A Review of the Rheological and Chemical Properties of Sasobit-Modified Asphalt Binders and Life Cycle Assessment of Warm Mix Asphalt Mixtures

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ABSTRACT

Numerous research and review studies have been conducted by various researchers on the introduction of Warm Mix Asphalt (WMA) technology with the aim of reducing energy consumption and environmental pollutants, and each has briefly analyzed the advantages and disadvantages of this technology on asphalt mixtures and bituminous binders. This study has been conducted as a review study considering the scientific position of Iran in the field of WMA related research as well as the potential for its field application in the construction of green and environmentally friendly pavements. Based on previous studies, this research focuses on the rheological behavior of Sasobit-modified binders and also investigates their chemical characteristics and the life cycle of modified pavements. The analysis and evaluation of previous research findings indicate that the behavior of Sasobit-modified binders is influenced by simultaneous changes in the rheological, chemical, and microstructural characteristics of the binder. Understanding the rheological and chemical characteristics of modified binders, particularly through tests such as Atomic Force Microscopy (AFM), Fourier Transform Infrared Spectroscopy (FTIR), Saturates–Aromatics–Resins–Asphaltenes (SARA) fractionation, and Surface Free Energy (SFE), and integrating the results obtained from these tests, can provide a more comprehensive understanding of the performance of Sasobit and help predict the behavior of binders modified with this additive. Therefore, considering the simultaneous rheological, chemical, and environmental aspects of Sasobit-modified binders and pavements can facilitate the targeted selection and application of this additive in the development of Warm Mix Asphalt.

KEYWORDS

Sasobit, Chemical Properties, Microstructure, Aging, Life Cycle Assessment (LCA)

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1. Introduction

Nowadays, base binders are often modified with additives and polymers, such as crumb rubber and styrene-butadiene-styrene (SBS), because they do not perform adequately over a wide range of temperatures. These modifications can improve the performance range of the binder. However, the use of high polymer contents increases binder viscosity and reduces the workability of the modified asphalt mixture. On the other hand, the high production temperatures required for modified hot mix asphalt can have several negative environmental impacts, including higher greenhouse gas emissions, increased carbon monoxide emissions, and greater fuel consumption. These effects cannot be overlooked. In addition, in line with the policies adopted by developing countries, long-term plans have been developed to phase out fossil fuels from energy production and minimize carbon emissions. Achieving these goals requires the use of clean and innovative technologies to move toward sustainable development. In this regard, warm mix asphalt (WMA) technology has emerged as a promising approach and is considered a sustainable solution for reducing carbon emissions while improving economic efficiency [1]. Among WMA additives, Sasobit is one of the most widely used organic additives for producing warm mix asphalt. By reducing binder viscosity, Sasobit improves the workability of asphalt mixtures and reduces the energy required for mixing and compaction. In recent years, this additive has received more attention than many other WMA additives, and several studies have investigated its performance and compared it with other additives. Given the importance of this topic, the effects of Sasobit on the chemical and microstructural characteristics of Sasobit-modified asphalt binders are discussed and reviewed in this study.

2. Methodology

Despite the considerable increase in studies on the use of Sasobit in recent years, a detailed review of the previous literature shows that some aspects of the behavior of Sasobit-modified asphalt binders still require a more comprehensive analysis and synthesis. Previous studies have mainly focused on the performance of warm mix asphalt and changes in rheological properties, while the relationships among changes in the chemical characteristics of the binder, microstructural features, rheological behavior, and overall performance of Sasobit-modified binders have received less integrated attention. In addition, the results obtained from microstructural characterization techniques, including FTIR, SARA, AFM, and SFE, have often been reported separately in previous studies. Therefore, further investigation is needed to understand the combined effects of these changes on binder behavior, particularly under aging conditions and when Sasobit is used together with other additives. Accordingly, a comprehensive review is needed to synthesize and analyze the relationships among the chemical characteristics, microstructural characterization, and rheological properties of Sasobit-modified asphalt binders.

3. Results and discussion

- **Atomic Force Microscopy (AFM)**

Atomic force microscopy is an advanced surface imaging technique used to evaluate the microstructure and nanomechanical properties of asphalt binders. In study, AFM was used to evaluate the microstructure of asphalt binder modified with three different additives, namely Sasobit, Advera, and Evotherm. The results showed that Advera and Evotherm did not significantly change the bee-like structures of the modified binder. In contrast, Sasobit reduced the width of the bee-like structures and made them more elongated [2] (Figure 1a and b).

