Effect of Different Warm Mixing Agents on the Macro-Micro Properties of Asphalt

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Abstract: This study investigates the effects of three warm mix asphalt (WMA) additives—Sasobit, Leadcap, and EvothermTM-DAT—on the macro- and micro-properties of 70# base asphalt and SBS-modified asphalt. Various dosages were used to prepare different WMA binders, which were evaluated through conventional performance tests, viscosity-temperature measurements, and fluorescence microscopy. Results showed that the inclusion of WMA additives generally reduced penetration and elongation, with Sasobit having the most significant impact on microstructure, especially in base asphalt. DAT exhibited minimal influence on both macro and micro properties, indicating a more stable and uniform blending behavior. The viscosity-temperature analysis revealed that DAT provided the most stable working viscosity across different temperatures. Fluorescence microscopy confirmed that Sasobit caused microstructural changes such as network cracking in base asphalt, whereas DAT and Leadcap maintained a uniform distribution. Among the three, DAT showed the best warm mix performance and compatibility, followed by Leadcap and Sasobit. These findings provide useful guidance for the selection and application of WMA technologies in sustainable pavement engineering.

Keywords: Sasobit; Leadcap; Evotherm; Warm mixing agent; Fluorescence

1. Introduction

With its excellent performance in durability, smoothness, and driving comfort, asphalt pavement has become the dominant form of road surface globally, especially for highways and expressways [1, 2]. However, the environmental cost of traditional hot mix asphalt (HMA) cannot be ignored. During production and construction, HMA requires high temperatures (usually over 150°C), which leads to significant emissions of greenhouse gases and other harmful substances. This not only contributes to environmental degradation but also poses health risks to workers and nearby populations.

To address these issues, warm mix asphalt (WMA) technology has been developed, which enables asphalt mixtures to be produced and laid at temperatures 20–40°C lower than conventional HMA. This significantly reduces energy consumption and pollutant emissions, making WMA an environmentally friendly alternative that aligns with the goals of sustainable infrastructure development [3, 4].

Numerous warm mix additives have been introduced over the past decade, including organic additives (e.g., Sasobit), chemical surfactants (e.g., Evotherm), and inorganic compounds (e.g., zeolite) [5-7]. Each functions differently in altering the viscosity and workability of asphalt binders. However, comparative studies on their macro- and micro-behaviors—particularly when used with both base and polymer-modified asphalts—are still limited.

In this study, three widely used WMA additives—Sasobit, Leadcap, and EvothermTM-DAT—were selected to investigate their influence on the physical properties, viscosity behavior, and microstructure of asphalt. The goal is to provide technical insights into the selection of optimal WMA additives for different engineering needs, supporting the broader objective of green and low-carbon highway development.

2. Raw Material

2.1 Materials

Two types of asphalt binders were selected for this study: $70^{\#}$ base asphalt and SBS-modified asphalt, both widely used in road construction in China. The physical properties of these binders are shown in Table 1. The temperature-mixed additives include Sasobit (a long-chain aliphatic hydrocarbon wax), Leadcap (a proprietary chemical additive with viscosity reduction properties), and EvothermTM-DAT (a surfactant agent designed to improve coating and adhesion), and their performances are shown in Table 2.

Each additive was incorporated into the asphalt at varying dosages based on literature recommendations and preliminary trial results. The goal was to assess the dosage sensitivity and performance threshold of each warm mix agent when used with both base and polymer-modified binders.

Table 1. Asphalt Technical Index

Technical index	$70^{\#}$ Base asphalt	SBS modified asphalt
Penetration(25℃, 0.1mm)	66.0	48
Softening point(℃)	46.5	84
Ductility(10℃/5℃, cm)	45	32

Table 2. Technical Indexes of Different Temperature Mix Agents

Technical index	Sasobit	Leadcap	EvothermTM-DAT
Appearance	White solid particle	White powdery crystal	Oily dark green
25℃ Density(cm)	0.95	/	0.97
Main component	Saturated hydrocarbon	/	Surfactant

2.2 Mixing Procedure

Warm mix asphalt binders were prepared using the dry mixing method. The base or SBS-modified asphalt was first heated to a temperature of 160°C to ensure full liquefaction. The warm mix additive was then gradually added while maintaining continuous stirring using a high-speed shear mixer (IKA T25 Ultra-Turrax) operating at 5000 rpm for 15 minutes to ensure uniform dispersion. The mixture was subsequently conditioned for 10 minutes at the target blending temperature to allow chemical interaction and temperature equilibrium.

