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AGING OF ASPHALT BINDERS AND ASPHALT MIXTURES. SUMMARY PART II: AGING SIMULATION AND AGING REDUCTION TECHNIQUES

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ABSTRACT

This the second part of an article written with the purpose of summarizing and describing the most important aspects that the pavement engineer should know about the aging of asphalt binders and asphalt mixtures. The first part presented the changes in physical and chemical properties undergone in asphalt binders and asphalt mixtures when they age. This article shows the most widely used methods for simulating the aging of asphalt materials. Additionally, the most popular and currently used techniques for reducing aging effects in mechanical response and durability of asphalt mixtures in service are presented.

Keywords: aging, simulation, reduction techniques, asphalt binder, asphalt mixture.

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1. INDRODUCTION

1.1. Aging Simulation

In order to attempt asphalt binder aging simulation, thin film tests in RTFOT (Rolling Thin Film Oven Test; AASHTO T 240) and PAV (Pressure Asphalt Vessel, EN 14769) are the most widely used. Asphalt binders obtained in both tests are used in order to evaluate short-term and long-term aging resistance, respectively. On the other hand, in order to simulate short-term and long-term aging of asphalt mixtures, the most widely used techniques or protocols for conditioning are named STOA (Short Term Oven Aging) and LTOA (Long Term Oven Aging), respectively. These were proposed by AASHTO R30 based on studies carried out by [1]. In theory, when subjecting samples to STOA+LTOA processes, it is possible to simulate aging in mixes during 7-10 years of service [2].

It is important to highlight, that there is no aging simulation technique for asphalt binders and asphalt mixtures that can perfectly simulate what is occurring within the pavement, given that these tests do not use the real maximum temperatures to which asphalt binders will be subjected within the mix, as well as other differential factors such as UV radiation and other environmental effects. Additionally, these tests do not evaluate the effects related to the nature of the aggregates, among other factors (form, mineralogy, absorption and porosity, among others) and the volumetric composition of mixes (especially the content of voids and asphalt) [2-5]. Jemison et al. [3] for example, mention that the type of aging experienced in a plant and in RTFOT ovens is different and hardly comparable, in other words, ovens do not precisely predict chemical and physical changes that occur during the aging process of asphalt mixtures in asphalt plants. Only in some cases, aging results are similar. In general terms, understanding and attempting to predict environmental influence on the behavior experienced by in situ asphalt mixtures is a complex task which still has not completely revealed its results [6]. Even researchers such as [7] mention, that asphalt binders may undergo different levels of aging depending on the type of test they are subjected to, this makes it complicated to predict the response of these materials when they age.

1.2. Short-Term Asphalt Binder Aging Simulation

Thin Film Oven Test (TFOT) was introduced by [8]. In this test, a 50 ml asphalt binder sample is placed on a 14 cm diameter flat device, which results in a 3.2 mm thick binder film. Two or more devices are placed on a rotating element which spins at 5 to 6 rpm inside an oven for 5 hours at 163 °C. The main disadvantage of the test is that aging due to loss of volatile agents in the asphalt film is only superficial. Therefore, ever since the decade of the 50s modifications for the test were beginning to be developed, especially in order to work with thinner films called microfilm. Then, RTFOT appears, which is perhaps the most significant modification made to TFOT. In this test, eight glass recipients contain 35g of sample (each one), each one on a vertically rotating device (as occurs in an asphalt plant at 15 rpm) while hot air is applied to each sample. Each sample generates an asphalt film with a thickness of less than 3.2 mm (films with a thickness of 1.25mm). This test was developed by the Californian Division of Highways. Air flows at a range of 4000 ml/min. During this test, the binder flows continuously. Temperature is of 163 °C during 85 minutes [2]. Test conditions are not identical to those occurring at an asphalt plant, however, experience has demonstrated that asphalt hardening in this test is reasonably well correlated with the one observed in asphalt plants.

