Utilization of Waste Denim Fibers in Asphalt Pavement: A Review

[1] Gailan Ismat Safaeldeen

[1] Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq

ABSTRACT

The purpose of this study is to discuss how waste denim fibers (WDF) can be utilized as a modifier in applications for green asphalt pavement construction. It was discussed where denim fiber comes from, what it is made of, and its characteristics. It also covered how WDF affected the rheological and physical characteristics of unmodified- and modified-asphalt binders. The reasons for using denim fiber as a modifier for basic and modified-asphalts were also emphasized, including its mechanical qualities, water content is lower than most of natural fiber, and sustainability in terms of low costs and simultaneous environmental problems mitigation. However, there are challenges to using WDF in the construction of pavements, including the design of the blending process, figuring out an easy, affordable way to dissolve the fiber in asphalt, and the presence of the water content of the fibers, which may influence the cohesion and adhesion performance of asphalt binders and mixtures. The research gaps and recommendations for future studies were also summarized in this short review. It seems likely that long-lasting, affordable, and eco-friendly denim fiber-modified asphalt and rut- and fatigue-resistant asphalt mixtures would be developed in the near future. This will lower the annual maintenance costs for flexible pavements that are needed all over the world.

Keywords: Waste denim fiber, Asphalt, Waste materials, Modifier,

1. Introduction.

Asphalt binder is a complex viscoelastic substance that significantly affects how asphalt pavement behaves [1]. Among all the pavements in the globe, it contributes to about 95% of the construction of the pavements. Due to the growth in heavy traffic and weather changes over the past few decades, the asphalt pavement is subject to various forms of defects over time [2]. The most frequent of these distresses are rutting, fatigue, and low-temperature cracking distresses, which are thought to be some of the key factors that determine how long an asphalt pavement will last [3]. Every year, millions of dollars are spent on upkeep and repairs for pavement failures. In order to improve the performance of asphalt mixtures and pavements, researchers and engineers are also always looking for ways to enhance the qualities of the asphalt binders. The best course of action is to modify the asphalt binder [4, 5]. The flexible pavement industry is also exploring for sustainable alternative modifiers to improve performance while reducing its carbon footprint [6, 7]. In general, the two most significant methods employed for this purpose are polymers and fibers [5, 8, 9].

Since 4000 years ago in China, the concept of employing fibers to alter the characteristics and behavior of materials has existed. When the Great Wall was completed 2000 years ago, they utilized the fiber to support the clay arch.

On the other hand, it was also asserted that modern fiber reinforcing of materials began in the early 1960s [5]. The usage of fibers including nylon, polyester, carbon, glass, cellulose, mineral, and polypropylene fibers as well as synthetic fibers, among other additives, has received more attention in recent years as researchers have worked to modify bitumen to improve its technical properties [10, 11]. The enhancement of moisture resistance, the enhancement of fatigue life qualities, the improvement of low-temperature cracking resistance, and increased durability are only a few of these remarkable effects. Additionally, enhancing the bitumen's viscoelastic qualities will increase rutting resistance and prevent the binder from draining from mixtures of gap-graded asphalt [5, 12].

Among the most widely used fibers to enhance bitumen and asphalt mixtures, especially stone mastic asphalt, is cellulose fiber (CF). For bitumen applications, CF is typically utilized as a reinforcing aging and rheology modifier. In order to improve the durability of asphalt mixtures, a thick bitumen film covering the aggregate is known as the essential fiber (CF). Additionally, it was mentioned that cellulose fiber makes asphalt mixture more stiff and resistant to high and low temperatures [13]. However, the most prevalent fibers are excessively expensive, driving up the price of asphalt paving overall [11, 14]. The environmental impact has since become apparent in society. To lower the cost of such engineering goods and to help reduce environmental pollution, governments and researchers are searching for novel fiber resources from industries, urban garbage, and farmland for use in pavement engineering applications [11, 15]. One of the best candidates that has received attention during the past few years is waste denim fiber.

