140 mm diameter
154 container (giving a binder film that is approximately 3,2 mm thick) within the heated vessel.
155 The pressure is 2,07 MPa for 20 hours at temperatures between 90 °C and 110 °C. Testing of
156 the PAV (and RTFOT) aged bitumen in the DSR, bending beam rheometer and, in some
157 states, the direct tension test is required for performance grading of bitumen.

158

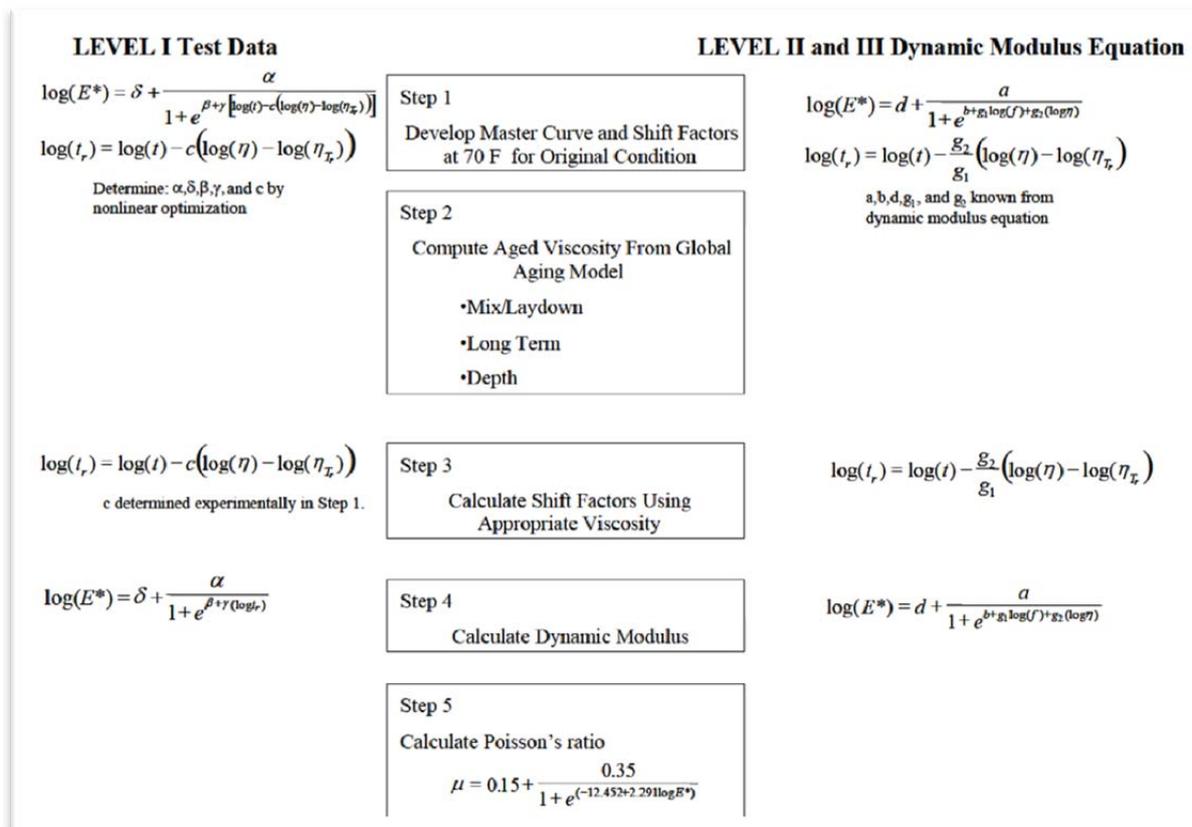
159 **Europe** In Europe the suggested sample size is the same as in the USA (50 grams in 140 mm
160 containers, but different sizes containers are allowed as well. In case of a different size, the
161 amount of binder must be adjusted to ensure a layer thickness of approximately 3,2 mm. The
162 pressures and temperatures used overlap with those used in the USA, but there are small
163 differences, in Europe the pressure is 2,1 MPa (versus 2,07 in de USA) and the temperature
164 range is 80°C to 115°C (versus 90 °C and 110 °C). More importantly, the current European
165 bitumen standards do not require PAV aging or testing of PAV aged binder to assess the
166 sensitivity to long term aging.

167 The European standards also allow using the Rotating Cylinder Aging Test (RCAT,
168 EN15323) for aging of bitumen, the RCAT can be used for both short and long term aging but
169 despite its versatility RTFOT and PAV set-ups are more widely available and as such have
170 become more or less the standard procedure for bitumen aging in Europe.

