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The impact of mixing and compaction temperature on asphalt pavement performance: A review

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Abstract

Asphalt pavement performance is significantly influenced by compaction temperature, which is crucial for achieving density and structural strength. Higher temperatures can make the material more workable and less viscous, but can also cause issues like aggregate disintegration and binder draindown. Temperature directly affects the timing of asphalt mixture mixing, as it decreases the time required to mix the asphalt. Asphalt mixtures are sensitive to temperature changes, and the mix's plastic state is affected. To ensure proper compacting and use, the mix must be kept at a specific temperature. Too cold or too hot temperatures can cause the mixture to harden before use, while too cold or too hot temperatures can cause the mix to harden. This document reviews the influence of mixing and compaction temperatures on the performance of asphalt pavements. It examines how temperature affects the workability of asphalt, the risks of aggregate disintegration. The review aims to provide insights into the necessary temperature ranges for effective compaction to ensure sufficient density and structural strength in asphalt pavements.

Key words: mixing, compaction, temperature, asphalt performance.

تأثير درجة حرارة الخلط والدمك على أداء الرصف الاسفلتي: دراسة مراجعة

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الملخص

يتأثر أداء رصف الأسفلت بشكل كبير بدرجة حرارة الضغط، والتي تعتبر عاملاً حاسماً في تحقيق الكثافة والقوة الهيكلية. يمكن أن تجعل درجات الحرارة المرتفعة المادة أكثر قابلية للتشغيل وأقل لزوجة، ولكنها يمكن أن تسبب أيضاً مشاكل مثل تفكك الركام وتسرب المادة الرابطة. تؤثر درجة الحرارة بشكل مباشر على توقيت خلط خليط الأسفلت، حيث إنها تقلل من الوقت اللازم لخلط الأسفلت. خلطات الأسفلت حساسة للتغيرات في درجة الحرارة، وتؤثر على الحالة البلاستيكية للخلطة. لضمان الضغط والاستخدام المناسبين، يجب الحفاظ على الخلطة عند درجة حرارة محددة. يمكن أن تؤدي درجات الحرارة شديدة البرودة أو شديدة الحرارة إلى تصلب الخليط قبل الاستخدام، بينما يمكن أن تؤدي درجات الحرارة شديدة البرودة أو شديدة الحرارة إلى تصلب الخليط. تستعرض هذه الوثيقة تأثير درجات حرارة الخلط والضغط على أداء رصف الأسفلت. وتبحث في كيفية تأثير درجة الحرارة على قابلية تشغيل الأسفلت، ومخاطر تفكك الركام. تهدف المراجعة إلى تقديم رؤى حول نطاقات درجات الحرارة اللازمة للضغط الفعال لضمان الكثافة الكافية والقوة الهيكلية في رصف الأسفلت.

الكلمات المفتاحية: الخلط، الدمك، درجة الحرارة، أداء الرصف.

1. Introduction

Pavements, designed to resist traffic loads and climatic action, are flexible structures built on natural soils. They can be rigid or flexible, with failure mechanisms triggered by heavy vehicle loadings, climate, drainage, material qualities, and insufficient layer thicknesses. [1]. Insufficient temperatures may hinder effective bonding between aggregates and binder, while overly high temperatures can accelerate material aging or diminish the effectiveness of added modifiers. Ultimately, understanding how

these components interact under different environmental conditions enables engineers to create asphalt mixtures that are specifically designed for various applications whether for highways meant to handle heavy traffic or lighter constructions like parking lots [2]. The complex interplay of temperature during these phases directly impacts the workability of asphalt mixtures, the effectiveness of aggregate coating by bitumen, and ultimately, the long-term stability and performance of the pavement [3]. Maintaining appropriate temperatures is critical because excessively high temperatures can lead to accelerated aging of asphalt binders and aggregate disintegration, while insufficient temperatures hinder proper compaction and mixture workability [4]. This review aims to synthesize current research on the optimal temperature ranges for mixing and compaction, focusing on their influence on the volumetric properties, mechanical characteristics, and durability of asphalt pavements. Furthermore, temperature directly influences the viscosity of asphalt binders, which is a critical factor in achieving adequate workability and proper aggregate coating during the mixing process. Mixing duration and temperature are essential for the performance and longevity of asphalt mixtures. Optimal mixing time promotes a uniform blend of aggregates, asphalt binder, and modifiers, while inadequate mixing can weaken structural integrity. Proper compaction enhances mechanical properties, ensuring shear strength and flexibility. Loss of density during construction can lead to moisture issues and oxidation, compromising structural integrity. Achieving at least 92% of maximum theoretical density is vital for preventing early cracking and deformation of asphalt pavements post installation.

