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Investigating the Influence of Steel Fibre on Self-Healing in Stone Mastic Asphalt Mixtures Using the Indirect Tensile Strength Test: A Case Study Aligned with the Sustainable Development Goal (SDG) 9

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Abstract

This study driven by the urgent need to improve the durability and resilience of road infrastructure in response to increasing traffic loads and environmental challenges. By focusing on the self-healing properties of Stone Mastic Asphalt (SMA) mixtures, this study aims to tackle a critical challenge in pavement engineering; by focusing on the self-healing properties of Stone Mastic Asphalt (SMA) mixtures, this study aims to tackle a critical challenge in pavement engineering, thereby reducing the frequency and cost of road maintenance while ensuring sustainable road performance. SMA is a gap-graded hot mix commonly utilized for heavily trafficked roadways, providing 30% to 40% enhanced resistance to permanent deformation and rutting relative to dense-graded asphalt. SMA's higher binder content increases its susceptibility to moisture-induced degradation and variations in temperature, necessitating modifications to improve its durability. The incorporation of steel fibre has been identified as a viable solution, enhancing moisture resistance and self-healing capabilities. This study aimed to assess the effectiveness of incorporating steel fibre into SMA mixtures, with particular emphasis on enhancements in specific gravity, abrasion resistance, and indirect tensile strength. This study investigated four proportions of steel fibres (0%, 0.30%, 0.50%, and 0.70%) in SMA mixtures with a 6.2% PEN 60/70 binder content. Comprehensive testing, which included specific gravity, Marshall stability, and indirect tensile strength tests, was performed to evaluate performance. The findings indicated that the incorporation of steel fibre markedly improved the tensile deformation resistance, stability, and abrasion resistance of the SMA mixture. The 0.30% steel fibre proportion yielded the most favorable performance enhancement among the tested ratios. This research supports the SDG 9 objective of promoting resilient and sustainable infrastructure by demonstrating that steel fibre-modified asphalt mixtures improve the durability and safety of road structures.

Keywords: Stone Mastic Asphalt, Steel Fibre, Self-Healing, Indirect Tensile Strength, Sustainable Development Goal

Introduction

This study aligns with Sustainable Development Goal (SDG) 9, which highlights the significance of constructing resilient infrastructure, encouraging innovation, and advancing sustainable industrialization. Infrastructure supports economic growth and societal welfare, making its durability and sustainability essential. SDG 9 specifically emphasizes the advancement of infrastructure that is both resilient and adaptable to future challenges, including increased urbanization and climate change. Pavement is essential in highway building, providing a smooth experience for users. The vehicular weight-induced traffic load is conveyed from the upper layer to the subsurface soil layer (Topolnicki & Holding, 2020). Pavement is classified into two categories: rigid pavement and flexible pavement (Mohod & Kadam, 2016). The primary road network in Malaysia mostly employs flexible pavement because of its capacity to flex and deflect under load. However, adverse weather and persistent tire pressure have worsened the state of the highway infrastructure. Increased traffic volumes and substantial vehicles have led to pavement failures, including rutting, fatigue cracking, stripping, and reflective cracking (Pais et al., 2013). These concerns, along with reduced traffic volume, frequent deceleration, and acceleration, accelerate pavement degradation, resulting in the asphalt binder becoming brittle and losing its adhesive properties, which leads to the separation of binder from aggregates. Consistent maintenance, comprising crack sealing, surface treatments, and patch repairs, is crucial to attaining the projected lifespan of the pavement (Shaffie et al., 2021). To mitigate these issues and decrease maintenance costs, the deployment of self-healing asphalt pavement is crucial for prolonging the service life of roadways.

The investigation of steel fibre-reinforced SMA directly enhances the development of robust infrastructure, a fundamental aspect of SDG 9. The self-healing capabilities of steel fibres reduced the necessity and scope of maintenance, therefore decreasing resource consumption, cutting energy usage, and lessening the environmental impact of road construction and repairs (Garcia, 2012). This research enhances the longevity of pavements and minimizes repair requirements, so fostering a sustainable methodology for road infrastructure essential for enduring economic and environmental viability. The durability and longevity of asphalt pavements are crucial for the efficient operation of transportation systems. Stone Mastic Asphalt (SMA), recognized for its superior rut resistance and structural integrity, is extensively utilized in high-stress environments such as highways and urban roadways. Nonetheless, despite these benefits, SMA mixes are susceptible to deterioration, especially cracking induced by recurrent traffic loads and temperature variations. Over time, these forces can result in substantial deterioration of the pavement, requiring expensive maintenance and rehabilitation measures (Brown & Mallick, 2001). Researchers have investigated new solutions to these challenges, including the addition of self-healing mechanisms into asphalt mixtures. Self-healing asphalt denotes the material's capacity to recover from micro-damage independently, without external assistance. This approach, inspired by natural biological healing processes, has gained considerable prominence in civil engineering, especially regarding sustainable infrastructure (Garcia, 2012). Recent advancements indicate that steel fibres have emerged as a potential additive in asphalt technology, improving both the mechanical qualities and self-healing capabilities of SMA mixtures. Steel fibres enhance tensile strength and crack resistance (Wang et al., 2020), while offering a structural framework that facilitates crack closure, thereby improving the self-healing capabilities of SMA (Sangiorgi et al., 2016). Despite the increasing interest in self-healing materials, research particularly examining the effect of steel fibres in promoting self-healing in SMA remains limited.