171

172 **Asphalt concrete**173 *USA*

174 In the MEPDG (13), the effect of aging on the bitumen properties is determined using
 175 bitumen aging tests and this is related to the effect on the stiffness of the mixture through
 176 regression relations that take the mix composition into account (FIGURE 1).



177 **FIGURE 1 Aging of AC properties in the MEPDG works through regression based on**
 178 **bitumen aging (copy of fig 2.2.3 (13))**
 179

180
 181 *Europe*

182 Although the current standards for Asphalt Concrete do not require aging of the asphalt
 183 concrete itself, the CEN standards do provide tests for aging of AC. There is a test standard
 184 for hot mix asphalt saturation aging (SATS (15)). This standard aims to assess the durability
 185 of adhesion in base and binder courses by aging specimens in the presence of water. The test
 186 is currently limited to mixtures with a binder content between 3,5 and 5,5% of 10/20 hard
 187 paving grade binder and air voids between 6% and 10%. In this tests five AC cores are first
 188 partially saturated ($\leq 80\%$) by putting them in a vacuum desiccator covered with distilled
 189 water for half an hour at a pressure of 40-70 kPa. After this, the specimens are placed on
 190 different levels in the SATS set-up. The set-up is partially filled with water, causing one
 191 specimen to be under water and the other four at various heights above the water level. The
 192 specimens are left in the set-up at a pressure of 2,1 MPa and a temperature of 85°C for 65
 193 hours. The dynamic stiffness (using the indirect tension test, EN12697-26 Annex C) is
 194 determined before and after conditioning and the average of the stiffness ratios of the four
 195 specimens that were placed above water level is used to obtain the mixture stiffness ratio.
 196 Currently, this test is used in the United Kingdom. Experience with this test in other countries
 197 is very limited.

198 CEN TC227 is currently working on a draft standard which allows the assessment of the
199 effect of oxidative aging of asphalt mixtures (prEN 12697-52:2014, (16)). This standard aims
200 to provide methods for laboratory aging of both loose (pre-compaction) asphalt concrete and
201 AC cores, either produced in the laboratory or obtained from the field. The aged material
202 can be used to make specimens and assess the effect of aging on the mixture properties or
203 binder can be extracted from the aged AC to assess the effect of aging in the presence of filler
204 and aggregates on binder properties.

205

206 **SUMMARY OF SOME RECENT AND ONGOING RESEARCH**

207

208 The importance of the topic is illustrated by the amount of research on this topic. As a result,
209 this section cannot possibly cover all work going on in this area. Instead, it focusses on some
210 trends that various projects have in common regarding the relation between laboratory and
211 field aging in order to arrive at a protocol to further develop this relation. Projects regarding
212 the relation between the laboratory aging methods and field aging aim to establish a match
213 between the chemical and physical (changes in) properties between both for long and/or short
214 term aging.