After preparation, the modified binders were poured into preheated containers for subsequent testing. All samples were prepared and stored according to the specifications of JTG E20-2011, with particular attention to temperature control to simulate field construction conditions. In addition to temperature and stirring speed control, care was taken to prevent premature aging of the asphalt binders during blending. The additives were stored in sealed containers and weighed with a precision electronic balance (±0.01 g accuracy). The entire mixing process was conducted using a high-shear mixer equipped with a temperature feedback loop to maintain a constant temperature. Following blending, the asphalt samples were left to rest for 10 minutes to eliminate entrapped air and achieve thermodynamic stability before subsequent testing. This preparation protocol ensures that the influence of warm mix agents on asphalt performance is accurately and reproducibly assessed.

3. Preparation of Warm Mix Asphalt

In this study, based on previous research experience, three kinds of warm mixing agents were added to $70^{\#}$ matrix asphalt and SBS-modified asphalt with different mixing amounts respectively by the admixture method to prepare different kinds of warm mixing asphalt. The mixing scheme is shown in Table 3. According to the mixing scheme, the flow chart of different kinds of warm mix asphalt is shown in Figure 1. At the same time, according to the requirements of JTG E20-2011 "Test Rules for Asphalt and Asphalt Mixture of Highway Engineering" (hereinafter referred to as "Rules"), the basic performance test of all kinds of warm mix asphalt was carried out.

4. Performance Test of Warm Mix Asphalt

4.1 Influence of Warm Mixing Agent on Three Indexes of Asphalt

According to the requirements of the Regulations (T0604-0606), three indexes of different kinds of warm mix asphalt were tested, and the test results are shown in Figure 2.

As can be seen from Figure 2, the penetration degree of 70# matrix asphalt and SBS-modified asphalt showed a linear decreasing trend with the increase of the dosage of three warm mix agents, indicating that warm mix made asphalt thicken and harden. The main reason is that after adding a warm mix agent to asphalt, a series of complex physical and chemical reactions were generated with asphalt, forming a spatial network structure with good stability and not easy to deform [8]. The softening point of 70# matrix asphalt increases and the softening point of SBS modified asphalt decreases with the increase of the dosage of three warm mix agents. These results indicate that the addition of a warm mix agent is beneficial to improving the temperature sensitivity of the base asphalt and reducing the temperature sensitivity of SBS-modified asphalt. In addition, with the increase of Sasobit content, the asphalt-base elongation and TFOT residual elongation decreased at 15℃. When the content was greater than 3%, it did not meet the requirements of the specification. The optimal Sasobit content was determined to be 3%. For base asphalt, Leadcap can slightly reduce the penetration of asphalt, has no effect on the softening point, but can significantly improve the 10℃ elongation of asphalt. With the increase in dosage, the elongation decreases and the low-temperature performance decreases. EvothermTM-DAT has little effect on the technical indicators of the matrix asphalt, and its label has not changed significantly.

Table 3. Dosage Plan of Warm Mixing Agent

Type of warm mix	Sasobit				Leadcap		Evotherm ^{TM} -DAT
Content of 70# matrix asphalt (%)	1	2	3	4	1.5	2	10
SBS modified asphalt content (%)	3				1.5		10