The Indirect Tensile Strength (ITS) test is a crucial technique for assessing the tensile characteristics of asphalt mixtures, replicating the actual stresses experienced by pavements. This study seeks to examine the effect of steel fibres on the self-healing properties of SMA mixes through the ITS test. Prior research has shown that fibre-reinforced SMA possess enhanced tensile strength and fatigue resistance (Shafabakhsh & Ani, 2015); nevertheless, the specific interactions between steel fibres and the inherent healing processes of SMA are yet inadequately investigated. This study aims to address this deficiency by investigating the capacity of steel fibres to improve the self-healing characteristics of SMA, hence fostering more durable and sustainable pavement solutions. The rapid increase in traffic volume, heavy vehicles, and severe environmental conditions have markedly accelerated pavement degradation in areas like Malaysia, where flexible pavement constitutes the predominant road infrastructure. Defects like rutting, fatigue cracking, and reflective cracks have grown increasingly prevalent, resulting in frequent repairs and diminished pavement longevity (Pais et al., 2013). Regular maintenance, including crack sealing, surface treatments, and patching, is crucial to attain the expected lifespan of these roadways (Shaffie et al., 2021).

The concept of self-healing asphalt, capable of independently repairing its own damage under certain conditions such as temperature and rest periods (Garcez et al., 2018), presents a viable resolution to these challenges. Recently, researchers have concentrated on creating advanced materials and methods for the rehabilitation of asphalt pavement (Ajam, 2019; Gao et al., 2019; Li et al., 2019). This study will examine the influence of steel fibres on the self-healing characteristics of SMA through the ITS test, while also assessing the impact of microwave heating as a catalyst for the healing process (Sarsam & Al Tuwayyij, 2020). Despite several studies examining different fibres in asphalt mixtures, there is insufficient study focused on the impact of steel fibres on self-healing properties under indirect tensile strength testing and microwave heating. Recent studies underscore the promise of self-healing asphalt systems, particularly in temperature-regulated environments, to mitigate pavement deterioration. Self-healing asphalt mixtures can repair micro-cracks during rest periods or by external heating methods like microwave heating (Garcez et al., 2018). Advanced materials like microcapsules, nanoparticles, and steel fibres have demonstrated potential in augmenting the natural self-healing capabilities of asphalt, facilitating the restoration of mechanical strength and prolonging pavement longevity (Ajam, 2019; Gao et al., 2019). These technologies offer economical and sustainable options for asphalt maintenance.

The addition of steel fibres with SMA promotes advancements in material science and infrastructure engineering. This study advances self-healing materials, improving asphalt mixture performance and aligning with SDG 9's goals for innovative solutions that enhance industrial resilience and sustainability (Wang et al., 2020). This research ultimately aids in the development of more intelligent and sustainable infrastructure systems that correspond with the global objective of SDG 9—resilient, sustainable, and inclusive infrastructure for all.

Materials and Methods

This study developed Stone Mastic Asphalt (SMA) using a blend of coarse aggregate, fine aggregate, binder, and filler. The coarse and fine aggregates were obtained from Kajang Rocks Quarry, dried, and sieved to a specified size range, with a nominal size of 20 mm, in compliance with the JKR Malaysia criteria for SMA20. Binder with a penetration grade of 60/70 was obtained from Kemaman Binder Company for use into the mixture. Steel fibre (Figure 1), provided by Gardner Global Enterprise, was incorporated into the SMA at different proportions of 0%, 0.3%, 0.5%, and 0.7% of the total weight of the mixture. The tests that were performed included evaluations of properties and performance, such as bulk specific gravity, theoretical maximum specific gravity, Marshall stability and flow, Indirect Tensile Strength (ITS) (before and after the healing effect), and microwave heating. Comprehensive experiments were conducted on two sample types: modified stone mastic asphalt mixture and unmodified stone mastic asphalt mixture. This method was essential to comprehensively assess the volumetric properties and performance of the SMA mixture with the inclusion of steel fibre. This study attempts to clarify the effect of steel fibre on asphalt pavement, highlighting its potential to improve durability and self-healing properties of the road surface. Understanding the effect of different steel fibre amounts allows for the development of stronger and more durable asphalt mixtures, thereby improving the safety and longevity of road infrastructures.