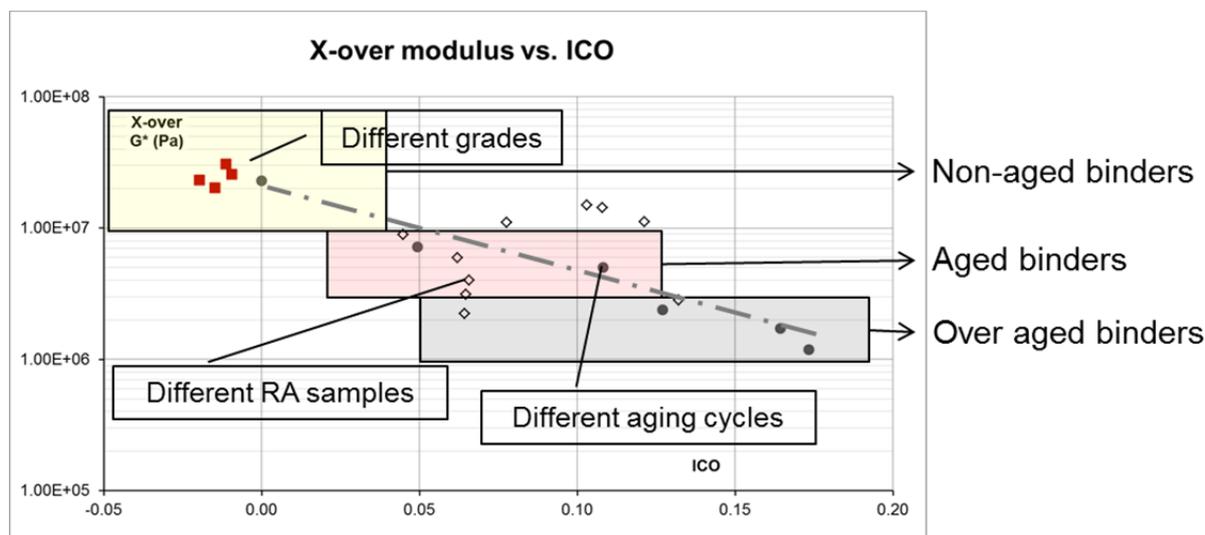
215 **Short term aging**

216 Typically, it is found that the RTFOT test provides a good indicator of bitumen aging during
217 production. The type of plant and the composition of the asphalt mixture do not seem to have
218 a large influence on the field aging (17). The test does not predict the aging due production,
219 its fixed temperature and duration does not account for variations in production temperature,
220 storage and transport time and weather conditions, but it does provide a reliable indication of
221 the binder sensitivity due to the production process of hot mix asphalt (HMA). For penetration
222 binders the test shows the effect of bitumen source and grade on the aging susceptibility (6).
223 When using two different bitumens in exactly the same mix and using exactly the same
224 production conditions, the bitumen that showed the most aging in the RTFOT will age most
225 during actual production and construction (1). As such, the test is a good sensitivity indicator.
226 It does not seem to be representative for hard grade, polymer modified and warm mix binders.
227 For hard grade binders and polymers, this is probably because these materials do not mix as
228 well as penetration binders. For warm mix binders, the test temperature is probably
229 unrealistically high (17). So for those materials and production methods, other tests or test
230 conditions may be needed.

231 **Long term aging**

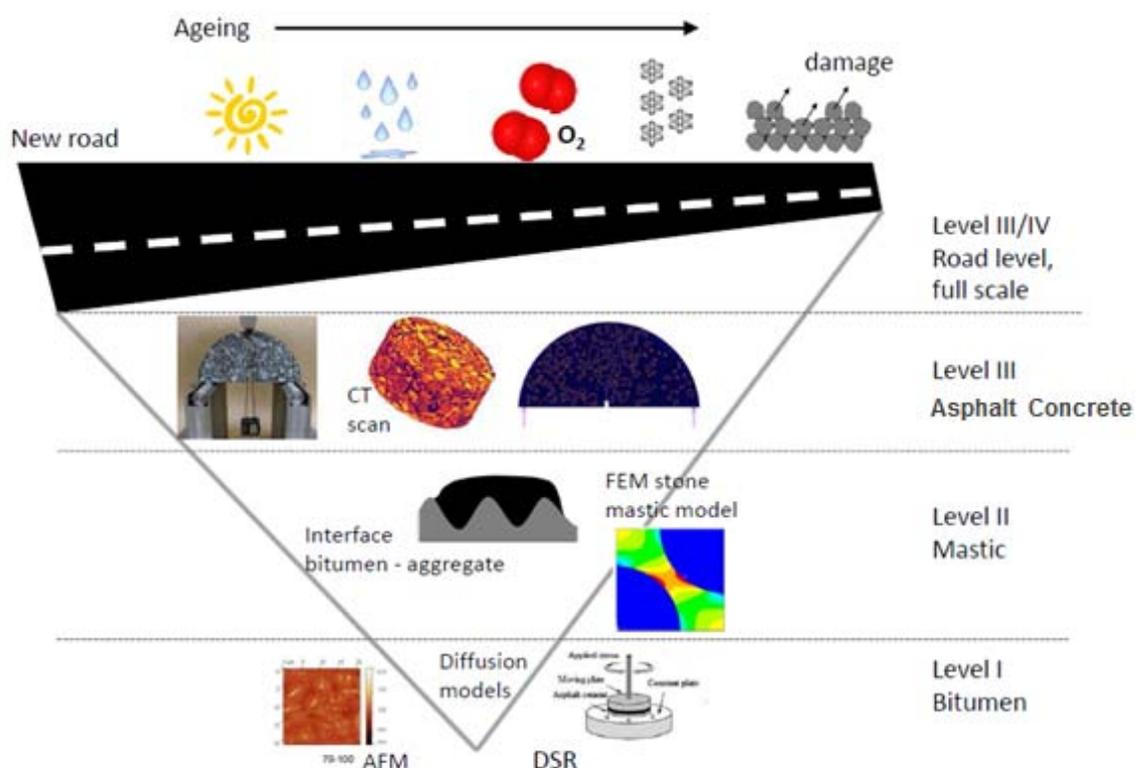
232 The most common test for long term aging is the pressure aging vessel (PAV, (9), (10)).
233 Although in Europe there is also good experience with another method (Rotating Cylinder
234 Method or RCAT), that equipment is much less wide spread. An important consideration in
235 long term aging testing is the temperature. The high temperatures used in short term aging are
236 not useful for long term aging tests, because they introduce secondary reactions. This has led
237 to tests at lower temperatures and longer aging times. However, none of those tests can
238 simulate the actual field aging (6), since that depends on local weather conditions
239 (temperature and water/moisture (19)) and mix composition properties such as the void
240 content and/or bitumen film thickness (6, 20) and the type of minerals (especially filler (21))
241 used. The effect of mix composition was also found in a study on aging of Porous Asphalt
242 with penetration 70/100 bitumen, where the relative importance of aging due to production
243 was found to be considerably less important than predicted by the Shell bitumen handbook
244 (FIGURE 2, 13).

