Chapter

Introductory Chapter: Asphalt and Asphalt Mixture

Haitao Zhang

1. Introduction

As the most important material for pavement construction, asphalt has always been valued. In 1987, the US Congress established the Strategic Highway Research Program (SHRP) to improve the performance and durability of US highways. The PG performance grading proposed by the US SHRP program is being learned and used by many countries in the world as a new technology. As a kind of polymer material, the microstructure of asphalt is very complicated. Therefore, the microstructure is not used as the evaluation index and standard, but the characteristic index and standard with theological basis are used in the classification of asphalt. The asphalt standards adopted by various countries also have their own characteristics. Some asphalt indexes are many, such as SHRP asphalt performance specifications and the European CEN asphalt new standards, and some have only a few indicators, such as the new Canadian asphalt standard and the Australian asphalt standard. The research on technical indexes and standards of asphalt in China has been carried out for many years, mainly referring to the indexes and standards of foreign countries. At the same time, combined with the test and material characteristics of China, some modifications have been made. The asphalt mixture is a multiphase dispersion system with space network structure, which is composed of aggregate and binder, and the mechanical strength of the asphalt mixture is mainly composed of the internal friction resistance and the embedding force between the mineral particles and the adhesive force between the asphalt cement and the mineral material. According to the proportion of the embedded structure and the dense structure in the asphalt mixture, the asphalt mixture structure is generally divided into three types: a suspended dense structure, a skeleton void structure, and a skeleton dense structure. Although the performance of a single material in asphalt mixture plays a very important role in the performance of asphalt mixture, the combination characteristics of asphalt and aggregate composition system in asphalt mixture have greater influence on the performance of asphalt mixture. The properties of asphalt mixture include permanent deformation, fatigue cracking, and low temperature cracking [1, 2].

There are three methods for asphalt mix design, namely Marshall design method, Hveem design method, and Superpave design method. The asphalt binder used in the Marshall design method of China asphalt mixture is based on the asphalt technical index system of JTG F40-2011. The system evaluates the performance of road asphalt with three major indexes of asphalt. According to different design traffic volume and different natural factors (temperature, etc.), asphalt binder is selected. A new asphalt mixture design system, superior performance asphalt pavement (Superpave), has been developed by the Strategic Highway Research Program in the United States. Compared with Marshall design method, Superpave design method is a completely different asphalt mixture composition design system, which includes new test equipment, material selection and design, test standards, and so on. With the continuous development of human society, people's functional requirements for pavements are increasing. How to further enhance the mechanical performance of asphalt pavements while taking into account functional indicators (drainage, noise reduction, anti-sliding, etc.) has become a problem to be solved.

Asphalt and asphalt mixtures mainly include (**Figure 1**):

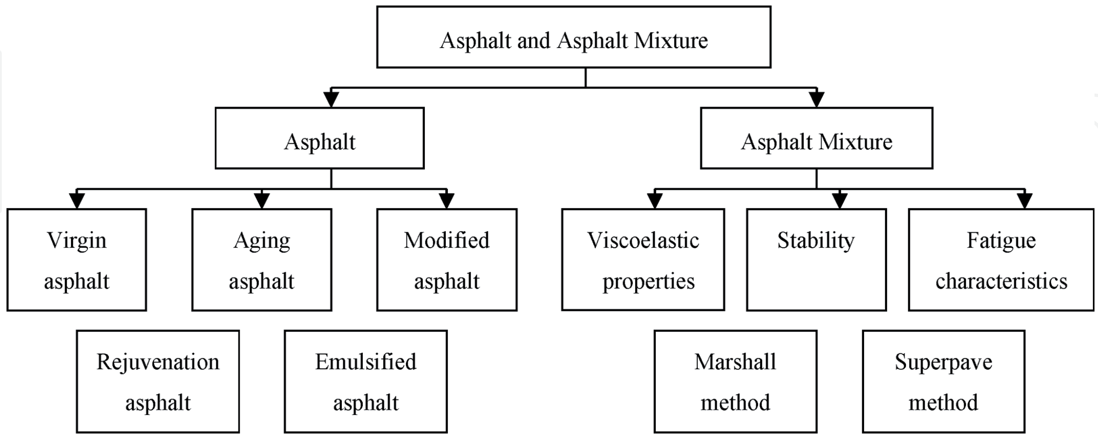

Figure 1.
Classification of asphalt and asphalt mixture.