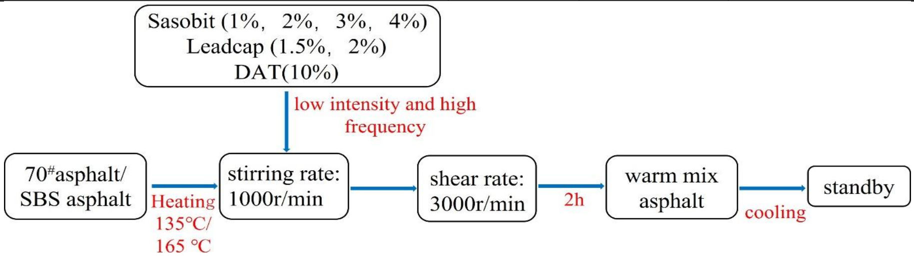

Figure 1. Preparation Flow Chart of Different Types of Warm Mix Asphalt

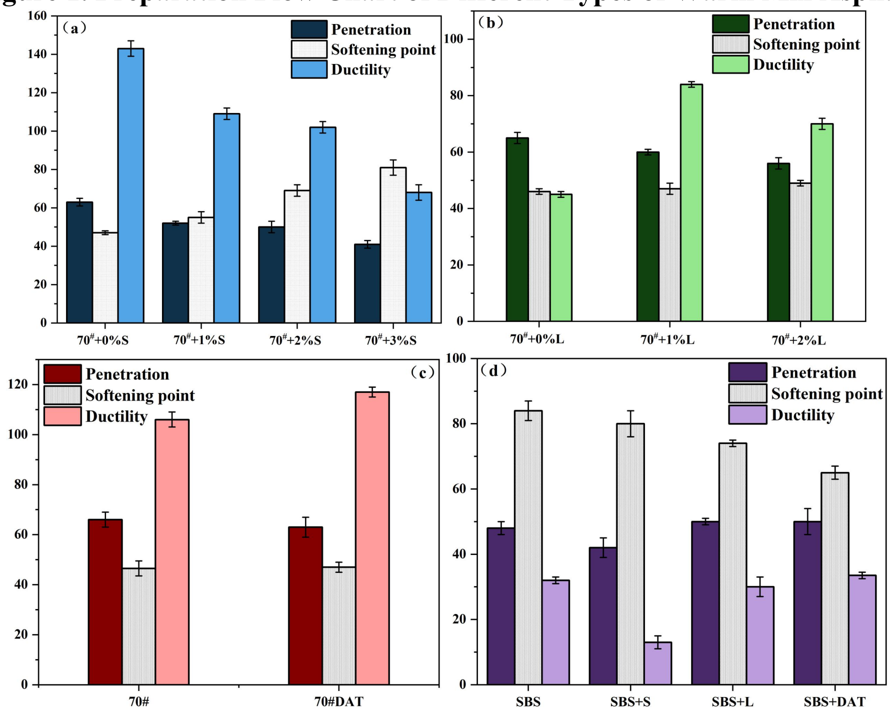

Figure 2. Three Indexes of Asphalt Modified by Different Temperature Mixtures (a: 70#+Sasobit; b: 70#+ Leadcap; c: 70#+ DAT; d: SBS+ DAT.)

These results also illustrate that the influence of warm mix agents is not only dosage-dependent but also material-specific. Sasobit, with its crystalline structure, induces a more pronounced hardening effect, particularly when used in unmodified base asphalt. In contrast, DAT, due to its surfactant nature, has a gentler interaction and better compatibility with SBS polymer networks. The influence of Leadcap appears moderate, with minor enhancements in elongation observed at lower dosages, likely due to improved binder workability. However, these benefits diminish at higher contents, suggesting a saturation point beyond which structural benefits plateau or decline [9]. These contrasting behaviors underline the need to optimize additive type and content based on the specific binder type and target climate.

4.2 Influence of Warm Mixing Agent on Viscosity-Temperature Characteristics of Asphalt

Asphalt is a kind of viscoelastic material, mechanical properties vary with the temperature and loading time. Viscosity is the ability of a fluid to resist the flow of fluid externally by creating internal friction caused by gravity between the molecular structures inside the fluid. Therefore, viscosity indirectly reflects the molecular structure and distribution of fluid. According to the requirements of the Regulations (T0625), a Brookfield rotary viscometer was used in this study to measure the viscosity of asphalt at different temperatures, and the test results are shown in Figure 3.

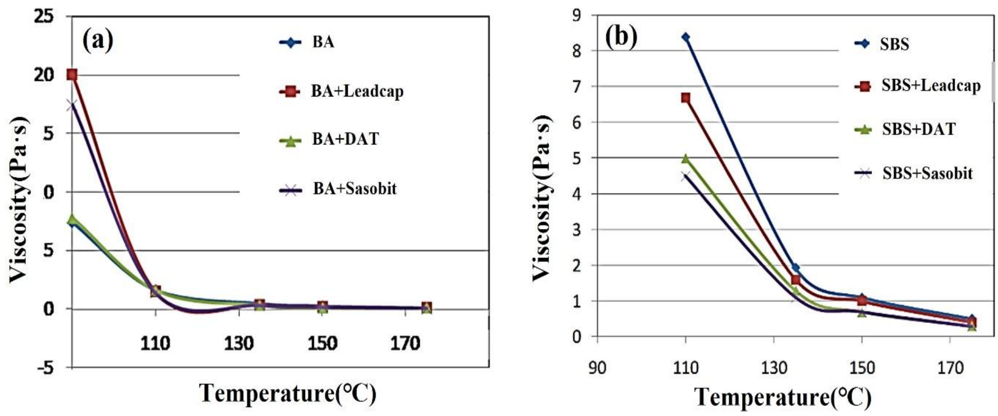

Figure 3. Viscosity-Temperature Curves of Asphalt Modified with Different Temperature Mixtures