2. Mixing Time and Mixing Temperature

The temperatures at which mixing and compaction occur are crucial factors that greatly influence the performance of hot-mix asphalt (HMA) pavements. Generally, the mixing temperature is maintained about 10 to 20 degrees Celsius higher than the compaction temperature, ensuring that aggregates are thoroughly coated with the asphalt binder. This careful blending enhances workability and ensures a uniform mixture ready for application. Research indicates that optimal mixing time and temperatures for asphalt mixtures are crucial, with approximately 180 degrees Celsius being ideal for conventional hot mix asphalt. While extended mixing at elevated temperatures can improve uniformity,

it may damage sensitive materials. These factors significantly influence road performance, including rutting resistance and moisture sensitivity, and inadequate mixing can result in premature pavement failures and increased maintenance costs [5].

2.1 Importance of Mixing Time

Mixing duration and temperature are critical factors that significantly influence the performance and longevity of asphalt mixtures. Optimal mixing time ensures thorough integration of aggregates, asphalt binder, and modifiers, which enhances mixture consistency. Insufficient mixing can lead to poor adhesion between particles, undermining structural integrity [6] [7].

Temperature plays a crucial role in controlling the viscosity of asphalt binder during mixing. Higher temperatures reduce viscosity, promoting better incorporation of aggregates and additives. However, exceeding recommended temperature limits can result in thermal breakdown of the binder or increased emissions of volatile organic compounds (VOCs). Conversely, mixing at too low a temperature may cause inadequate coverage of aggregates and diminished performance.

Research indicates that the optimal mixing time for dry modified asphalt mixtures is around 150 seconds, where both high and low temperature performances improve. Over-mixing, which disrupts the even distribution of modifier on aggregate surfaces, can lead to performance decline if mixing continues beyond this optimal point [8].

Figure (1) shows that the study reveals that the performance of modified asphalt is influenced by the mixing duration, with high temperature and low temperature performances improving gradually and deteriorating with prolonged mixing. Water stability performance peaks earlier at 90 seconds. Over mixing can disrupt the modifier film, leading to non-uniform dispersion. Optimizing mixing duration is crucial to prevent over mixing and reduce modifier effectiveness, with optimal peak performance times of 150 seconds for high temperature/low temperature and 90 seconds for water stability.

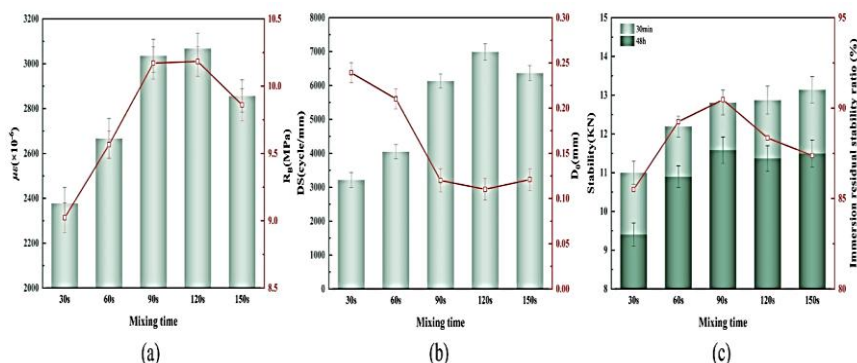


Fig 1 Influence of mixing time on the performance of asphalt mixtures [9]

Similarly, studies on hot mix asphalt (HMA) containing reclaimed asphalt pavement (RAP) have revealed how extended mixing times affect various volumetric properties and compactability. While longer mixing durations may enhance certain traits such as compactability, they can also produce adverse effects on mechanical strength and stability if they surpass optimal levels. For example, although some mixers showed improved performance with longer mixing times, others experienced significant reductions in stiffness when subjected to excessive mixing durations [9].

The aging process in recycled asphalt pavement mixtures is exacerbated by the presence of aged binder, requiring precise control over mixing parameters to maintain material homogeneity [10][11][12]. Asphalt pavement lifespan is significantly influenced by short term aging during production and field operations, which alters bitumen's chemical and physical characteristics by increasing its stiffness through oxidation [13] [14].

The results highlight how important it is to maximize mixing time in order to achieve desired asphalt pavement performance characteristics, especially when it comes to striking a balance between mixture homogeneity, binder integrity, and aging characteristics. In order to prolong the pavement's service life and guarantee its long term durability and resistance to distresses like rutting and cracking, this optimization is essential.

2.2 Mixing Temperature

Many studies have indicated that the mixing temperature of asphalt mixtures has a significant impact on their road performance. [9] Higher mixing temperatures improve the flow characteristics of asphalt binders, facilitating better dispersion and interaction with aggregates. This is crucial for modified asphalt mixtures that include

additives, as elevated temperatures allow these modifiers to melt and blend effectively, enhancing adhesion [5]. The experimental results are shown in Figure 2.