According to [9], RTFOT has the following main limitations: a) difficulty in cleaning the glass bottles after the test, which leads to loss of material; b) the method is not recommended for highly viscous materials such as low penetration asphalt binders and asphalts modified with polymers, given that test temperature (163 °C) is too low when compared to the one undergo by these asphalts inside the asphalt plant. This would not allow a correct simulation of the aging process, on the other hand, it would not allow the generation of a uniform thin asphalt film with good exposure to oxygen [10-11]. According to [12], the modified test that uses the rotating German flask (Modified German Rotating Flask - MGRF) could be an acceptable alternative to RTFOT for these types of high viscosity asphalts. Another solution consists in the inclusion of a single steel cylindric piece inside the bottles in order to insure the thickness of the asphalt film and in order to avoid the escaping of material [5] as well as increasing RTOFT test temperature [13-14]. Yan et al. (2017) for example, propose increasing it to 178 °C in order to allow the fluidification of asphalt binder. For the case of high stiffness and high viscosity SBS modified asphalts, Yan et al. [11] recommended the following procedure for producing thin films with the purpose of being able to perform the RTFOT test on modified asphalts: a) Dissolving the modified asphalt with solvents (they recommended tetrahydrofuran - THF) in order to prepare asphalt binder solutions with a certain degree of concentration; b) injecting a certain amount of asphalt binder solution into a plate, which has a rubber washer inside of which an asphalt binder solution is poured; c) Waiting for solvents to evaporate; d) removing the rubber washer, leaving a thin rubber film on the plate; e) placing plates in the aging oven. The problem with extraction techniques consists in the fact that the used solvent may change the asphalt's chemical structure [3, 15]. On the contrary, for the case of warm mixes, it is advisable to use lower aging temperatures [16].

Several modifications have been carried out on RTFOT. A is Nitrogen Rolling Thin Oven Test (NRTFOT) used for determine the loss of volatile elements in a more precise manner during test [17]. The difference is that this test, instead of air, applies nitrogen. Other tests for evaluating short-term aging are briefly described up next [5]:

- Rotating Flask Test (DIN 52016). Consists in aging 100 g of asphalt binder in a flask that rotates during 150 minutes at a temperature of 165 °C and at 20 rpm.
- Shell Microfilm Test. This test is a different variation of the TFOT. In this case, an asphalt film of 5 micrometers is aged for two hours over a glass plate at 107 °C.
- Rolling Microfilm Oven Test (RMFOT). This test is a modification of the RTFOT which has the purpose of obtaining much thinner films for aging. Benzene is added to samples and then allowed to evaporate. The result of this process is the creation of a 20-micrometer binder film, which is aged at 99 °C during 24 hours. The main disadvantage of this test is the small quantity of aged asphalt binder (0.5 g per recipient), which can be then used in turn, to perform other tests.
- The Thin Film Accelerated Test (TFAAT). Developed by [18], is a modification of RMFOT. In this test, a 15-micrometer film is oxidized in a chromatographic gas column at 130 °C for 24 hours, passing air through the column. This test can also be performed at 113 °C, but in this case, the films exposure period must be for three days.
- Modified Rolling Thin Film Oven Test (RTFOTM). As previously mentioned, one of the main problems of RTOFT is that, for the case of modified asphalts, given their high viscosity, these do not roll inside the bottle during test. Additionally, some modified asphalts may have the tendency of falling outside of bottles (especially those that foam). RTFOTM was developed because of this. It is an identical to the RTFOT test, except that in this case a system with steel rods of 12.7 cm in length with 6.4 mm of diameter inside glass bottles during aging. The principle is that steel rods generate shear forces in order to extend the binder.

Gamarra and Ossa [19], proposed a thermal-oxidative aging procedure based on mechanical stirring. They placed 150 g of asphalt binder inside a metallic recipient with 8 mm in diameter, and then heated it at a temperature of 163 °C (reducing its viscosity to around 100 Pa-s) in order to facilitate its stirring. Once the material reached this temperature, they used a conventional mechanical stirrer with a helical propeller shaped impeller of 55 mm in diameter at an approximate speed of 1800 rpm. The stirring process continued during time periods of 2.5, 5.0, 7.5 and 10 h, respectively.

