Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(11) (2022) 1045-1048
DOI: 10.22060/ceej.2020.18548.6897

Effect of Long-Term Aging on Low-Temperature Cracking of Asphalt Mixtures using Mechanical and Thermodynamic Methods

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ABSTRACT: One of the common phenomena in the cracking of asphalt pavements is thermal cracks or cracks due to low temperature, which occur in cold regions and accelerate the distresses of road structures. Numerous different factors can affect the behavior of asphalt mixtures at low temperatures. The factors affecting heat cracking in asphalt concrete pavements are generally divided into three categories: materials, environment, and geometry of the pavement structure. Factors related to materials in the occurrence of thermal cracks include bitumen, type and aggregate granulation, percentage of bitumen, and percentage of air pores. One of the most important factors affecting the occurrence of thermal cracks in bitumen is its aging or the age of pavement. As a result, bitumen aging has a direct effect on pavement performance. In most existing studies to investigate the aging performance of asphalt mixes, the results of mechanical tests are used to investigate the thermal cracking potential of an asphalt mix and less attention is paid to the basic properties of materials that are important in the event of this cracking. Accordingly, the present study investigates the effect of aging on thermal cracking of 12 different compositions of asphalt mixtures through mechanical methods and surface free energy (SFE), which is based on the main properties of the material. Thermal cracking of asphalt mixtures has been evaluated by performing semi-circular bending mechanical tests and thermodynamic tests by determining the SFE components of bitumen and aggregates. The results showed that the parameters of fracture energy and fracture toughness, which are known as indicators of sensitivity of asphalt mix to thermal cracking, for aged asphalt mixtures between 6.3-13.7% and between 6.5-10.7%, respectively. The results of SFE tests showed that aging causes an increase in the non-polar component between 1.3-1.5% and a decrease in the acidic and basic free energy components of bitumen between 41.1-53.4% and between 334.2-349.6%, respectively. These results have increased the amount of free cohesive energy from 0.63 to 1.03 (ergs/cm2). Also, aging reduces the free energy of bitumen-aggregate adhesion with a maximum reduction of 2.61 (ergs/cm2). This means that aging reduces the cover-ability of bitumen on the aggregate surface and the resistance to fracture at the bitumen-aggregate interface.

Review History:

Received: Jun. 05, 2020
Revised: Nov. 13, 2020
Accepted: Nov. 15, 2020
Available Online: Nov. 18, 2020

Keywords:

Hot asphalt mix
Thermal cracking
Aging
Semi-circular bending test
Surface free energy.

1- Introduction

The aging of bitumen occurs during the production process of asphalt mix and during operation, which is exposed to environmental conditions [1]. The first stage of aging, called short-term aging, usually occurs at a high rate. Short-term aging occurs when bitumen and aggregates are heated to high temperatures and mixed. At the end of this stage, the asphalt mixture is moved to the project site, spread, and compacted, which is considered as part of short-term aging. The second stage of aging, known as long-term aging, occurs much faster than the first stage during the operation period. After applying the asphalt mixture, aging usually occurs for 2-3 years so that the specific gravity of the asphalt mixture reaches its maximum and after this time no more compaction occurs. Most of the aging occurs at this time, but usually, the aging process continues between 8 and 12 years [2]. Aging significantly affects the mechanical properties of asphalt mixtures (including hardness modulus, phase angle, etc.) and consequently the performance of asphalt mixtures. Therefore, it is necessary to know the characteristics of the aged asphalt mixture to properly plan the mixing of asphalt layers and pavement structures [3].