276 are based on the current standards and fit both the USA and CEN procedure, while research
 277 using repeated PAV aging cycles at 100°C shows that after 40 hours at 100 degrees, but
 278 without previous RTFOT aging, the chemical (ICO from FTIR) and rheological (cross-over
 279 modulus from DSR) properties of laboratory aged and field samples were similar (FIGURE
 280 4, (28)). At 100°C the temperature is low enough so that the effect of secondary reactions is
 281 negligible. As such, these conditions are appropriate for kinetic expressions for in service
 282 pavement performance. For high temperature processes and possibly also for repeated
 283 recycling (very long term) more sophisticated methods are needed.
 284



285
 286 **FIGURE 4: Chemical (carbonyl index) and rheological (cross-over modulus) properties**
 287 **of laboratory aged and field samples (28)**
 288

289 Additional relations to account for mix composition and micro structure (i.e. the chemo-
 290 mechanical aspects of aging) will need to be developed to take this information to the level of
 291 pavement aging. This will require a considerable research effort in multi-scale testing and
 292 modelling (FIGURE 5). However, in the mean time for practical applications, the
 293 requirements for the maximum changes in rheological properties can continue to be used.
 294 These requirements can be augmented by adding chemical requirements and/or by developing
 295 differentiated requirements for groups of materials (i.e. porous and dense mixture, mixtures
 296 with chemically active and inert fillers) or climate zones. Input for such adapted requirements
 297 should come from consistent monitoring of field aging, which will also provide the means to
 298 validate the models and laboratory test data.
 299



300
301 **FIGURE 5: Example of an testing and modelling program aiming to account for local**
302 **climate and mixture composition effects in aging (29)**
303

304 SUMMARY AND CONCLUSIONS

305 In this paper, the USA and EU approaches to aging are compared, showing that those contain
306 the same test equipment and almost identical conditions for aging. This allows the exchange
307 of data and experience.
308

309 These tests are found to be most suitable for binders (not asphalt concrete) and to give only an
310 indication of the sensitivity to aging. For short term aging RTFOT conditioning gives a
311 reasonable indication of bitumen aging during asphalt concrete production and construction
312 (1,6). But this only holds for penetration grade binders during hot mix production and
313 construction. In its current form it doesn't work for hard grades, PMB's or warm mixes (17).
314

315 For long term aging, because of the many variables involved, developing a single test method
316 to characterise aging sensitivity of bitumen, let alone asphalt concrete, seems impossible.
317 However, using more elaborate protocols in existing, practical tests, can provide more
318 information and be used to determine the kinetic properties. A PAV protocol for testing at two
319 temperatures and time intervals, for example, could provide additional aging information for
320 the short term and enable model development and validation on the long term.
321

322 RECOMMENDATIONS

323 Extend PAV conditioning to cover two temperatures and two conditioning periods, Based on
324 the current standards and research, PAV tests at 90 and 100 degrees Celsius and 20 and 40
325 hours, respectively, are suggested. The low values for temperature and duration are based on
326 the current standards and fit both the USA and CEN procedure, while research shows that

327 after 40 hours of PAV at 100 degrees, without previous RTFOT, the chemical (FTIR) and
 328 rheological (DSR) properties of laboratory aged and field samples were similar (28, 1). At
 329 100°C the temperature is low enough so that the effect of secondary reactions is negligible. As
 330 such, these conditions are appropriate for kinetic expressions for in service pavement
 331 performance. For high temperature processes and possibly also for repeated recycling (very
 332 long term) more sophisticated methods are needed.

333

334 To provide the necessary background for requirements that take into account the effects of
 335 local climate and mix composition on aging, consistent field monitoring of temperature and
 336 UV radiation in various climate zones, as well as regular sampling over time to monitor aging
 337 over time is needed. Also, sampling at various pavement depths is needed to determine the
 338 aging gradient with depth. Such monitoring projects will provide the input for more specific
 339 requirements and model validation and ensure the applicability for pavement performance
 340 prediction.

341 In setting up such monitoring projects, it is important to get the properties and/or composition
 342 of both the virgin bitumen and the bitumen after mixing, transport and placement in the
 343 pavement. These provide the starting points for both the material and pavement structure
 344 point of view and can be used to assess the development of aging products over time.

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