1.3. Long-Term Asphalt Binder Aging Simulation

In order to perform the PAV test, first, asphalt binder is aged in an RTFOT or an TFOT. The residue obtained from these ovens is oxidized in a pressurized aging recipient. PAV procedure requires aging 50 g of asphalt binder in a 14 cm diameter pan. Inside the hot recipient, asphalt binder (in films of up to 3.2 mm of thickness) is pressurized at 2.07 MPa for 20 hours at a temperature between 90 and 110 °C [2]. PAV also has a main limitation of simulating high viscosity and/or modified asphalts. Differently to RTFOT, it is advisable to reduce test temperature on PAV in order to simulate long-term aging for these types of asphalt binders. Other tests used for simulating long-term asphalt binder aging are [5]:

- Rotating Cylinder Ageing Test (RCAT). Developed by the Belgium Road Research Centre (BRRC). Its concept is similar to RTFOT, however, this method was better developed for simulating long-term asphalt binder aging. This test allows numerous evaluations on physical and chemical properties of analyzed asphalt binder. It uses one device consisting of a cylinder (tube) with an internal diameter of 12.4 cm and a length of 30 cm. The tube has a central opening of 4.3 cm in diameter on one end, where asphalt binder may be introduced and extracted. After loading a cylinder with a maximum of 500 g of asphalt binder, a stainless-steel roller of 29.6 cm in length and 3.4 cm in diameter. The cylinder rotates at 1 rpm, and oxygen flows through the opening at a speed of 75 ml/min. Tests are performed at temperatures between 70 and 110 ºC.
- Iowa Durability Test (IDT). This test consists in aging a residue of asphalt binder from a TFOT test in a recipient, subjecting it to a pressure of 2.07 MPa and using pure oxygen at a temperature of 65 °C during 1000 hours. Lee [20] found that in IDT, aging is similar to the one found in asphalt binder films aged over a period of 5 years on the field. Based on broad experimental tests and field correlations, [20] concluded that 46 hours of IDT test are equivalent to 60 months of aging in the field for Iowa conditions.
- Pressure Oxidation Bomb (POB). POB shows the sample of the residual binder obtained in the TFOT or RTFOT is subjected during 96 hours to a pressure of 2.07 MPa and 65 °C.
- High Pressure Ageing Test (HiPAT). This is a modification of PAV. It uses a lower temperature (85 °C) and a longer test duration (65 hours). The reason for this modification is that in PAV real temperatures are not simulated, and generally, these are higher than those expected in pavement. A similar device to HiPAT for simulating aging of emulsions and asphalt binders that have been reduced with a high quantity of volatile oils and uses an extension of the test, in which samples are initially subjected to 85 °C for two hours in the RTFOT with nitrogen, followed by an application of hot air that lasts for 22 hours.

The PAV test, along with UV and infrared aging techniques, in theory, simulate the aging reached by asphalt binder during its useful life within the asphalt mixture (long-term aging) [21]. The sun emits energy in the form of electromagnetic radiation with bands that have a wavelength between 200 and 3000nm. Approximately 7 % of the solar radiation that reaches the earth’s surface is UV radiation (180-400 nm), 42% is inside the visible field spectrum (400-800 nm), and the remaining 51% is infrared radiation (IR) (800-3000 nm) [22]. UV procedures are more effective than infrared in terms of changes of physical properties of the analyzed asphalt binder. There are different methods for simulating UV aging, given that there is no existing standardized procedure. Most studies agree in varying the intensity of the radiation used, as well as asphalt film thickness and conditioning of samples during different periods of time and temperatures [2]. According to [23], although UV radiation aging techniques properly simulate the in-situ conditions of the binder, in practice, this type of aging mainly involves the more external portion of the analyzed binder (around 4 μm). In addition to UV and infrared radiation techniques, techniques that use microwaves have also been evaluated. Bishara [24] developed this technique. It applies microwave radiation at a temperature of 147 °C and an air pressure of 3.08 MPa during 4.5 hours. Based on physical, rheological and chemical analysis of the analyzed asphalt binders, they concluded the following: i) that results are comparable to those obtained for RTFOT+PAV; ii) microwave aging reduces more than 80% of the testing time; iii) it has a greater degree of repetitiveness than RTFOT+PAV.

Some researchers simulate long term aging using PAV, but subjecting asphalt films to diverse temperatures and exposure times (for example, [25]). Others expose asphalt films to climate during prolonged time periods, in order to then evaluate its physical properties in time. Chen et al. [26] for example, showed in Changsha (city with moist monsoonal subtropical climate), from June 2017 until May 2018, asphalt films of 3.2 mm in thickness which were previously aged in a TFOT in external climate, in order to then evaluate changes in its properties.

1.4. Short-Term and Long-Term Asphalt Mixture Aging

Regarding asphalt mixtures, studies in relation to the aging phenomenon may be divided in four categories: heating, oxidation, UV or infrared treatments and Steric Hardening. The basic process consists in first aging a mix and then determining the effects of aging on key parameters for the material such as stiffness, viscosity, resistance, etc. Within the heating procedure, mixes are normally exposed to high temperatures during a determined time period. Oxidation tests use a combination of high temperatures and oxidation techniques.