In recent years, the use of surface free energy (SFE) method as one of the valid methods in the science of adhesion in the occurrence and modeling of moisture failure of asphalt mixtures has been used, which has interesting results about the process of this failure and the role of effective parameters in it [4, 5]. However, the use of this theory to investigate the occurrence of low-temperature cracking has not been considered. Given the close relationship between the occurrence of thermal cracking and the theory of thermodynamics, it can be expected that its use can be useful

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in identifying the effective parameters in the occurrence of cracking of asphalt mixtures. Accordingly, in this study, using the SFE method, the effect of long-term aging on the thermal cracking potential of asphalt mixtures is investigated and the results of this theory are compared with the results of mechanical tests. The most important objectives of the present study are as follow:

-The effect of aging on bitumen SFE components and cracking in mastic.

-The effect of aging on the free energy of bitumen-aggregate adhesion and cracking at the bitumen-aggregate contact surface.

-Investigation of the effect of aging on the results of performance tests of asphalt mixtures at low temperatures.

-Relationship between the results of thermodynamic parameters and semicircular bending of asphalt mixtures.

2- Methodology

In this study, two types of bitumen with a degree of performance of PG 58-22 and PG 64-16 and a polymer additive called polyethylene with very high molecular weight (UHMWPE) in two percent of bitumen mass, along with two types of base aggregates (limestone and granite) Used. experiments to determine the SFE of bitumen and aggregates are performed separately in different states, and mechanical tests are performed to determine the potential for low-temperature cracking on asphalt mixtures.

In this research, UHMWPE polymer has been used to improve bitumen. For this purpose, a high-speed agitator was used. The mixing process was continued for 25 minutes to modify the bitumen so that the additive particles were evenly distributed in the bitumen space. To prevent the temperature of the bitumen from decreasing next to the bitumen container, the heater surrounding the bitumen container has been used. Because the modified bitumens may have suffered some aging at the mentioned temperature and time, this process has also been performed for the control bitumens so that the effect of aging in analyzing the results and comparing the results does not cause errors.

3- Results and Discussion

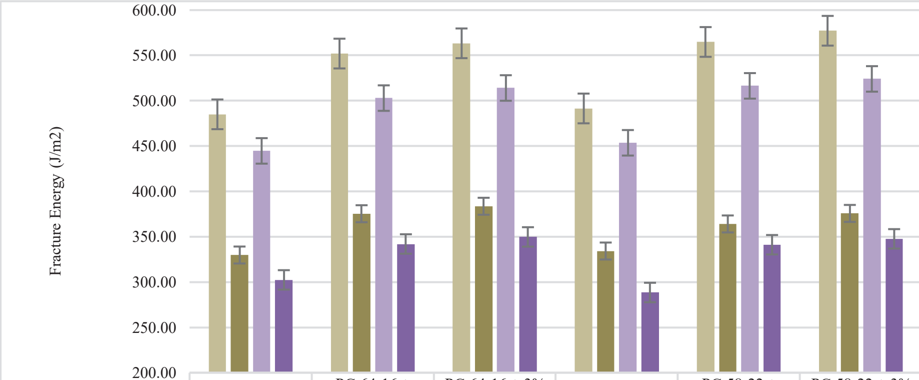
The results of measurements of SFE components of the base and modified bitumens in the form of unaged and aged are presented in Table 1. The results related to the acidic components and the SFE base in Table 1 show that the bitumens in the ground state shows more acidic properties compared to the basic properties. The use of UHMWPE has increased the free energy component of the surface and decreased its acid component. The aging process has caused the acidic component of SFE to increase significantly and its alkaline component to decrease slightly. This can have a negative effect on the adhesion due to the polar cohesions formed between the aged bitumen and the aggregates such as limestone.

The results related to the polar SFE component of aged and aged bitumens in Table 1 show that PG 28-22 bitumen has a higher polarity component compared to PG bitumen 16-64. Polar cohesions usually do not have good strength against moisture but have good resistance to environmental conditions. Oxidation with high temperatures increases the polarity of molecules and thus increases the aggregation and cohesion of these molecules. The use of the UHMWPE additive also increases the polar SFE component of the modified bitumen. The increasing polar SFE component is also observed due to aging in the modified bitumens.