Figure 1.0 Steel fibre

Volumetric Properties Test

Four tests were performed to evaluate the volumetric properties of the SMA mixtures: the bulk specific gravity (G_{mb}) test, the theoretical maximum specific gravity (G_{mm}) test, and the Marshall stability and flow tests. Twelve SMA mixture samples with variable steel fibre contents (0%, 0.3%, 0.5%, and 0.7%) were utilized for the G_{mb} test, whereas eight samples with differing steel fibre percentages were examined for G_{mm}. The G_{mb} test ascertained the specific gravity of compacted SMA samples by comparing the weight of the samples with that of an equivalent volume of water. The samples were assessed in three conditions: dry, submerged in water, and saturated surface dry, facilitating precise determination of their specific gravity. The G_{mm} test, which assessed the air void content of the well-compacted SMA mixes, was performed utilizing the Rice technique in accordance with ASTM 2041 and AASHTO 209 standards. The SMA mixes, consisting of binder and aggregates, were combined and spread on a tray, permitted to cool to ambient temperature, and their dry mass was documented. The mixture was sealed in a plastic bag and immersed in a water bath at 25°C for 10 minutes to remove any trapped air and achieve a consistent mass.

12 SMA mixture samples (Figure 2) with different steel fibre contents (0%, 0.3%, 0.5%, and 0.7%) were evaluated for Marshall stability and flow tests following ASTM D6927 criteria. The Marshall stability test examined the tensile strength of the SMA samples, whilst the flow test tested its resistance to deformation (rutting) (Sengul et al., 2013). Prior to testing, the samples were immersed in a 60°C water bath for 30 minutes, subsequently placed individually into the Marshall stability testing apparatus. A constant rate of deformation was applied to each sample, and the greatest load they could endure before to failure was documented as the Marshall stability value. The flow value was ascertained from the deformation at the peak load point.

Figure 2.0 Marshall Sample for steel fibre

Process of Creating Cracks

The assessment of self-healing properties in modified Stone Mastic Asphalt (SMA) mixtures was conducted using the Indirect Tensile Strength (ITS) test (Figure 3). This test aimed to create controlled cracks in the sample to evaluate the strength of both modified (containing 0.3%, 0.5%, and 0.7% steel fibre) and unmodified SMA mixtures, before and after the self-healing actions. The comparison of test results before and after healing phase highlighted the potential advantages of incorporating steel fibres into SMA mixtures for improved durability and damage recovery.

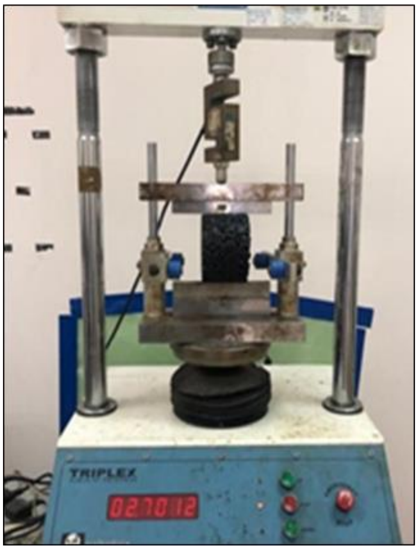

Figure 3.0 ITS Test Machine

During the ITS test, a uniform deformation rate was applied diametrically to the samples until the first signs of failure, leading to the formation of cracks. The test ended after the monitored load decreased by 20% from the peak load to prevent excessive deformation and to ensure the development of a representative cracking for further self-healing assessment. The formula employed for calculating the tensile strength of the sample, or ITS values, is as equation 1.

$$ITS = \frac{2Pmax}{\pi dh} \tag{1}$$

Where P_{max} is the peak load, in kN, while d is the diameter of the samples in mm, and h is the height of the samples, in mm.

The self-healing process started by subjecting the cracked sample to designated environmental conditions, including regulated heating, to facilitate the flow of binder and repair the micro-cracks generated during the ITS test. After a specified healing period, the sample were re-evaluated to assess their restored strength. Comparing the ITS values before and after healing allows for the assessment of steel fibres' efficiency in improving the self-healing properties of SMA mixtures, offering significant insights into their ability to reduce maintenance needs and prolong pavement longevity.

Evaluation of Self-Healing

Following to the initial Indirect Tensile Strength (ITS) test, the cracked samples were allowed to cool at ambient temperature until they reached stabilization at 25°C in preparation of the healing phase. The healing process involved subjecting the samples to microwave radiation, a method under investigation for its ability to improve the self-healing properties of asphalt mixes by producing heat that promotes the flow of binder and the sealing of micro-cracks. The samples were positioned in a microwave (as depicted in Figure 4) and heated for 100 seconds to assess the effect of microwave-induced temperature on the healing efficacy of the SMA mixes.