The conditioning protocol for the long-term mix in AASHTO R30 initiated by considering the results of studies such as the ones carried out by [27], however, it was developed in [1]. This protocol was designed to simulate in theory, the aging by the mix compacted during 7-10 years of service. In this method, asphalt mixtures in a loose state are initially subjected to short-term aging. This is done by placing mixes in an oven at 135° C during two to four hours (this process is called STOA - Short-Term Oven Aging). Then, STOA aged mixes are compacted, and the long-term aging process is simulated by placing mixes in an oven for 85° C during 120 hours. According to [4], the process described reproduces in-field aging for 15 years of service. Temperatures superior to 85° C could generate the destruction of samples, especially those that possess a high content of voids [28]. One of the main critiques made to the study developed by [1], is that for the development of this methodology, they mainly based their work in the resilient modulus test, which is not a mechanical parameter that evaluates damages to the mix. On the other hand. According to Smith and Howard [29], the literature suggests, that the current state of the art in regards to conditioning of mixes does not reliably reproduce 5 years of aging on the field for 5 years of service in some common climates in USA. In addition, they suggest to investigate additional protocols that consider other combined damage mechanisms (for example, moisture damage, tire wear, and volumetric changes through freeze–thaw cycles). Smith and Howard [29] mention that the 7-10 years of aging simulation on the field claimed by AASHTO R30 is not being supported by current research or other literature sources. These researchers recommend subjecting tests to oxidation processes inside the oven (for example, 5 days in the oven at 85 ° C), then subjecting them for 14 to 28 days in water at 64 °C, then subjecting them to cycles of freezing-drying (-22 ° during one day) accompanied by Cantabro tests for simulating 4-5 years of service. Additionally, in order to simulate long-term aging of mixes, several authors advise considering the effects of UV radiation [30-32].

Another test that seeks to evaluate the effects of aging and moisture damage simultaneously is SATS (saturation Aging Tensile Stiffness, EN 12697-45). In the conditioning phase, five samples (100 mm in diameter and 60 mm in thickness) are subjected to saturation through the use of a vacuum system. Then, they are transferred to a pressurized recipient that is partially full of water where they are subjected to a conditioning procedure through by storing them at a temperature of 85° C and a pressure of 2.1 MPs during 65 h. In regards to SATS conditioned mixes, resilient modulus tests are performed and the resulting value is divided by the one obtained before conditioning in order to evaluate the sensitivity of the compacted mix to the combined effects of aging and moisture [33-35].

Steiner et al. [36], provide an aging procedure that is named Viennese (VAPro). Inside a triaxial cell with a forced flow of a gaseous oxidizing agent (ozone and nitric oxides) which pass through a sample of asphalt mixture which is found to have similar temperatures to those present during summer time (45-70 °C) in order to increase the oxidation velocity of the material. According to them, this method accelerates the aging of material in shorter time frames than the ones that can be obtained with RTFOT+PAV.

Kumar and Goetz [37] used an oxidation method for the mix which consisted in blowing air with a pressure of 0.5 mm of water through compact samples which were aging at 60 °C during periods of 1, 2, 4, 6 and 10 days. In order to determine the hardening of mixes, creep tests were performed after each oxidation cycle, subjecting samples to cycles of loading/unloading at 21° C. They began with a load of 1 psi for conditioning and then they were subjected to 10 psi with loading and unloading periods of one minute each. Finally, the axial deformation of the specimen was determined by subjecting it to a load of 5 psi during 4 min.

Kemp and Predoehl [38] aged an asphalt mastic (using Ottawa sand as filler) and using an inclined rotating oven called TODT (Tilt Oven Asphalt Durability Test) and an angle of 1.06°, with the purpose of preventing asphalt binder from migrating from the bottles in the moment of rotation. Test temperature was 60 °C during different exposure times until getting to 1200 hours. Asphalt binder was recovered and analyzed after treatment and significant increases in viscosity were observed as exposure time increased.