2. Modified asphalt and mixture

As early as the early nineteenth century, rubber powder was first applied to asphalt. Rubber-modified asphalt first appeared in people's field of vision. In the middle of the nineteenth century, the vulcanization of asphalt was first proposed. It was found that the vulcanization of asphalt can have an important impact on the high temperature properties of asphalt. In the early twentieth century, France built the first road using rubber-modified asphalt. In the 1950s, the United States and Japan also conducted in-depth exploration of rubber-modified asphalt and verified it through the paving of many test roads. In the middle of the twentieth century, SBS-modified asphalt was studied, and there was a major breakthrough in 30 years. Nowadays SBS-modified asphalt has become popular; in the 1960s, styrene-butadiene (SBR)-modified asphalt was successfully developed. It was found that SBR-modified asphalt has a good improvement effect on low temperature stability. In the mid-1980s, China began research on SBS asphalt, from which SBS-modified asphalt appeared on the Chinese highway as the most extensive asphalt binder. At this stage, China's SBS-modified asphalt production has exceeded 500,000 tons; in the 1990s, rubber powder-modified asphalt began to appear in China, and in 1993, the first rubber-modified asphalt pavement was paved in Shenyang. Since then, modified asphalt has appeared in China's high-grade highways. During the 2008 Olympic Games, China launched the theme of Green Olympics, High-tech Olympics, and Humanistic Olympics. China put forward new ideas on the disposal of used rubber powder and organized a series of scientific research related to waste rubber powder [3].

The so-called modified asphalt (mixture) refers to an asphalt binder made of rubber, resin, high molecular polymer, natural asphalt, ground rubber powder, or other external admixture (modifier), thereby improving the asphalt or the performance of the asphalt mixture. A modifier refers to a natural or artificial organic or inorganic material added to asphalt (mixture). At the same time, with the development of the times, a single modifier has a certain effect on improving the durability of the asphalt mixture, but its ability to resist aging, plastic deformation, fatigue, and other durability is relatively weak, so the modification effect of a single modifier on asphalt cannot meet the requirements of existing pavement performance. Therefore, composite-modified asphalt has emerged. Composite-modified asphalt mainly refers to multiple modification of matrix asphalt.

Regarding the classification of modified asphalt, there is no uniform classification standard in the world, and it is currently classified mainly according to the variety of modifiers used. The modified asphalt can be roughly divided into three categories according to the different modifiers:

1. Rubber and thermoplastic elastomer-modified asphalt including natural rubber-modified asphalt, SBS-modified asphalt, styrene-butadiene rubber-modified asphalt, neoprene-modified asphalt, butadiene rubber-modified asphalt, butyl rubber-modified asphalt, waster rubber- and recycled rubber-modified asphalt, other rubber-modified asphalt (such as ethylene propylene rubber, nitrile rubber, etc.).

2. Plastic- and synthetic resin class-modified asphalt including polyethylene-modified asphalt, ethylene-vinyl acetate polymer-modified asphalt, polystyrene-modified asphalt, coumarin resin-modified asphalt, epoxy resin-modified asphalt, α-olefin random polymer-modified asphalt.

3. Resonance-type polymer-modified asphalt: the asphalt is modified by adding two or more polymers to the asphalt at the same time. The two or more kinds of polymers referred to herein may be two separate high molecular polymers or may be a so-called polymer alloy which has been previously blended to form a polymer interpenetrating network.

As a complex polymer hydrocarbon, asphalt exhibits typical elastic-visco-plasticity under certain temperature and load. The main purpose of adding modifiers is to improve the high and low temperature properties of asphalt mixtures (anti-rutting, anti-fatigue, anti-aging, resistance to low temperature cracking, etc.). The mechanism of action of the modifier can be summarized as follows: the modifier is sufficiently miscible with the asphalt. On the basis of this, the modifier adsorbs the light components in the asphalt and swells, the swelling modifier, and the rest of the asphalt. The components interact to form a new resulting system, combined with the inherent properties of the modifier itself to provide a corresponding improvement in asphalt performance. At the same time, in the grinding process and under the action of the stabilizer or the catalyst, the chain scission and the cross-linking reaction occur, and some network structures are formed, so that the viscosity and storage stability of the modified asphalt are improved. Therefore, the modified asphalt is a new structural material that has both the basic characteristics of asphalt and polymer.