The selection of microwave radiation is predicated on its capacity to swiftly and uniformly heat the internal composition of the asphalt, hence enhancing binder fluidity and facilitating crack closing, especially when augmented with steel fibres. Steel fibres, because to their thermal conductivity, might expedite heat diffusion inside the SMA mixture, hence potentially enhancing the healing process. Following the 100-second heating interval, the samples were meticulously extracted from the microwave, and the progression of cracks was visually examined and recorded. The extent of cracking closure was evaluated to determine the efficacy of the self-healing mechanism, specifically concerning the differing proportions of steel fibres (0.3%, 0.5%, and 0.7%) in the samples. The examination and evaluation of crack healing provide insights into the impact of varying fibre contents on the mixture's capacity to recover from damage. After the examination of the cracks, the samples were prepared for the subsequent part of the investigation, which entailed re-testing the sample using the ITS test to assess the recovered strength following the healing process. The outcomes of the second test were compared with the original ITS values to assess the healing efficacy and ascertain the ideal steel fibre content for improving self-healing in SMA mixes.

Figure 4.0 Sample in microwave.

Evaluation of Healing Rate

After completing the initial self-healing assessment of the modified and unmodified SMA mixture samples, all sample were permitted to rest for 24 hours at a stable temperature of 25 ºC. The rest period allowed the samples to attain thermal equilibrium prior to additional testing. After the samples reached the target temperature, the Indirect Tensile Strength (ITS) test was conducted once more to evaluate the healing rate of both the modified and unmodified SMA mixtures. The healing rate (HR) was determined using equation (2):

$$HR\ (\%) = \frac{ITSafter}{ITSbefore} \qquad (2)$$

Where ITS_{after} represents the Indirect Tensile Strength of the sample after the healing process and ITS_{before} represents the Indirect Tensile Strength of the sample at the beginning of the experiment.

The calculated healing rate for all SMA samples, including both modified (with 0.3%, 0.5%, and 0.7% steel fibre) and unmodified variants, was then compared. This comparison aimed to determine the optimum steel fibre content for improving the self-healing properties of the

SMA mixtures. The objective of the healing rate assessment was to measure the restoration of strength in the asphalt mixtures after the self-healing procedure. Comparing the ITS values before and after healing enabled the assessment of the extent of initial strength recovery, yielding significant insights into the efficiency of the healing process. The variation in steel fibre content allowed the determination of the ideal steel fibre proportion to enhance the healing capabilities of asphalt, hence improving the durability and performance of SMA mixtures in practical applications. This investigation enhanced the comprehension of the impact of steel fibres on crack closure and strength recovery, particularly under microwave radiation exposure. The conductive qualities of steel fibre may improve heat distribution within the mixture, facilitating the self-healing process by enhancing binder flow and cracking closure efficiency.

Result and Discussion

Volumetric Properties Test

The volumetric properties of asphalt mixtures, such as bulk specific gravity (G_{mb}), theoretical maximum specific gravity (G_{mm}), and air void content, are crucial indicators of the mixture's quality and performance. These properties are essential in ascertaining the durability, strength, and deformation resistance of asphalt pavements under traffic loads. For Stone Mastic Asphalt (SMA), recognized for its superior rut resistance and structural stability, it is crucial to maintain ideal volumetric properties to guarantee long-term performance. Figure 5 illustrates the relationship between bulk specific gravity (G_{mb}) and theoretical maximum specific gravity (G_{mm}) across different steel fibre contents in Stone Mastic Asphalt (SMA) mixtures. The findings reveal clear patterns regarding the influence of steel fibres on specific gravities, carrying significant implications for compaction and air void content in the modified mixtures. The addition of steel fibres into SMA mixtures produced different effects on the bulk specific gravity, as illustrated in the figure. At a steel fibre level of 0.3%, the G_{mb} significantly increased to 2.248 relative to the control mixture (2.243), signifying enhanced compaction. The increase indicates that 0.3% steel fibre improves the mixture's density by diminishing air void content, resulting in enhanced structural integrity performance. Nonetheless, as the steel fibre content increased to 0.5% and 0.7%, the bulk specific gravity decreased to 2.236 and 2.228, respectively. The decrease in bulk specific gravity with increased steel fibre content aligns with Tapkin's (2008) findings, which indicated that fibres generally possess a lower density than other constituents in asphalt mixtures, leading to a reduction in overall bulk specific gravity when included in greater amounts. A study by Wang et al. (2020) supports that fibre-reinforced mixes, although improving mechanical properties, generally display reduced bulk specific gravity at higher fibre contents due to increased air void content. The air void content is directly correlated with bulk specific gravity, where higher G_{mb} values signify reduced air voids and enhanced compaction. The increase in G_{mb} at 0.3% steel fibre content indicates that this ratio efficiently reduces air voids, improving the mixture's efficiency. In contrast, higher fibre content enhances air voids, which could compromise the mechanical properties of the SMA. Excessive air voids might result in higher permeability and premature pavement deterioration, whereas inadequate air voids may contribute to rutting and bleeding under traffic loads (Tapkin, 2008). Notwithstanding these variations, all tested mixtures adhered to the permissible range of 2.2 to 2.5 for SMA mixtures, indicating that the steel fibre modifications, particularly at 0.3%, sustained excellent performance levels.