The used denim fiber is obtained from garments that have been purchased, discarded, and factory textile waste as well as unsold clothing items. An average pair of denim jeans uses roughly 3781 liters of water during the recycling process, which costs the company a lot of money. In addition to the material separation's complexity, which is difficult [16]. Therefore, using denim wastes in bitumen applications will increase sustainability by conserving available resources like water. A significant percentage of cellulose up to 95% as well as waxes, nitrogenous stuff, and pertinacious compounds are present in the denim waste fiber. Around ninety countries generate 20 million tons of cotton each year, which is utilized to make denim clothing [17, 18]. Over 75% of the world's cotton is produced in the United States, China, India, Uzbekistan, Pakistan, and West Africa. Turkey and Brazil are taking into account the other significant cotton producers. According to another study, cotton fiber required to make denim clothing is produced globally on a yearly basis in amounts of roughly 25 million tons. After a short while, those turn into waste products that require practical and effective disposal techniques [18]. This short review summarizes the utilization of waste denim fiber in asphalt pavement applications and highlights the motivations, challenges and future directions for other interested researchers and industries.

2. Literature review

Waste denim fiber (WDF) was first used to modify bitumen by Al-Sabaeei at al. [19]. A tiny amount of WDF components (0, 0.5, 1 and 1.5%) were added, and the investigation was only focused on unaged modified bitumen. The results showed that WDF decreased temperature susceptibility while increasing bitumen stiffness and permanent deformation resistance. The differences in the impacts of WDF and nanosilica particles separately and in composite on the high-temperature performance of asphalt binder were further investigated in another study [20]. Each modifier was applied at a rate of 0, 2, 4, and 6% of the blend's overall weight. Physical properties testing was done to determine ductility, softening points, and penetration. Additionally, a dynamic shear rheometer was used to examine the rheological characteristics of base and modified binders both before and after short-term aging. According to the results, adding NS to WDF-modified bitumen decreases penetration values, temperature sensitivity, and ductility while increasing softening point and rutting resistance properties. According to the MSCR test results,

the non-recoverable creep compliance (Jnr) decreaces while the percentage of recovery (%R) increases with NS content increments of up to 4%. Bitumen's performance grade has been upgraded for binders modified with NS-WDF at 4% NS and 4% WDF, going from PG 64S to PG**H. These results demonstrate the bitumen's extraordinary improvement in rutting resistance and flexibility.

Using response surface methodology (RSM), the physical properties of the WDF-modified bioasphalt binders were optimized [21]. Utilizing a high-shear mixer, 16 mixes of base and bio-asphalt binders were established, and their performance was assessed using penetrations, softening point temperatures, and temperature susceptibility tests. RSM optimized the attributes in order to determine the ideal amount of additions that could be suggested. Findings showed that adding WDF to the base and bioasphalt binders decreased the penetration values and increased the softening point temperatures and the penetration indexes. These results demonstrate the performance of WDF-modified bio-asphalt binders in intermediate- and high-temperatures pavement application. The developed models' numerical optimization result showed that 5% WCO and 6% WDF can be used to get the best attributes. Similar research was done to assess how WDF affected the physical characteristics of the rubberized asphalt binder [22]. RSM was used in the experimental design, data analysis, modelling, and multiobjective optimizations processes. Utilizing a high shear mixer, base asphalt was replaced with 0, 5, 10, and 15% tire pyrolosis oil (TPO) and 0, 2, 4, and 6% WDF. TPO and WDF's combined impacts on bitumen penetrations, softening points, and temperature susceptibility were assessed. The result revealed that the consistency and temperature susceptibility of basic bitumen is significantly impacted by the addition of TPO and/or WDF. High levels of correlation were seen in the dependent variables and responses in RSM analysis. The results of the numerical multi-objective optimization demonstrated that 8.4% TPO and 6% WDF are sufficient to get the best characteristics.

A recent study was conducted to develop models that can be used to predict the permanent deformation parameters of WDF/nanosilica (NS)-composite asphalts [23]. RSM and machine learning techniques were used. The criteria taken into account were the shear strain, accumulated shear strain, non-recoverable creep compliance (Jnr), percentage of recovery (%R), and modified by NS, WDF, and NS/WDF-composite asphalts. Figure 1 depicts the aspect of WDF and nanosilica particles. The RSM statistical analysis showed that at different shear stress levels at the 95% confidence interval, shear strain, cumulative shear strain, Jnr, and R are all greatly impacted by the NS and WDF. Additionally, all responses to the RSM-based prediction models had correlation coefficients (R2) greater than 0.8, suggesting appropriate consistency between the factors from the experimental works and the anticipated MSCR parameters by the generated models. Analysis of the ML models shows that the Extreme Gradient Boosting regression is one of the best models for predicting the shear strain and accumulated strain. With the highest R2 of 0.99 and the smallest root mean square error (RMSE) of 1% among the investigated ML modells, Decision Tree Regression (DTR) performs the best in predicting Jnr and % R, demonstrating its capacity to accurately capture the laboratory MSCR rutting parameters. The performance of the generated ML modells outperforms the RSM in predicting the MSCR rutting parameters, according to analysis of the XGB regression and DTR results.