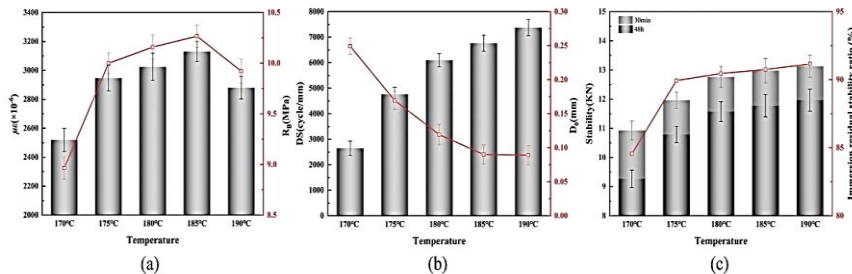


Fig 2 Influence of mixing temperature on the performance of asphalt mixtures [9]

As seen in Figure 2, High temperature performance of asphalt mixtures improves with increasing mixing temperature, enhancing load-bearing capacity and resistance to rutting. However, mixing temperatures above 185°C risk severe aging, especially when exposed to air. Low temperature performance tests show a decrease in maximum tensile strain after mixing temperature exceeds 190°C, likely due to asphalt aging and component oxidation.

Inadequate mixing can lead to poor distribution of aggregate coating and binder, reducing strength and increasing permeability. Conversely, excessive mixing at high temperatures can accelerate binder oxidation, resulting in premature embrittlement and decreased fatigue life.

3. Compaction Temperature

The ideal asphalt compaction temperature is between 135°C and 150°C, allowing malleable mixtures for effective aggregate coating and high density. Maintaining above 100°C ensures relative compaction levels over 97%, preventing structural failures and reduced service life [15]. Laboratory studies indicate that reducing temperatures from 140°C leads to decreased Marshall Stability values, showing impaired bonding and strength properties. Additionally, rapid cooling before adequate compaction can cause issues like aggregate segregation.

Asphalt compaction is a crucial process in the construction and maintenance of asphalt pavements, involving the compression of the asphalt mixture along with aggregate materials to achieve optimal density. The primary objective of this compaction is to reduce air

voids within the asphalt layer, leading to a dense and uniform pavement mix [16].

Improper compaction temperatures can significantly compromise the performance of dense-graded asphalt mixtures, leading to reduced density, increased air voids, and ultimately diminished pavement strength [17]. These deficiencies contribute to increased susceptibility to moisture damage, rutting, and fatigue cracking, thereby shortening the service life of the pavement [18].

Research indicates that achieving a high level of densification is vital to prevent future issues such as cracking and rutting. Asphalt compaction plays vital roles beyond aesthetics; it is essential for ensuring durability, structural integrity, and an extended service life of pavements under various loading conditions.

3.1 Overview of Compaction Temperature Effects on Workability and Viscosity

The workability and viscosity of asphalt mixtures are strongly influenced by the compaction temperature. During mixing and compaction, viscosity or flow resistance is crucial. Effective compaction may be hampered by high viscosity, which could compromise structural integrity and reduce density. Low viscosity, on the other hand, could make the mixture unstable and excessively fluid [19].

Lower temperatures lead to increased air void content, affecting Marshall Stiffness and potentially reducing it by 10% to 70%. This compromises pavement stability and durability. Maintaining appropriate mixing and compaction temperatures is crucial for optimal bonding between aggregate particles and asphalt binders [20].

Temperature fluctuations during transportation from mixing facilities to job sites can cause inconsistent viscosity and workability, leading to increased void content, compromising structural integrity, and increasing premature failure risk [19]. In order to increase workability at lower temperatures without compromising performance, warm-mix additives were created. By lowering the viscosity of the binder, these additives enable efficient compaction even at lower temperatures [15].

Effects on Stability of Aggregates

Asphalt compaction temperature significantly affects aggregate stability. Higher temperatures increase lubrication and interaction,

promoting tighter interlocking and stability. Conversely, lower temperatures restrict binder flow, reducing aggregate contact and stability [19]. Research shows that lower compaction temperatures lead to higher air void content, causing decreased stability under traffic loads. Elevated temperatures ensure better binder distribution, minimizing segregation risks and ensuring uniform pavement performance. Rapid cooling during transport can cause "cyclic segregation," negatively impacting asphalt properties like permeability and density [21].

Aggregate orientation affects mixture performance, with higher compaction enhancing contact and particle alignment, while lower temperatures can lead to thicker binder films, reducing friction and stability [22]. Maintaining aggregate stability during compaction requires determining the proper binder content. Bleeding under load may happen from excessive binder's over compaction and lack of air spaces. In order to maximize aggregate stability and guarantee pavement durability, it is crucial to balance binder levels with suitable compaction temperatures [15].