The theoretical maximum specific gravity indicates that G_{mm} decreases with an increase in steel fibre content from 0% to 0.5%. The control SMA mixture (0% steel fibre) showed the highest G_{mm} value of 2.510, whereas the mixture containing 0.3% steel fibre exhibited a notable decrease to 2.388. The G_{mm} decreased to a minimum value of 2.343 at a steel fibre content of 0.5%. The observed decline is due to the lower density of steel fibres compared to aggregate and binder, leading to a reduction in the overall specific gravity of the mixture as fibre content increases (Sengul et al., 2013). At a steel fibre content of 0.7%, the G_{mm} value increased to 2.417, yet it remained lower than that of the control mixture. This indicates that although steel fibres generally reduce specific gravity, this effect may be decreased at higher concentrations due to enhanced distribution or improved compaction of the fibres within the mixture. The small increase in G_{mm} by 0.7% suggests that the fibres improve the internal composition of the mixture, resulting in enhanced compaction efficiency (Sarsam & Al Tuwayyij, 2020). The analysis of bulk specific gravity (G_{mb}) and theoretical maximum specific gravity (G_{mm}) demonstrates that incorporating steel fibres in SMA mixtures can improve compaction and reduce air void content at lower fibre contents (e.g., 0.3%), thereby enhancing the structural performance of the mixture. Higher fibre content (0.5% and 0.7%) results in a decrease of specific gravities, indicating that excessive fibre may increase air voids and adversely affect the overall performance of the mixture. Consequently, a steel fibre content of 0.3% is identified as the most balanced and effective proportion for maintaining optimal specific gravity and performance in SMA mixtures.

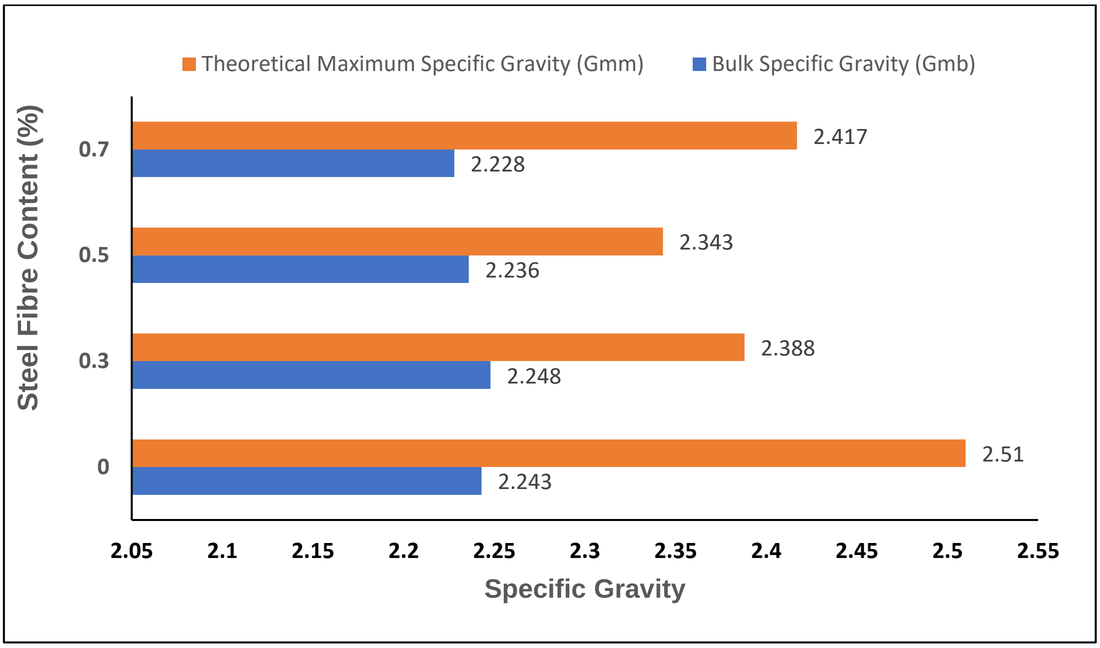

Figure 5.0 Bulk specific gravity (G_{mb}) and Theoretical maximum specific gravity (G_{mm})

According to the values presented in Figure 6, the unmodified SMA sample with 0.7% steel fibre content exhibits the highest air void content at 10.6%, leading to the lowest compaction percentage of 89.4%. The SMA sample modified with 0.5% steel fibre demonstrates the highest compaction percentage at 95.5%, which correlates with the lowest air void content at 4.5%. This pattern illustrates an inverse correlation between air void content percentage and compaction levels. With an increase in air void content, compaction diminishes, as air voids contribute to a reduction in the overall density of the SMA samples. Optimal air void content is crucial for the effective performance of the SMA sample. Serin et al. (2012) demonstrated that the inclusion of steel fibres in asphalt mixtures leads to a reduction in air void content and an increase in the density of the mixture. The research concluded that steel fibres enhance the compatibility of the mix by improving the bonding between aggregates and load distribution, resulting in reduced air void content. This aligns with the current observation that the SMA sample containing 0.5% steel fibre exhibits the lowest air void content and the highest level of compaction.