Hugo and Kennedy [39] described asphalt mixture oven aging method where mixes are subjected to 100 °C. The procedure used to take between four and seven days in a dry atmosphere oven and in an oven with an atmosphere of 80% relative humidity in order to evaluate the effects of roadway projects near the coast. Likewise, asphalt binders were recovered from cores obtained in laboratory manufactured slabs. Sample viscosity was determined after the aging treatment and reported a significant increase in said physical property. Additionally, since samples were weighed before and after treatment, it was also possible to determine the loss of volatile elements. UV radiation effects was also evaluated in mixes by comparing laboratory prepared slabs and slabs extracted from recently built field projects. To estimations were used for this test: the first was exposing samples to 54 hours, to conditions similar to those used by [40], and the second one by using a Weather-Ometer Atlas during a period of 14 days. This way, they concluded that the aging index is a function of the percentage of voids, asphalt binder content and the penetration of the binder (asphalt binder type).

Kim et al. [41] used a modified POB and used 100 psi of pressure and 60 °C. These temperature and pressure levels were selected in an arbitrary manner because of safety purposes and in order to preserve the form of asphalt mixtures. Properties such as indirect tensile strength, resilient modulus, fatigue life and permanent deformation of mixes were measured before and after aging tests. They also extracted six in-field samples of three projects built in Oregon, United States (a total of 18 samples) and these were subjected to modulus tests. Some of the conclusions reported in this study were: i) POB is an effective mechanism for aging asphalt binders and asphalt mixtures through oxidation; ii) the relationship between modulus and Fraass breaking point are good indicators of the aging rate of mixes and asphalt binders, respectively; iii) the aging relationship of mixes varies with the relationship of voids contained in them. Mixes with a high content of voids age quicker, although the aging rate also depends on asphalt binder properties; iv) tests carried out in this study show that asphalt binders aged in a POB for 5 days have a similar composition to those recovered from field samples that have been in service for 5 to 10 years.

Mo et al. [42], performed a long-term aging test where they exposed porous asphalt mixtures during 1000 hours, to a combination of UV light (60 w/m^2, 300-400 wavelength), a temperature of 40 °C, relative humidity of 70% and environment oxygen flow, which in consequence reflect the first three years of in-field aging.

Some researchers have evaluated the aging of asphalt mixtures by exposing them only to climate during prolonged time periods, in order to then evaluate their physical properties on the field. Rondón and Reyes [43] for example, evaluated changes in resilient modulus, permanent deformation and resistance under monotonic load of a hot mix asphalt when it was exposed to the environment of the city of Bogotá D.C. (Colombia) during 47-48 months. Mixes were elaborated using two different asphalt binders (AC 80-100 and AC 60-70). These studies conclude that, the behavior in mixes depends on the type of asphalt binder used. In addition, the tendency in mixes, was increase in stiffness values with time and exposure to the environment, mainly occurring due to hardening processes that come through aging of asphalt binders. Khalid [44] placed asphalt mixtures samples in the roof of a building and exposed them to climate during 18 months. Said samples were manufactured using four asphalt cements (AC 80-100, two asphalts modified with SBS and EVA, and another one modified with synthetic rubber). The maximum and minimum temperatures reported were 29.7 and -3.6 ° C. Precipitation during the first 18 months was 1364 mm. They reported a notable increase in stiffness during the first 12 months, and then, said stiffness began to stabilize.

2. METHODS FOR REDUCING AGING EFFECTS

2.1. Rejuvenators

During the asphalt binder aging process, the loss of lighter components (saturated and aromatic) which become volatile [45], the conversion of aromatic compounds and resins into asphaltenes [46], and the increase of asphaltene content, produce as a result, the alteration of colloidal equilibrium. The introduction of rejuvenators that contain similar structures to maltenes into aged asphalt binders, compensate for their loss and promote colloidal stability in asphalt binders that may be properly dispersed in maltenes without precipitation or flocculation [10, 47-49]. In terms of physical properties, rejuvenators have the purpose of attempting to reduce asphalt binder stiffness, improving its thermal susceptibility, its behavior at low service temperatures and promoting its adhesion, among others [50-52]. According to ASTM D4552, a rejuvenator must have a viscosity that is sufficiently low in order to mix with aged asphalt binder, and having a flash point that is sufficiently high in order to be safe. According to [53], there are three rejuvenating methods. The most common method is mixing a rejuvenator with the aged asphalt mixture at a high temperature (140 °C-150 °C) or by spraying it over the surface of pavement. The second procedure utilizes Rejuvenator Seal Materials (RSM) used over aged pavement. The third rejuvenation procedure uses encapsulated rejuvenators, which upon breaking their capsule, the rejuvenator is liberated and filters inside micro-cracks, helping the healing process [45]. According to [54], the propagation of rejuvenators over the surface of roads has secondary effects, such as the reduction of skidding resistance of the surface pavement and only penetrates inside the first centimeters. In addition, roadways must be closed for some time after the application of this type of rejuvenators.