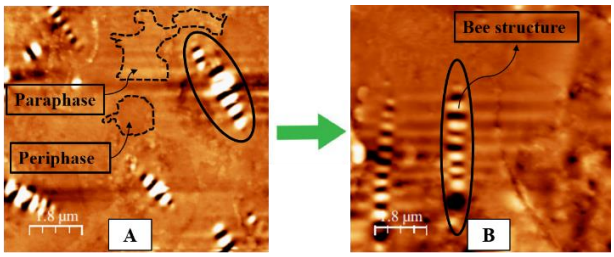

Fig. 1. Microstructure and various phases of: a) Neat binder and b) Sasobit-modified binder [2]

With increasing Sasobit content, the number and length of the bee-like structures decreased and increased, respectively [3]. In fact, the formation of bee-like structures is attributed to the arrangement of asphaltenes around the wax crystal network under van der Waals forces. These changes in the bee-like structures may be related to the wax molecules present in Sasobit-modified binders. The molecular weight of wax additives can have different effects on the microstructure and phases present in asphalt binders.

- **Fourier-Transform Infrared Spectroscopy (FTIR)**

FTIR spectroscopy is a powerful tool for identifying and evaluating the functional groups and chemical components present in neat and modified asphalt binders (Figure 2). Several studies have investigated the chemical composition and functional groups of Sasobit-modified binders. Figure 2 presents a comparative FTIR spectrum of the base and modified asphalt binders. The presence of the main functional groups in different absorption regions, including C–H, O–H, and carbonyl groups, can be observed in these spectra. The structural changes caused by Sasobit modification can be evaluated based on changes in the intensity and position of the absorption bands. As an organic additive, Sasobit mainly contains organic compounds associated with C–H bonds, including methylene and methyl groups, as well as carbonyl groups, and can therefore influence the chemical characteristics of asphalt binders. The addition of Sasobit

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increases the intensity of the carbonyl absorption band at around 1700 cm^{-1}, which indicates the initiation of oxidation and aging in high-viscosity asphalt mixtures [4].

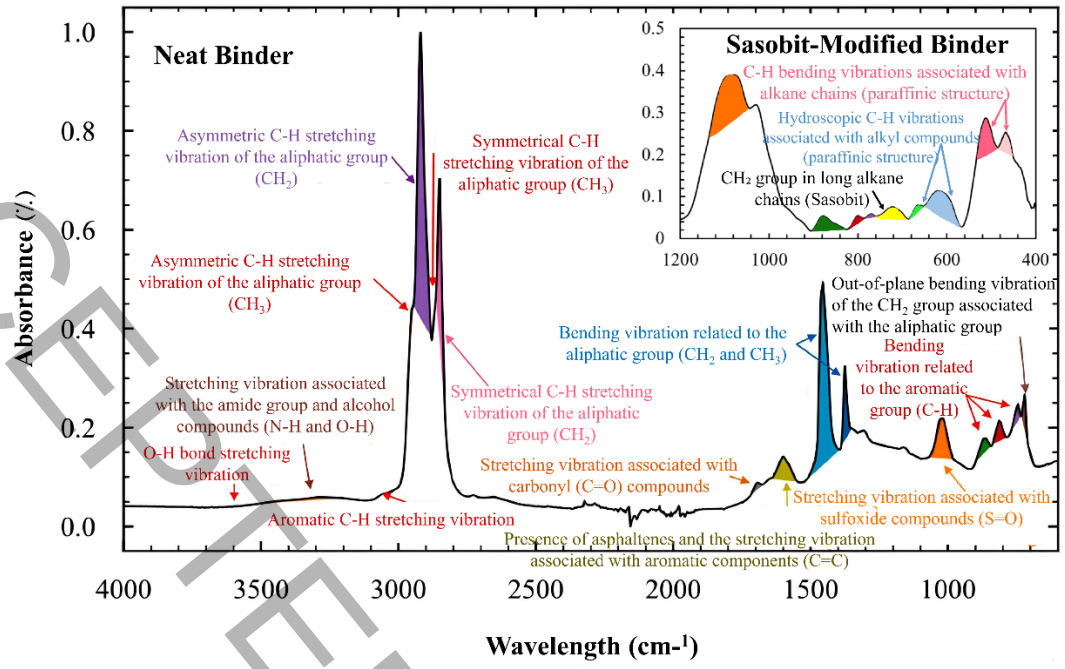

Fig. 2. Functional groups of neat and Sasobit-modified binder [5]

- **SARA Fractionation**

SARA fractionation is used to simplify the analysis and provide a better understanding of the main chemical components of asphalt binders. Due to its chemical structure, Sasobit can cause changes in the different SARA fractions, although only a limited number of studies have investigated this aspect. The SARA analysis showed that Sasobit had a similar effect to aged RAP binder. As the Sasobit content increased, the weight percentages of asphaltenes and maltenes increased and decreased, respectively [6]. Li et al. investigated changes in the SARA fractions during aging using five binders obtained from different crude oil sources. During both short-term and long-term aging, the asphaltene fraction consistently increased. This increase was attributed to the conversion of aromatics into resins and subsequently of resins into asphaltenes [7]. As shown in Figure 3, the saturate fraction remained almost unchanged during the aging process, while the maltene-to-asphaltene ratio decreased. This change contributes to an increase in binder viscosity.