As can be seen from the figure above, the critical temperature for the matrix asphalt binder is about 100℃—110℃. When the temperature is lower than 100℃, the viscosity of Brinell is higher than that of matrix asphalt. When the temperature is higher than 100℃, the viscosity decreases with the increase of the dosage. For the SBS-modified asphalt binder, there is a similar performance but not obvious. When the temperature is higher than 130℃, the difference in viscosity reduction effect of the three warm mixing agents is reduced. No matter the base asphalt or SBS-modified asphalt, with the addition of DAT, the binder has a small working viscosity and stable working characteristics at various temperatures.

These findings highlight that the thermal response of warm-mixed binders is crucial for construction feasibility. A steep viscosity drop, as observed in Sasobit-modified asphalt above 110℃, may enhance workability but raises concerns about thermal sensitivity. In contrast, DAT-modified binders maintain a more gradual viscosity-temperature curve, ensuring better control during transport and paving. This gradual viscosity response is particularly beneficial in cold or highly variable climatic regions, where sudden changes in binder flow properties may otherwise compromise compaction effectiveness and pavement performance [10]. The moderate profile of Leadcap suggests that it may be suitable for transitional applications where balance between stiffness and flexibility is required.

4.3 Image analysis of Asphalt Modified with Warm Mixing Agent Based on Fluorescence Microscopy

In this study, fluorescence microscopic tests were carried out on asphalt modified with different temperature mixes, and the fluorescence images of asphalt modified with different temperature mixes are shown in Figure 4.

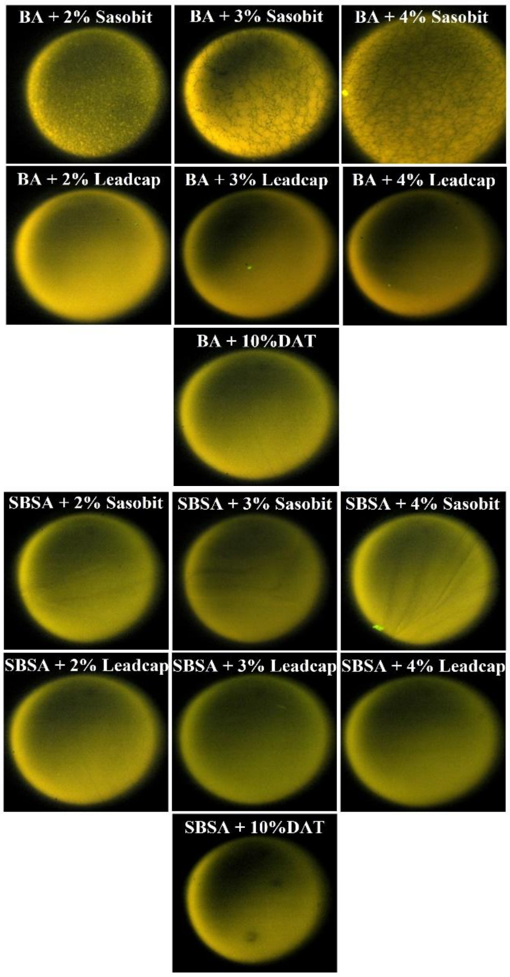

Figure 4. Fluorescence Images of Modified Asphalt with Different Temperature Mixtures

As can be seen from Figure 4, the surface of the matrix asphalt added with Sasobit presents obvious uneven block cracking. With the increase of Sasobit content, the surface of the asphalt gradually changes from particle distribution to mesh crack distribution, in which there are disorganized black cracks, indicating that Sasobit is not well dissolved in asphalt. The asphalt itself has undergone structural changes. The asphalt images added with Leadcap and DAT are no different from the original asphalt images, and there is no obvious phase interface, indicating that Leadcap and DAT are evenly mixed with asphalt and can be better integrated. At the same time, combined with the results of the asphalt test, this corresponds to the results of fluorescence image analysis. In addition, the overall mixture of Sasobit and SBS-modified asphalt is relatively uniform, and the mesh crack distribution phenomenon in the matrix asphalt does not appear in the Sasobit-warm-mixed modified asphalt at each dosage, but it can be seen that the SBS-modified asphalt with Sasobit produces a flocculent reinforced image form, which may be the result of the action of SBS modifier and warm mixing agent. The images of modified asphalt with different Leadcap content are no different from the original asphalt images, and Leadcap can also be mixed with SBS-modified asphalt more evenly. DAT and SBS-modified asphalt have no obvious interface, and the two are well integrated, showing a relatively uniform mixing system. It should be pointed out that the small black circle in the figure is the small bubble left after the action of warm mixing agent and hot asphalt, which has no essential impact on the uniformity of warm mixing asphalt. Combined with the results of the asphalt performance test, it can be seen that the performance indexes of warm mix asphalt and original asphalt are the same, and the warm mix agent has no adverse effect on the asphalt performance.