During the latest years, studies that use bio-modificators or bio-asphalts. Some such as swine manure has managed to reduce the viscosity of the base asphalt, improving cracking susceptibility at low temperatures, improving ductility and fracture energy [55-56]. Zadshir et al. [61] used this swine manure through sprinkling or "fog sealing" over pavement surface in order to delay aging caused mainly through UV radiation. Other used bio-rejuvenator that produce a good performance are distilled oil, waste cooking oil, maize oil, waste edible vegetable oil, soy oil, ground coffee oil, corn oil, corn crop residues, sawdust, and bio-diesel residues and their derivates such as cotton oil [51, 62-71]. Zhang et al. [72] used bio-oil derived from waste wood as a rejuvenator. According to them, this bio- rejuvenator has a high content of light compounds which help to reduce stiffness of aged asphalt binders. According to [62-63, 73], rejuvenating with bio-oil has the potential of restoring rheological properties of asphalt binders that have aged for an equivalent level of that found in virgin asphalt binders. Furthermore [74], explored the possibility of encapsulating waste cooking oil in microcapsules in order to rejuvenate aged asphalt binders. Results indicated that said encapsulated oil restored physical properties to a similar condition found in original asphalt binder.

2.2. Other Methods

Heat induction is a technique for sealing micro-cracks. Another promising and non-invasive approach is the addition of electricity conducting particles into the asphalt mixture, which may be heated through the combination of external electromagnetic induction. When these particles are heated, asphalt binder expands within the mix and its viscosity is reduced, giving it the capacity to flow through cracks and sealing them [75-77]. Another technique consists in heating and softening the existing asphalt layer by using electric resistance systems, microwaves or heaters that radiate infrared rays. However, these techniques could lead to a greater degree of asphalt binder aging [78]. Some use antioxidant agents, light protection agents and UV ray absorbing agents [79-82]. Among these, multidimensional nano-materials comprised of stratified silicates and inorganic nano-particles have been widely studied, and have reported beneficial effects in thermal aging resistance and photo-oxidation [83-86].

Liu et al. [87] used amorphous poly alpha olefin (APAO), which is a type of amorphous low molecular weight copolymer that is produced through the polymerization of propylene and ethylene. APAO is a milky white solid with a good tenacity, resistance to acid and alkaline agents, and has anti-oxidant properties. APAO is mixed with asphalt binder at high temperatures. Arafat et al [88] given its antioxidant properties, used three types of lignin in order to modify asphalt binder (replacing 6% of its mass): commercially available Kraft lignin, lignin precipitated from black liquor inside a laboratory and lignin produced using rice hulls, improved long-term asphalt binder aging resistance and PG at high service temperatures. Another anti-aging agent used is layered double hydroxide (Layered Double Hydroxides – LDH) [89]. Some researchers advise the use of pozzolanic materials such as lime and cement in order to reduce the aging effects in asphalt binders [90-92]. Norambuena-Contreras et al. [54] recommend the use of polymeric calcium alginate for the self- healing of asphalt binder.

3. CONCLUSIONS

Based on the literature reviewed, it is possible to conclude the following in regards to simulation techniques: i) the most currently used techniques for simulating short-term asphalt binder and asphalt mixture aging are RTFOT and STOA, respectively; ii) for the case of long-term aging, the most used ones are PAV and STOA+LTOA, respectively; iii) despite the broad number of investigations carried out, there is still no technique that can completely reproduce the aging conditions of asphalt materials, given that it is complicated to reproduce all the required environmental conditions inside a laboratory, (for example, UV, water, changes in temperature, among others); iv) aging simulation techniques must be accompanied by other techniques associated to the effects of durability (for example, interaction with water, abrasion wear resistance, among others). In order to reduce the aging of asphalt material, the most studied techniques are heat induction, superficial coating with protective materials and anti-oxidants, and modification of asphalts with rejuvenators, polymers, pozzolanic materials and nano-materials. All of these techniques are interesting, but still need a greater validation with in-field experimentation.

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