In summary, improving pavement performance, lifespan, and resilience against traffic induced stresses requires an understanding of how compaction temperature fluctuations impact aggregate interactions in asphalt mixtures.

Binder Draindown Concerns

Elevated temperatures can lead to binder draindown, where the asphalt binder separates from the aggregate and accumulates at the bottom of the mix, resulting in an uneven binder distribution and premature pavement failure. This phenomenon is particularly problematic in mixes with high binder content or coarse aggregate gradations, necessitating careful temperature control during both mixing and transport [23]. These risks underscore the importance of maintaining precise temperature control during production to ensure the long-term performance and durability of asphalt pavements [24]. Furthermore, excessively high production temperatures can detrimentally impact the adhesive properties of binders, increasing the susceptibility of warm mix asphalt to stripping and moisture damage [12]. Conversely, operating at lower temperatures, such as those used in Warm Mix Asphalt technologies, offers significant environmental and economic benefits by reducing energy consumption and greenhouse gas emissions [25] [3].

Binder draindown in asphalt mixtures, particularly at high temperatures, can negatively affect pavement mechanical properties and longevity. It detaches binder from aggregates, reducing effective content. Maintaining ideal compaction temperatures is crucial for adhesion and reducing draindown, but excessive temperatures can cause premature aging or reduced elasticity [19]. Maintaining appropriate viscosity levels that offer strong adhesion between aggregates and binders while minimizing draindown requires reaching the optimal compaction temperature. Overly high temperatures can cause early aging or reduced elasticity in modified binders, which can affect performance. Throughout every stage, engineers and contractors need to keep a close eye on temperatures to maximize efficiency and minimize draindown issues.

4. Conclusion

Maintaining control over mixing and compaction temperatures is essential for durable asphalt pavements, preventing premature hardening and mechanical integrity issues. Different asphalt mixture types require specific temperature ranges, influenced by factors such as Reclaimed Asphalt Pavement content. Warm mix asphalt can be compacted at lower temperatures than hot mix asphalt, which helps reduce energy use and environmental impact. Additionally, rubberized bitumen mixtures require adjusted temperatures since conventional binder viscosity criteria may predict excessively high temperatures, risking binder degradation.

The ideal asphalt compaction temperature is between 135°C and 150°C, allowing malleable mixtures and high density. Maintaining above 100°C ensures 97% relative compaction, preventing structural failures and reduced service life.

Asphalt pavement technology is evolving, necessitating innovative methods to improve mixtures. Recycled asphalt pavement (RAP) and warm-mix asphalt (WMA) technologies are growing, offering improved performance and reduced environmental impact. These technologies can lower mixing temperatures and enhance rut resistance and durability. The ideal compaction temperature is crucial for maintaining viscosity levels, adhesion between aggregates and binders, and reducing draindown. Overheating can impair performance, so engineers and contractors must monitor temperatures throughout all phases.

It is evident that the flexibility index was considerably impacted by the high mixing and compaction temperatures. When the mixing

and compaction temperatures are raised by 20 degrees Celsius, asphalt mixtures begin to behave more brittlely. Based on the test results, it can be concluded that increasing the production temperatures of the HMA mix to achieve higher density in field is not an effective strategy as it sacrifices the durability of the mix. Asphalt pavement compaction is crucial for roadway durability and functionality. Maintaining an optimal temperature during the process is essential, with warm mix asphalt mixtures recommended between 100°C and 120°C. Excessive temperatures can affect the curing reaction. High densification is essential to prevent cracking and rutting. Multiple passes and monitoring environmental factors like temperature and humidity are recommended for optimal results.

5. Suggestions

The temperature directly influences of asphalt binders, which is a critical factor in achieving adequate workability and proper aggregate coating during the mixing process . Future research should also investigate the long-term performance of asphalt pavements constructed using warm mix asphalt and recycled asphalt pavement techniques, considering their potential to reduce environmental burdens.

Compaction of asphalt pavement is essential to the longevity and functionality of roads. In order to avoid cracking and rutting, high densification is required. For best results, it is advised to make many passes and keep an eye on environmental variables like temperature and humidity.

As asphalt pavement technology advances, new approaches to enhance combinations are required. Warm-mix asphalt (WMA) and recycled asphalt pavement (RAP) technologies are expanding because they provide better performance and less environmental effect. These innovations can improve durability and rut resistance while lowering mixing temperatures. Maintaining viscosity levels, adhesion between aggregates and binders, and minimizing draindown all depend on the optimal compaction temperature. Engineers and contractors must keep an eye on temperatures at every stage since overheating might affect performance.

Enhancing methods for temperature and density monitoring during installation would improve quality control in asphalt paving procedures, resulting in longer-lasting pavements that need less upkeep over time.

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