5. Conclusion

This study systematically evaluated the influence of three different warm mix asphalt (WMA) additives—Sasobit, Leadcap, and EvothermTM-DAT—on the macro- and micro-scale properties of 70# base asphalt and SBS-modified asphalt. Based on a series of conventional physical tests, viscosity-temperature analysis, and fluorescence microscopy observations, the following conclusions can be drawn:

(1) The incorporation of warm mix agents generally results in a stiffening effect on the asphalt binder, as evidenced by the reduction in penetration and ductility values. Among the additives, Sasobit demonstrated the strongest stiffening effect, particularly on base asphalt, while EvothermTM-DAT had the least impact on binder flexibility.

(2) The softening point of base asphalt increased with the addition of Sasobit and Leadcap, enhancing high-temperature stability. However, in SBS-modified asphalt, the same additives slightly reduced the softening point, possibly due to interference with the polymer network structure. DAT maintained the thermal properties of both binders effectively.

(3) Viscosity-temperature analysis revealed that DAT-modified binders exhibited the most favorable working viscosity across the temperature range, supporting improved workability and potential for lower mixing and compaction temperatures. Sasobit showed a sharper viscosity reduction only above certain thresholds, while Leadcap's effects were more moderate.

(4) Fluorescence microscopy indicated that Sasobit significantly altered the internal structure of base asphalt, forming crystalline zones and microcracks, potentially affecting long-term durability. In contrast, Leadcap and DAT produced a more homogeneous and stable blending interface.

In practice, DAT appears most suitable for applications requiring minimal performance compromise and greater environmental benefits. Leadcap offers a balanced profile, while Sasobit may be preferred where increased stiffness is required.Future studies should focus on asphalt mixture performance (rutting, fatigue, and moisture resistance), aging behavior, and life-cycle environmental assessments. Field validation and large-scale construction trials are also necessary to verify lab-scale results and guide real-world implementation of WMA technologies. From an engineering standpoint, the choice of warm mix additive should be based on the desired performance characteristics and local environmental conditions. For instance, in colder regions where thermal cracking is a concern, DAT may be the preferred option due to its minimal impact on ductility. In contrast, for high-temperature urban areas with frequent traffic loads, Sasobit may enhance rutting resistance. It is also recommended that dosage optimization be further investigated under field conditions, as lab-scale results may not fully represent field performance due to variability in mixing, compaction, and traffic-induced aging. Furthermore, economic assessments including cost-benefit analysis and environmental impact evaluation should accompany technical evaluation to support large-scale adoption of warm mix technologies.

6. Discussion

The comparative evaluation of Sasobit, Leadcap, and EvothermTM-DAT reveals distinct modification mechanisms that govern their interactions with asphalt binders. Sasobit, a wax-based additive, primarily functions through physical stiffening by forming a crystalline lattice within the binder. While this enhances rutting resistance at high temperatures, it may compromise flexibility, as reflected by the lower ductility values observed, particularly at low temperatures.

In contrast, Leadcap may function as a chemical modifier that alters the binder's flow characteristics without significantly impacting its phase morphology, resulting in moderate changes in viscosity and stiffness. Its relatively neutral influence on softening point and microstructure suggests that it functions primarily by improving workability rather than altering the fundamental binder matrix.

EvothermTM-DAT, being a surfactant-based agent, enhances coating and aggregate adhesion without significantly affecting the binder's intrinsic properties. Its ability to maintain ductility and softening point, while also delivering reduced viscosity across the operational temperature range, makes it highly favorable for field applications, especially in cooler climates or where rapid compaction is needed.

From an environmental standpoint, DAT offers the highest potential for energy savings and emission reduction, as it enables mixing at significantly lower temperatures without compromising performance. However, the long-term field performance, including oxidation and aging behavior, must be further studied.

These results align with previous findings, and reinforce the notion that warm mix technology should be tailored to specific climatic, structural, and logistical conditions to achieve optimal results.

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