3. Asphalt aging and rejuvenation

3.1 Mechanism of asphalt aging

Asphalt aging refers to a series of volatilization, oxidation, polymerization, and other changes under the action of environmental factors (heat, oxygen, sunlight, and water). In the aging process, the light components in the asphalt are volatilized and absorbed, the molecular structure is changed, the asphalt is hard and brittle, and the adhesive property is reduced to generate cracks. Asphalt aging is mainly manifested by increasing softening point and decreasing penetration. Although the aging of asphalt will enhance the rut resistance of asphalt pavement at high temperature, the low temperature performance and fatigue resistance of asphalt pavement will be greatly reduced; thus the adhesion and bonding ability of asphalt pavement will become worse. Asphalt aging is a gradual process, and its rate directly affects the service life of pavement, so it is the main factor affecting the durability of asphalt pavement [4].

3.2 Classification of asphalt aging

3.2.1 Short-term aging

1. Transport and storage process. The asphalt transportation is about 170°C, the number of the process asphalt is large and the depth is large, so that the contact air is small and the aging degree is small.

2. The aging of the mixing process. The aging of asphalt in this process will be further aggravated because the asphalt in this process is fully in contact with many factors, such as air.

3. The aging of the construction period. Asphalt from transportation to construction, temperature reduction and recovery to natural temperature, site paving, rolling, so that asphalt aging further development.

3.2.2 Long-term aging

The long-term aging of asphalt is a complex and slow process, continuous and uninterrupted, and the action factors are complex. The aging degree is further increased with the influence of vehicle load and temperature.

3.3 Aging of asphalt pavement and its influencing factors

3.3.1 External reasons

1. The service life of the road surface. The longer the service life of asphalt pavement, the worse the aging.

2. The asphalt pavement has different depths. The study shows that the depth of the asphalt pavement with severe aging is generally only in the range of 0.5–1 cm.

3. Asphalt pavement location is different. Aging is more severe in places where there are more axles than axle rolling less.

4. Grading type of mixture. Under the same porosity, the air permeability of intermittent graded mixture is smaller than that of continuous graded mixture.

3.3.2 The internal reasons

The aromatic components (Ar) in asphalt and oxygen in air are oxidized to form colloidal (R). In the process of aging, colloids can easily be transformed into asphaltene (A) components with poor relative molecular weight through polymerization and condensation.

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3.4 Asphalt regeneration mechanism

3.4.1 Regeneration mechanism of old asphalt materials

There are two theories on the mechanism of old asphalt regeneration:

1. Compatibility theory: it is considered that the aging of asphalt is due to the decrease of the compatibility of each component in the asphalt colloid system, which leads to the increase of the solubility parameter difference of the components. It is considered that the solubility parameter difference can be reduced by adding a certain regenerated agent and the asphalt can recover to (or even exceed) the original property [5].

2. The theory of component regulation: it is considered that the pavement performance of asphalt decreases due to the migration of components and the uncoordinated proportion of each component after aging. It is considered that the asphalt can be restored to its original properties by adding regenerated agent to adjust its components. Therefore, in order to restore the original performance of the aged asphalt, it is necessary to compare the components of the aged asphalt with the original asphalt and add the missing components (i.e., adding asphalt recycling agent) to the aging asphalt so that the components can be re-coordinated.

3.4.2 Asphalt regeneration method

1. New and old asphalt mixing and regeneration. Mix the new asphalt with higher grade with the old asphalt, and mix the softer new asphalt with the aged old asphalt. The mixed asphalt meets the road asphalt standard.

2. Regeneration agent regeneration. Adding proper amount of recycled additive to the old asphalt can not only adjust the viscosity of the old asphalt but also supplement the lost chemical components of the old asphalt, restore the performance of the original asphalt, and even exceed the performance of the original asphalt.

3. Mixed regeneration. When the new asphalt is added and the recycled agent is mixed, the recycled material can obtain better performance.