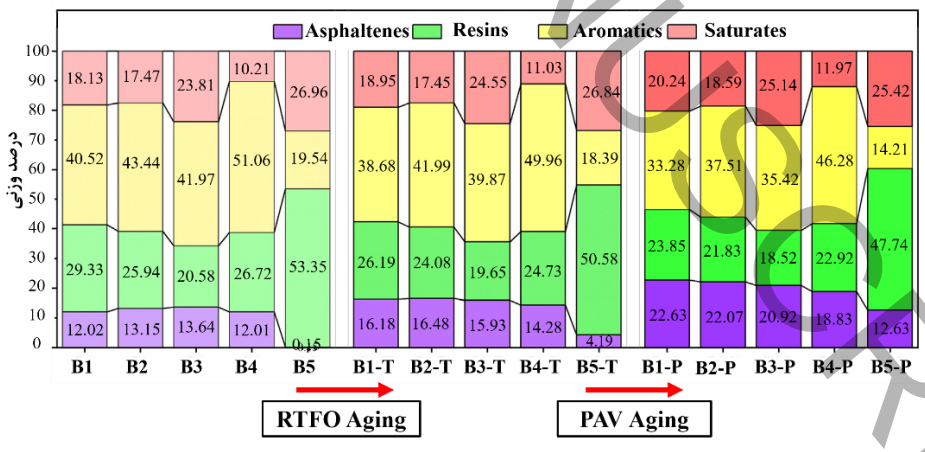

Fig. 3. Changes of different components of SARA fractions during the aging process of neat binders [7].

In general, for binders with high asphaltene contents, Sasobit can improve colloidal stability and structural properties by increasing the asphaltene content. However, these changes are less significant in binders with low asphaltene contents. During aging, neat binders generally show an increase in asphaltenes and resins and a decrease in aromatics, which leads to higher viscosity. In contrast, Sasobit-modified binders show a reduction in resins and an increase in aromatics, resulting in better flexibility.

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- **Surface Free Energy (SFE)**

Surface free energy analysis evaluates the compatibility between asphalt binder and different aggregates by measuring their surface free energies and applying thermodynamic relationships. In this regard, researchers have used SFE analysis to better understand the effect of Sasobit on the moisture resistance of modified asphalt mixtures. However, different results have been reported, mainly because the aggregates used in these studies had different chemical compositions and mineralogical characteristics. Some studies have reported that Sasobit can improve the adhesion between the asphalt binder and aggregate. Studies on surface free energy have shown that different additives can have different effects on the SFE of asphalt binders. From this perspective, Sasobit has shown less favorable performance than some other additives, as reported by Oyan et al. [8]. This reduction indicates lower moisture resistance and reduced adhesion capability of the asphalt binder.

- **Life Cycle Assessment (LCA)**

Life cycle assessment is a comprehensive tool that can be used to evaluate the environmental, economic, and social impacts of asphalt pavements throughout their service life. During the production and mixing of warm mix asphalt with Sasobit, lower temperatures are used compared with hot mix asphalt, resulting in lower energy consumption during this process. During transportation, the warm mix asphalt generates approximately the same level of pollutant emissions as hot mix asphalt over the distance between the plant and the project site. During the paving and compaction stages, however, warm mix asphalt produces lower emissions of harmful pollutants, such as asphalt fumes, NO_2, BSO, and benzo pyrene, compared with hot mix asphalt and hot polymer-modified asphalt.

4. Conclusions

In this review, Sasobit was introduced as one of the widely used additives in warm mix asphalt technology, and previous studies on its effects on the rheological and chemical properties of asphalt binders were reviewed and evaluated. The main findings can be summarized as follows:

- Microscopic investigations using AFM show that Sasobit has a significant effect on the morphology of modified asphalt binders. The additive reduces the width of the bee-like structures and makes them more elongated. As the Sasobit content increases, the number of these structures decreases, while their length increases. In addition, the length of the bee-like structures changes with the severity of aging.
- By reducing binder viscosity, Sasobit allows mixing and compaction to be performed at lower temperatures. The reduction in production temperature decreases the rate of oxidation and initial aging reactions during short-term aging. Therefore, Sasobit, either alone or in combination with other modifiers, can play an important role in reducing aging effects and improving binder durability.
- Due to its chemical structure, Sasobit changes the different SARA fractions of asphalt binder and shows a behavior similar to aged RAP binders in this regard. With the addition of Sasobit to the neat binder and a gradual increase in its content, the weight percentage of asphaltenes increases, while the maltene content decreases.
- Sasobit can have an unfavorable effect on the surface free energy of asphalt binder, which may affect the moisture resistance and overall performance of the asphalt mixture.
- Warm mix asphalt containing Sasobit can reduce pollutant emissions by more than 80% compared with conventional hot mix asphalt.

5. References

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