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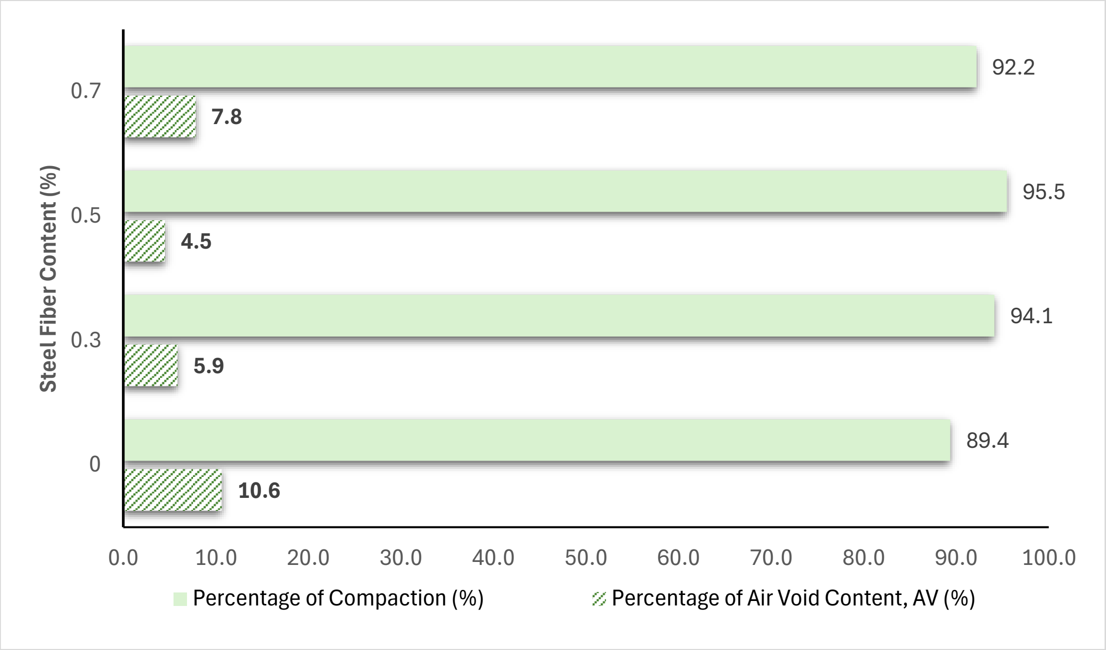

Figure 6.0 Air voids and Compaction

The values presented in Figure 7 indicates that the addition of steel fibre to SMA mixtures enhances stability and decreases deformation. The highest stability is attained at a steel fibre content of 0.3%, demonstrating a notable enhancement in performance relative to the unmodified mixture. Increased fibre contents of 0.5% and 0.7% continue to enhance stability, although with decreasing small benefits. Increased fibre content correlates with decreased flow values, indicating enhanced rigidity and reduced deformation under load. Overall, 0.3% steel fibre offers the most effective balance between improved stability and manageable rigidity, establishing it as the optimal content for performance enhancement (Jasni et al., 2020). investigated the effect of steel fibres on enhancing the resistance of asphalt mixtures to permanent deformation. The findings demonstrated that steel fibres enhanced stability and flow characteristics, with an optimal fibre content of 0.3% to 0.5% yielding the most suitable balance between strength and flexibility. The current study's findings indicate that a higher stability value was attained at a steel fibre content of 0.3%. Kureshi et al. (2019), found that steel fibre-reinforced asphalt mixes demonstrated enhanced stability and reduced flow values in comparison to conventional mixes. Research indicates that steel fibres enhance the structural integrity of asphalt mixtures through improved aggregate interlock and load distribution. This phenomenon explains the observed reduction in flow as steel fibre content increases in this study.