4. Functional asphalt mixture/pavement

With the continuous development of social civilization and the continuous improvement of road engineering construction level, people's understanding and functional needs of road are increasing day by day. Since the twenty-first century, the emergence of new functional materials and the development of cross-discipline have provided a powerful support for the design and construction of all kinds of environment-friendly functional pavement and further broaden the research field of pavement materials. Constructing environment-friendly functional pavement, further improving road area environment, has become the frontier direction of road engineering material discipline development. As a part of road structure which acts directly with driving load and natural environment, the traditional requirements of traditional pavement are load bearing, leveling, safety, and durability.

In addition to the basic requirements to ensure normal road driving conditions, modern pavement should also have new environmental protection functions, such as water permeability, noise reduction, low heat absorption, car exhaust pollution, and so on, from the point of view of improving human settlements. Pervious asphalt concrete, generally used as a wear layer for pavement. Many large-scale tests of permeable asphalt concrete were carried out in 1967 to determine the applicability of permeable asphalt macadam to heavy traffic roads. The research report of Szatkowski and Brown pointed out that the asphalt macadam mixed with large particle-size aggregate generally has the maximum voidage permeability and texture depth, and the material mixed with 19 mm aggregate has a good effect on reducing the water fog caused by traffic. By reducing a large amount of water fog, the reflection phenomenon on the road surface can be eliminated, so that the road signs can be kept in high visibility, which is beneficial to traffic safety. At the same time, the rainwater falling on the surface of the permeable asphalt gravel can flow out of the pavement through the pores inside the surface layer, so that it also acts as a drainage layer. The rainwater can be allowed to permeate out of the surface layer instead of being accumulated on the surface of the road to form a water film or runoff, thereby avoiding the phenomenon of water drift generated when the vehicle is traveling at a high speed on a general road surface in rainy days. The surface of the road has a rough macroscopic texture, and the tire surface strengthens the contact with the road surface when the vehicle is driving at high speed in rainy days, which helps to maintain good anti-slip ability. The noise generated by vehicles on porous pavement is much lower than that of ordinary asphalt pavement with the same anti-skid degree, 3–4 dB (A), lower when dry, and 78 dB (A) lower in wet condition. Another advantage of permeable asphalt macadam pavement is to reduce the rolling resistance of vehicle tires and save a lot of fuel.

Although permeable asphalt pavements have many distinct advantages, there are some disadvantages that must be overcome, for example, how to balance their mechanical properties and functional specifications. The allowable variation range of the asphalt content of the permeable asphalt mixture is small, and if the asphalt content is too low, the road surface may be damaged in advance. On the other hand, if the asphalt content is too high, the asphalt will flow in the process of transportation or paving, resulting in uneven asphalt content. At present, the mixing ratio design method of the porous asphalt mixture is to adopt a leak test and a scattering test. The existence of voids makes the pavement materials more exposed to water, air, ultraviolet, and other environmental factors. The formation mechanism of contact interface strength between aggregates and binders is systematically studied, which is of great significance to improve the bonding strength and durability of aggregates and binders. The composition characteristics and functional objectives of porous pavement materials determine that the service environment is relatively complex, and it is necessary to meet the function and balance of multiple physical fields, such as sound absorption, water permeability, heat transfer, and so on. Therefore, it is very important to study its road performance under the action of multi-physical field coupling [6].

5. Microstructure behavior of asphalt

In the process of asphalt research in recent years, the macroscopic study of asphalt has always been a leading position. Therefore, the proportion of the study on the microstructure characteristics of asphalt will gradually increase in the future research. Moreover, the microstructure of asphalt is extremely complex, and the domestic and foreign researches on it are not perfect, so increasing the research