The results show that the polar cohesion of bitumen plays a very important role in the performance of bitumen against its failure. Non-polar cohesions are usually due to the cohesion between aromatic oils and bitumen saturation. As a result of aging, it is observed that the percentage of these oils in bitumen decreases. This reduces the non-polar SFE component of the aged bitumen. Reduction in the non-polar SFE component of bitumen, in addition to increasing the viscosity and hardness, reduces the non-polar cohesions formed between the bitumen and the aggregates. These joints are very effective in the resistance of the asphalt mixture to exposure.

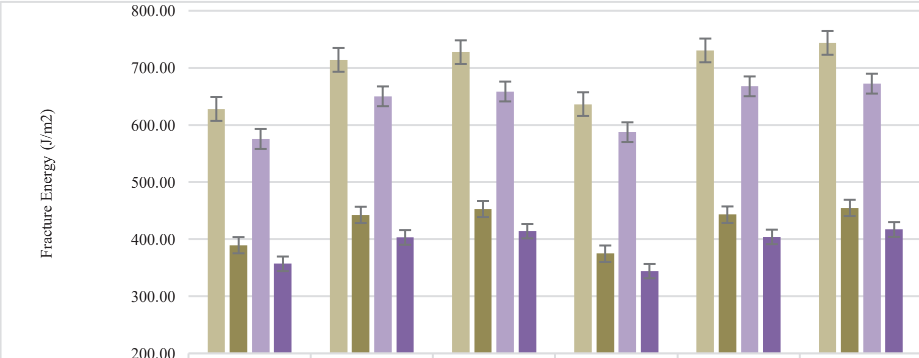
The results related to the failure parameter in different asphalt mixtures at low, medium, and high temperatures are presented in Figs. 1 to 3, respectively. The results showed that aging has significantly reduced the fracture energy in samples of asphalt mixtures. In fact, the aging of bitumen increases the amount of bitumen cohesion energy but decreases the bitumen-aggregate adhesion energy. Given that the fracture energy is the sum of the absorbed energy from the moment of loading to the moment of failure, it can be said that aging has caused the ability to absorb stress by the asphalt mixture. This is present in all samples of asphalt mixtures, where aging causes a reduction in the amount of fracture energy, but in samples made with bitumen PG 58-22 is more. In fact, these bitumens have better performance in cold weather conditions than PG bitumen 16-64. On the other hand, the amount of oil in these bitumens is more than PG bitumen 16-64. This causes the aging to cause a greater performance difference between the control and aged bitumens in samples containing PG 58-22 bitumen than PG 64-6 bitumen.

By comparing the results of the amount of fracture toughness in the aged and aged samples, it can be seen that aging has caused the value of the fracture toughness parameter to be significantly reduced. In fact, aging causes the percentage of asphaltene in the bitumen structure to increase and the lighter parts of the bitumen to evaporate or become larger molecules. These changes cause the aged bitumens to have less flexibility. Cold weather also intensifies the brittleness properties of bitumen. The result is low-temperature cracking in pavements that are several years old and exposed to thermal cycles or a very short cold period. Also, the comparison of the results between PG 58-22 and PG 64-6 bitumens shows that the use of PG 58-22 bitumen has caused the asphalt mixtures to have a better performance against low-temperature cracking. This can be attributed to the higher percentage of oils in the bitumen structure of PG 58-22.