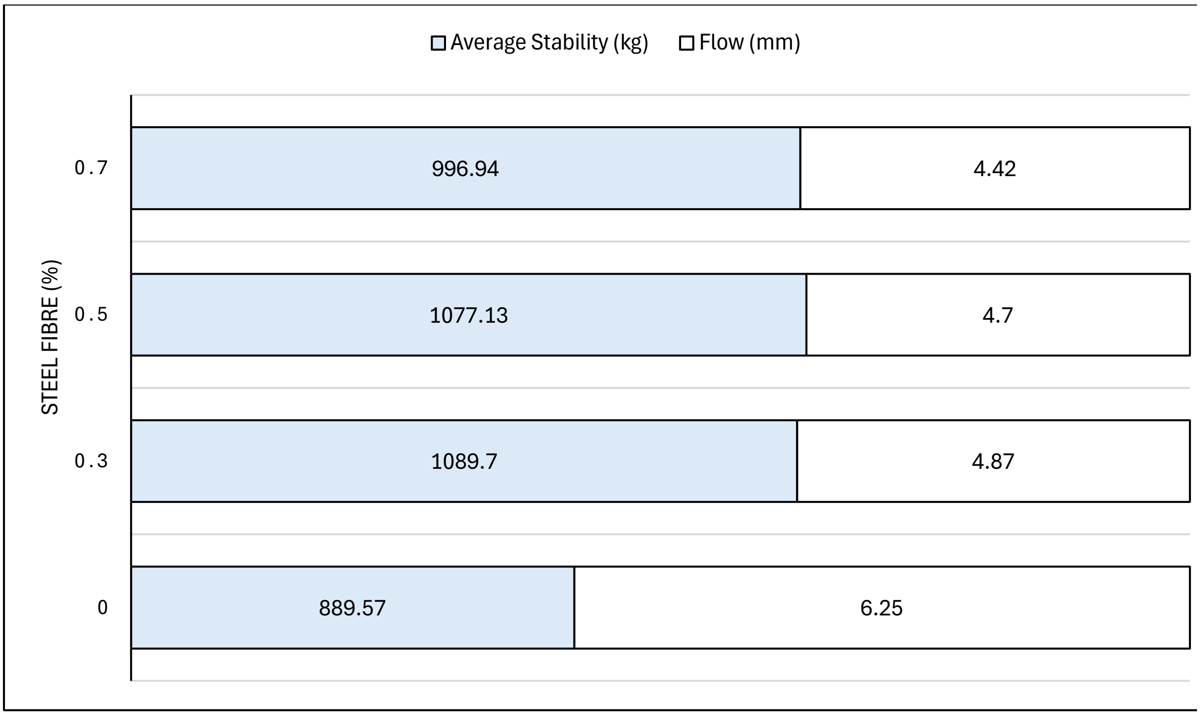

Figure 7.0 Stability and Flow

Self Healing Rate

Table 1 presents a comparison of indirect tensile strength (ITS) values before and after the healing process for different percentages of steel fibre content in SMA mixtures while Figure 8 presents the healing rate for different percentages of steel fibre content in SMA mixtures. The unmodified SMA mixture (0% steel fibre) demonstrates an initial ITS of 295.02 kPa. Although there is a reduction in strength after healing, it maintains an important portion of its initial strength, resulting in a final ITS of 247.24 kPa and a healing rate of 83.86%. This suggests that the unmodified mixture effectively regains its strength after healing. The SMA mixture containing 0.3% steel fibre exhibits slightly reduced ITS values, recorded at 253.66 kPa before healing and 218.65 kPa after healing. Nonetheless, it attains a maximum healing rate of 87.01%, indicating that the inclusion of 0.3% steel fibre improves the mixture's capacity to regain strength after damage.

The SMA mixture containing 0.5% steel fibre exhibits a notable decrease in initial and final ITS values, recorded at 229.77 kPa and 140.66 kPa, respectively, with the lowest healing rate of 59.96%. This suggests that an excessive amount of steel fibre reduces the mixture's ability to heal and regain its original strength. The SMA mixture containing 0.7% steel fibre exhibits a small enhancement in ITS values before and after healing (258.48 kPa and 162.83 kPa, respectively); however, the healing rate is relatively low at 63.32%. This indicates that although increased fibre content enhances initial strength, it does not markedly improve healing performance.

The findings align with prior research. Serin et al (2012), reported that excessive steel fibre can reduce the mechanical properties and healing ability of asphalt mixtures, while Jasni et al. (2020), noted that higher fibre content negatively impacts bonding between aggregates, resulting in reduced post-damage healing. Kureshi et al (2019), pointed out that excessive fibre content may hinder effective aggregate interlocking, which is crucial for maintaining strength and facilitating healing. The findings indicate that a steel fibre content of 0.3% achieves an optimal balance between initial strength and healing rate, whereas increased fibre contents, specifically 0.5% and 0.7%, result in reduced healing efficiency. The conclusion is supported by the performance of the SMA mixture containing 0.3% steel fibre, which succeeded in all conducted tests, including specific gravity, Marshall stability and flow, and indirect tensile strength tests. The 0.3% steel fibre mixture consistently demonstrated superior performance relative to mixtures with alternative steel fibre percentages, establishing it as the most effective content for improving the overall properties of stone mastic asphalt.

Table 8.0
Indirect tensile strength vs steel fibre content.