Fig. 1. The aspect of the used materials (a) WDF (b) NS particles

3. Motivations and challenges for utilizing waste denim fibers in Asphalt Pavement

One of the primary reasons for employing WDF is the fact that fibers made from waste denim clothing have better molecular and mechanical characteristics than fiber obtained from wood-pulp [24]. Additionally, it was discovered that waste denim fibers outperform equivalent lyocell fibers in terms of molecular weight, specific gravity, tensile strength, and wet strength [24]. The denim fiber's moisture content was reported to be around 8% [18]. That indicates there is no pretreatment is needing, unlike with others forms of natural fiber, which require upgrading to lower the moisture content prior to being added to asphalt binders and mixtures. Additionally, the resin in the denim-based garment wastes will aid to enhance the adhesive qualities of the asphalt binders and mixtures. In contrast to most polymers, which still have compatibility problems, the inclusion of resin aids in improving the use of denim fiber materials with bitumen. Particularly, the use of denim fibers in asphalt binders and mixtures via the introduction of a wet process would improve the homogeneity of the fiber modified asphalts and subsequently improve the performance in comparison to a fiber-modified asphalt mixture through a dry process. Due to the aforementioned characteristics, it is highly recommended that waste clothing fiber be used to modify asphalt binders and mixtures in order to address the lower moleculars weights issue and enhance viscosities, rutting resistances, and performances. WDF is less expensive than the most widely used commercial fibers [25]. These denim fiber characteristics are anticipated to improve researchers' drive to modify asphalt and mixtures in flexible pavement application, which will help to create more environmentally friendly asphalt pavement. Besides, the use of WDF in asphalt paving will help with improved resource management for the creation of cotton and synthetic fibers. Additionally, it reduces the negative economic and environmental effects of denim clothing waste [24].

The cellulose in bitumen problem, as well as designs of the blending processes, including the temperatures and the number of rounds per minute until the homogenous blends, provide some challenges in the wet process. However, the dissolving of cellulose is currently a topic of research for chemical researchers. Although there are a few materials and methods that can dissolve cellulose, they are generally very complex and expensive, so one of the difficulties of utilizing these waste materials in asphalt pavement application is finding a simple, inexpensive method to do so. A further difficulty is the water content of fibers, which is likely to have a detrimental impact on the cohesion and adhesive qualities of asphalt binders and mixtures, which in turn impairs the pavement's ability to withstand wear and tear. The problem is figuring out how to remove the moisture contents from the fibers, or at the very least how to choose the fiber type for this kind of asphalt modification. The sustainability of the fibers generated from

waste materials being utilized is also crucial. This means that leftover WDF supposed to be suitable enough to be utilized at
a cost-effective way than chemical substitute materials, which are not environmentally or economically viable.

Conclusion

It is vital to use waste material modifiers like denim fiber to modify asphalt binders and mixtures in order to dispose of such waste materials and enhance bitumen's qualities in a sustainable way. The following findings can be taken from the literature review that is currently being conducted:

- One of the least expensive and most accessible sustainable waste resources that might be suggested for asphalt pavement alteration is waste denim fiber.
- Waste denim fiber has shown promising results when added to asphalt binders. It demonstrated a considerable improvement in its consistency and physical characteristics.
- Waste denim fiber has shown excellent potential for use in asphalt binders. Rheological properties in terms of stiffness and permanent deformation parameters indicated a considerable improvement.
- Similarly, base and modified asphalt binders' resistance to elasticity deformation and temperature susceptibility was improved by using all of the waste denim fiber.
- Future studies on the advanced properties of asphalt binders incorporating used denim fiber in various environmental settings are advised in order to further our understanding of the use of such waste substances as construction materials.
- Future studies on developing predictive models to demonstrate the behavior of waste denim fiber in asphalt pavement using various modeling techniques are also recommended.

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