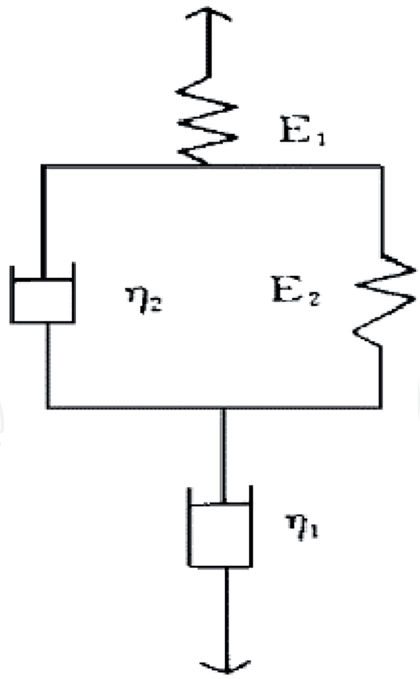

Figure 2.
Burgers model.

on the microstructure of asphalt has great significance for the development of asphalt. Rheological model, infrared spectrum, and atomic force microscope are used to study the microstructure of asphalt. Structural characteristics of asphalt are generally studied by using existing rheological models, including Maxwell model, Kelvin model, Burgers model, etc. However, Burgers model is the most common one that can demonstrate the viscoelasticity of asphalt in a more comprehensive way. And it is composed by a set of Maxwell models and a set of Kelvin models (shown in **Figure 2**). The constitutive equation is as follows:

$$x(t) = e\left[\frac{1}{E_1} + \frac{1}{Z_1}t - \frac{1}{Z_2}\left(2 - e^{\frac{-E_2}{Z_2}t}\right)\right]$$

where e is load, t is time, E_1 and E_2 are moduli of elasticity, and Z_1 and Z_2 are the viscosity coefficients.

According to the US SHRP program, when we understand two moduli of elasticity and two viscosity coefficients, we can understand the viscosity characteristics of different asphalt and thus understand the structural characteristics of asphalt. Infrared spectrum analysis can be used to analyze the microscopic mechanism of different modified asphalt and different aged asphalt. By scanning the changes of asphalt molecules by projection spectrum, the relationship between component content and characteristic absorption peak absorbance is analyzed, so as to determine the content of different components of different asphalt. Infrared spectrum analysis is common now because of its simple sample preparation and sampling, short test and analysis time, and high accuracy of measured results. The detection principle of AFM is that during the scanning process, the change in the height of the sample microsurface will change the micro-force (attraction or repulsion force) between the tip and the sample surface and the microcantilever will be deviated according to Hooke's law. Usually, this offset will cause the reflection number of the laser source irradiated on the back of the microcantilever to change, and it will be sensed by the photodiode. After processing, the surface topography of the sample, namely, the "peak structure," can be obtained. Through the observation of the peak structure of asphalt and image processing technology, the fractal dimension and other technical means are used to analyze the internal micro of asphalt. Different aging time and modifier will affect the area of "peak structure," which will also affect the microstructure characteristics of different asphalt.

In the development of modern asphalt, the research on modified asphalt has been more and more mature. More and more materials are used in the study of modified asphalt, from which a lot of valuable experience has been obtained. The asphalt modified by different materials has different effects. Among all modified asphalt, nanomaterial-modified asphalt is of great research value. In recent years, nanomaterials have been widely used in the field of road materials. Nano-modified asphalt is a kind of asphalt nanocomposite material, which mainly studies the performance of nanomaterials on road building materials. Many achievements have been made in the experimental research, practical application, and research methods of nanomaterial-modified asphalt at home and abroad, but there are still many deficiencies. Therefore, the preparation process of nanometer-modified asphalt should be improved, and new test methods and research methods should be explored to make the preparation process of nanometer-modified asphalt simple and the road performance good [7].

6. Asphalt pavement

Road pavement is divided into asphalt pavement, cement concrete pavement, and earth pavement. With the rapid growth of economy, people continue to improve and innovate in the construction of roads. In recent years, most of them use asphalt to build expressways or first-grade highways. People are also constantly renovating a large number of asphalt pavements built in the early stage to improve the pavement quality and make it more flat, so as to extend the service life of the pavement.

Asphalt pavement must have several basic conditions in the process of use:

1. It has some strength. The pavement will produce certain deformation under the action of load. If the allowable stress of pavement material is not enough to resist the stress generated by pavement structure layer, the pavement will produce failure cracking.

2. It has certain stability. Stability of asphalt pavement includes high and low temperature stability, water stability, etc. High temperature stability is shown in the ability to resist permanent deformation of asphalt pavement, and low temperature stability is shown in the ability to resist low temperature cracking of asphalt pavement. Water stability refers to the ability not to damage under the action of water and load.