Steel Fibre Content (%)	ITS Before Healing (kPa)	ITS After Healing(kPa)
0	295.02	247.24
0.3	253.66	218.65
0.5	229.77	140.66
0.7	258.48	162.83

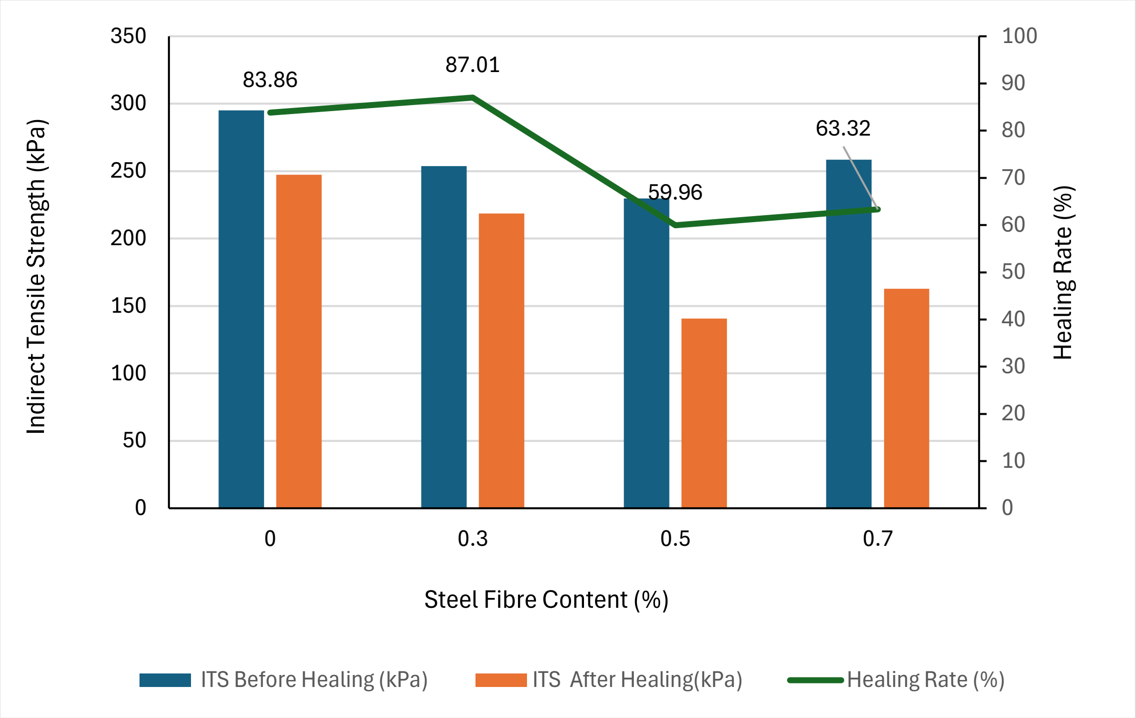

Figure 8.0 Healing rate vs steel fibre content.

The use of steel fibre into SMA not only improves its structural properties but also creates new avenues for sustainable road construction. This study carefully investigates the influence of varying steel fibre content on the immediate mechanical strength and long-term self-healing properties of SMA. These findings endorse the establishment of resilient infrastructure in accordance with Sustainable Development Goal (SDG) 9, promoting innovations that reduce resource consumption and enhance the durability of transportation networks.

Conclusion

In summary, the addition of steel fibres, especially at an amount of 0.3%, markedly improves the properties of Stone Mastic Asphalt (SMA) mixtures, supporting Sustainable Development Goal 9 (SDG 9) through the advancement of innovation and resilient infrastructure. The SMA mixture containing 0.3% steel fibre demonstrated a significant increase in bulk specific gravity, suggesting an enhanced mix design compared to the unmodified SMA. Higher fibre content (0.5% and 0.7%) led to small decreases in specific gravity; however, these mixtures continued to meet acceptable standards. The stability results indicated that the 0.3% steel fibre mixture exhibited optimal resistance to deformation, suggesting improved load-bearing capacity and durability over time. Indirect Tensile Strength (ITS) tests demonstrated that the 0.3% steel fibre mixture exhibited the optimal balance of tensile strength and healing properties, achieving the highest healing rate of 87.01% after damage. The 0.5% steel fibre mixture demonstrated a greater percentage difference in ITS before and after healing; however, it showed lower recovery. Consequently, 0.3% is identified as the optimal content for resilience and performance. The study concludes that the addition of 0.3% steel fibre in SMA mixtures provides an optimal balance of durability, strength, and recovery, rendering it the most effective modification for enhancing SMA. This innovation aligns with the objectives of SDG 9 by enhancing the sustainability, resilience, and cost-effectiveness of road infrastructure, thereby mitigating road deterioration and decreasing maintenance expenses. The findings highlight the potential of steel fibre as a suitable modifier for improving the performance of SMA in modern infrastructure development.

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