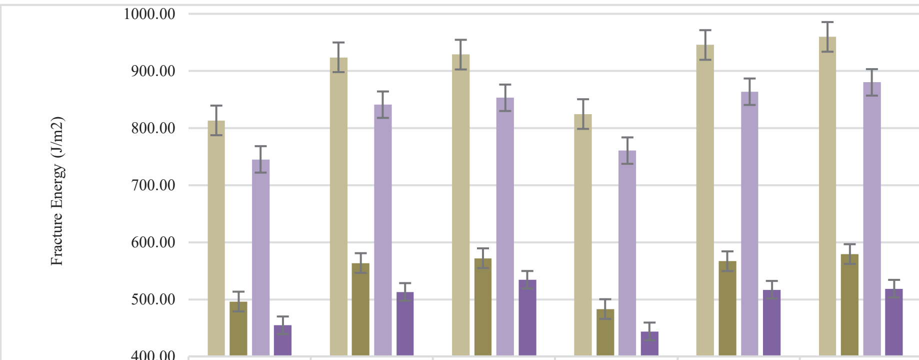
	PG 64-16	PG 64-16 + 1.5% UHMWPE	PG 64-16 + 3% UHMWPE	PG 58-22	PG 58-22 + 1.5% UHMWPE	PG 58-22 + 3% UHMWPE
Limestone (Unaged)	485.03	552.04	563.38	491.51	564.86	577.21
Limestone (Aged)	329.82	375.39	383.62	334.23	364.10	375.70
Granite (Unaged)	444.68	502.94	514.09	453.62	516.42	524.08
Granite (Aged)	302.38	342.00	349.78	288.46	341.16	347.65

Fig. 1. Fracture energy in controlled and aged samples (temperature -20 °C)



	PG 64-16	PG 64-16 + 1.5% UHMWPE	PG 64-16 + 3% UHMWPE	PG 58-22	PG 58-22 + 1.5% UHMWPE	PG 58-22 + 3% UHMWPE
Limestone (Unaged)	627.99	714.01	727.50	636.48	730.63	743.77
Limestone (Aged)	389.35	442.69	452.99	374.62	442.99	454.94
Granite (Unaged)	575.52	650.18	658.72	587.22	667.66	672.51
Granite (Aged)	356.82	403.11	414.07	344.07	403.95	416.95

Fig. 2. Fracture energy in controlled and aged samples (temperature -10 °C)



	PG 64-16	PG 64-16 + 1.5% UHMWPE	PG 64-16 + 3% UHMWPE	PG 58-22	PG 58-22 + 1.5% UHMWPE	PG 58-22 + 3% UHMWPE
Limestone (Unaged)	813.30	923.84	928.53	824.43	945.41	959.58
Limestone (Aged)	496.11	563.54	571.96	482.90	566.70	579.25
Granite (Unaged)	745.08	840.85	852.92	760.39	863.54	879.94
Granite (Aged)	454.50	512.92	534.18	443.84	516.76	518.66

Fig. 3. Fracture energy in controlled and aged samples (temperature 0 °C)

4- Conclusion

The aging process and its effect on the properties of asphalt mixtures have been studied in several studies. However, the study of the effect of aging on the basic properties of materials based on the concepts of the SFE method can provide results that provide a better view of the process of various failures in asphalt mixtures and provide methods to prevent these failures for researchers and design engineers. Accordingly, in this study, the role of long-term aging on bitumen SFE parameters and its effect on cohesion failure in bitumen and adhesion failure at the bitumen-aggregate contact surface has been investigated. Also, an attempt has been made to investigate the cracking potential of low temperature at three different temperatures using the semicircular bending method and the results of this experiment are compared with the results of the SFE method. The most important results obtained in this study are:

•Aging has caused the volatile oils of bitumen to evaporate and the concentration of heavy and polar parts such as asphalt to increase. This has led to an increase in the polar and non-polar SFE components of aged bitumens compared to unaged bitumens. Also, aging has caused an increase in the acidic component and a decrease in the SFE component of the bitumen used in this study.

•The aging of bitumen has caused a significant increase in the amount of free cohesive energy of this material. The main reason for this can be a decrease in the percentages of aged bitumen oil and an increase in its asphaltene concentration.

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HOW TO CITE THIS ARTICLE

P. Moradi, H. Shirmohammadi, Gh. H. Hamedi, Effect of Long-Term Aging on Low-Temperature Cracking of Asphalt Mixtures using Mechanical and Thermodynamic Methods, Amirkabir J. Civil Eng., 53(11) (2022) 1045-1048.

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