3. Good durability. There are many factors that affect the durability of asphalt pavement, including temperature, humidity, material performance, load size, and so on, which will have an impact on the durability.

4. Good flatness. Good flatness can reduce the loss of the car but also can improve the speed of the car and the ride in the process of comfort and safety.

5. Good skid resistance. The car on the smooth road driving lack of wheel and road friction, easy to appear dangerous, especially in rainy or snowy days when suddenly start or brake, will produce idling or skid phenomenon, serious traffic accidents will occur. Therefore, it requires high skid resistance for the road surface.

With the continuous development and improvement of asphalt pavement, there are many kinds of modern asphalt pavement, such as functional asphalt pavement, smart pavement, and recycled pavement. Functional asphalt pavement refers to the pavement with different functions on the basis of the original materials, which gives different functions and functions to asphalt pavement, including high-modulus anti-rutting asphalt pavement, porous drainage noise reduction asphalt pavement, and flame-retardant asphalt pavement. The appearance of functional pavement improves the performance of asphalt pavement and makes a great contribution to the improvement of ecological environment and sustainable development in the future. From the development trend of asphalt pavement in China, these roads have a good development prospect.

Europe has given an open definition of the smart road, which means that the next generation of roads should be adaptive, automated, and resilient, with the ability to easily accommodate new technologies and adapt to climate change. Smart road is all kinds of information, technology and function of the integration of the body, have more access to the information and data processing method, technology and development of the service function will be constantly updated, all of which require a unified architecture to build efficient, flexible and economic system, intelligent pavement for designers to provide the necessary guidance and support. Therefore, the development of intelligent road surface will be an important branch of road surface development in the future.

Globally, asphalt mixture recycling has been used in practical engineering since the early twentieth century, but it was ignored until the oil crisis of 1973. The emergence of oil crisis makes asphalt pavement regeneration technology has a great development. By the second half of the twentieth century, asphalt pavement recycling technology has made a lot of research achievements. The United States, Britain, Germany, Japan, and other countries have prepared suitable for their own application of recycling technology manuals, guidelines and specifications. Compared with Europe and America, the research on asphalt pavement regeneration technology started relatively late in Asian countries except Japan. With the deepening understanding of the huge environmental and economic benefits brought by this technology, Asian countries accelerated the research on this technology, and now it has been widely used in all countries. Recycled asphalt mixture can be regarded as a special asphalt mixture, because it contains a certain proportion of old mixture; this part of the old aging material will have a certain impact on the performance of recycled mixture. This will make a certain contribution to the environmental protection cause in the future [8].

7. Conclusions

In recent years, with the rapid development of the world transportation industry, the proportion of asphalt pavement in road engineering is increasing. Therefore, while the demand for asphalt and asphalt mixture is increasing, the quality requirements for materials are also increasing. In particular, new materials and new technologies are constantly emerging, and the application technology, theory, and technical specifications of asphalt materials have made great progress and updates. Porous structural materials can achieve functions such as noise reduction, water permeability, temperature reduction, and decomposition of automobile exhaust, but the durability, functional improvement, and curing methods of various materials need further study. The change in understanding of the pavement from a single channel function to a comprehensive channel plus environmentally friendly function is not only due to the expansion of the pavement function, which will lead to an update of the pavement material and structural technology design concepts. The results will drive the progress of modern road engineering technology and the development of related social industries. At present, the main problems in the research of asphalt and asphalt mixture are how to further improve the durability of asphalt pavement and the prevention and control of asphalt pavement diseases. These problems are the key problems that affect the service life of asphalt pavement. The proposal and research of these problems will further promote the application of asphalt pavement. The traditional asphalt pavement mainly emphasizes the mechanical properties of the pavement. With the continuous development of human society, asphalt pavement should not only meet the requirements of mechanical properties but also meet the functional requirements, such as pavement drainage, noise reduction, and so on. Asphalt pavement with both mechanical performance index and functional index has gradually become a research hotspot.

Author details

Haitao Zhang
College of Civil Engineering, Northeast Forestry University, Harbin, China

*Address all correspondence to: zht6781@163.com

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