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Research Article

Viscoelastic Behavior of Geotextile Reinforced Asphalt Concrete

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Keywords

Nonwoven geotextile, Asphalt concrete, Reinforcement, Stiffness, Load sustaining capacity.

Abstract

Asphalt concrete pavement is usually subjected to heavy vehicular loading and environmental impact. The tensile strength of the pavement could be improved by reinforcement to withstand such loading impacts. This work presents a laboratory investigation to evaluate the change in the viscoelastic behavior, stiffness and deformation characteristics of reinforced Asphalt concrete pavement. Two types of nonwoven continuous fiber geotextile with two different thicknesses (Geofalt and Typer) have been implemented. Asphalt concrete mixtures were designed as per Marshall test requirements and prepared as per the requirements for binder course of SCRB with 19 mm nominal maximum size of aggregates. Circular asphalt concrete specimens of 152.4 mm diameter and 38.1 mm thickness have been constructed using optimum asphalt content, and static compaction to a target density. The specimens were coupled, and the geotextile reinforcements were introduced in between, then tested in a model box of (50 x50 x70) cm filled with loose sand layer of 40 cm thickness representing the poor subgrade condition. A total of 12 circular specimens have been constructed and tested in duplicate. The load – deformation data was plotted and analyzed for the deformation and stiffness characteristics. It was noticed that at failure, the load sustaining capacity of geotextile reinforced mixture at the end of the viscoelastic stage increased by 116 % as compared with the case of control mixture. It is higher than that of the control mixture by (29, and 35.4) % for Geofalt and Typer reinforced asphalt concrete mixtures respectively. However, the stiffness of asphalt concrete mixtures at failure had increased after implementation of geotextile reinforcement by (25, and 31.2) % for Geofalt and Typer reinforced mixtures respectively. It was concluded that implementation of the nonwoven continuous fiber geotextile is beneficial in enhancing the sustainability of asphalt concrete.

1. Introduction

The implication of geosynthetics between the asphalt concrete layers can enhance the pavement performance through reinforcement function. Geosynthetics have been used within asphalt concrete to increase its structural capacity and control the development of reflective cracks into structural overlays. Several testing procedures have been adopted to quantify the performance of geosynthetic-reinforced asphalt pavements. Lytton, 1989 [1] assessed geotextile usage in asphalt concrete overlay as strain relief, undersealing, and reinforcing material. Fracture properties under thermal and fatigue loading were monitored. It was revealed that reflection cracking through the overlay could be retarded by implementation of geotextile. The deformation characteristics of textile reinforced Asphalt concrete pavement was assessed by Sarsam, 2013 [2]. It was concluded that the geotextile exhibited superior performance when reinforcing thin pavement layer. Sudarsanan et al., 2018 [3] investigated the interface bond strength of geotextiles in asphaltic concrete layers with the aid of shear tests. It was observed that the synthetic geotextile-reinforced samples improve the shear strength by 26% as compared with unreinforced asphalt concrete mixture. Sudarsanan et al. 2016 [4] reported that the propagation of crack through the overlay can be controlled by reducing the magnitude of tensile stresses at the crack-overlay interface by implementing tensile reinforcing member (geotextile), the positive improvement in the strength parameters of the geotextile reinforced pavement is comparable with the traditional flexible pavement. Sudarsanan et al. 2018 [5] evaluated the bond strength at interlayer between the asphalt pavement layers after implementation of reinforcements with a geosynthetic product impregnated with asphalt as a tack coat material. Habibpour et al., 2023 [6] evaluated the potential of using geosynthetics for reinforcing flexible pavement to improve the resistance to reflective cracking. It was found that the geotextile-reinforced asphalt concrete layer exhibited higher bonding. Reduction of rut depth of 25% for reinforced sections compared to the control have been observed. It was concluded that the geosynthetic interlayer was able to restrict reflective cracking propagation and improved fatigue performance. Yadav, 2022 [7] proposed that touch down area of the runway can be enhanced with the aid of reinforcement of geosynthetic layer to minimize deterioration and deflection and of the structure. It was observed that the load can be reduced by placing a geosynthetic reinforcement layer. It was revealed that a geosynthetic reinforced pavement structure for aprons and runways improves the load carrying capacity of the flexible pavement to sustain the heavy transport aircraft. Gullen et al., 2021 [8] evaluated the influence of reinforcing asphalt concrete with geosynthetic interlayers on crack retardation within hot-mix asphalt mixtures. Three-point bending beam test was conducted to evaluate the cracking resistance of geosynthetic interlayers. The results indicated that specimens with geosynthetic interlayers exhibited slower crack propagation rates and higher fracture-energy compared with control specimens. Imjai et al., 2019 [9] examined the performance of geosynthetics reinforced flexible pavement which were embedded at different pavement depths. The results show that the reinforcement had reduced the vertical static and dynamic stresses by 66% and 72% respectively. The geosynthetics reinforcements exhibited expected enhancement to prolong the lifespan of the pavement. Zornberg, 2017 [10] reported that

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various types of geosynthetics may be implemented to fulfill one or more specific functions such as separation, filtration, stiffening, reinforcement, drainage, barrier, and protection in a variety of roadway applications. Fleury et al., 2023 [11] reported that geosynthetics has proved to provide an interesting anti-reflective crack system. Adoption of geotextiles between the overlay and the cracked asphalt concrete layer may be considered as an attractive solution. Yin et al., 2022 [12] presented a numerical study of geotextile reinforced flexible pavement under static loading. The impact of reinforcement on improvement of rutting resistance performance was investigated. A significant decline in rutting of up to 25.2 % was attained with geotextile reinforcement. It was concluded that the deflection response behavior of the flexible pavement system is affected by the elastic modulus of geosynthetic material. A base course thickness reduction of up to 30% could be achieved without sacrificing the pavement's structural integrity when geotextile was implemented. Alimohammadi et al., 2021 [13] reviewed field experimental studies on geosynthetic reinforcement of flexible pavement. It was revealed that the main appreciable improvement to pavement by geosynthetics reinforcement depends on various factors such as hot mix asphalt thickness, base and subgrade stiffness and quality, and geogrid stiffness. Leonardi and Suraci, 2022 [14] presented the results of the finite element simulations and developed the rutting phenomenon in reinforced flexible pavement. The advantages given by the geosynthetic reinforcement embedded in the asphalt concrete layer in terms of permanent deformations were assessed. Ingrassia et al., 2020 [15] assessed the influence of geocomposite reinforcement on cracking and permanent deformation of thin asphalt pavements. A full-scale trial section was constructed with unreinforced and reinforced with geocomposite. Three-point bending tests were conducted. It was concluded that the geocomposite improved the resistance to permanent deformation as compared to the unreinforced pavement. The use of geocomposite can extend the service life of thin asphalt pavements in terms of both cracking and permanent deformation accumulation. Silva et al., 2024 [16] evaluated the impact of interface bond strength on the fracture resistance of geosynthetic-reinforced asphalt concrete using shear strength testing. A fiberglass was used as geosynthetic reinforcement. A correlation between interface shear strength tests and cross-shear tests was obtained. Saxena et al., 2023 [17] evaluated the cracking resistance of geosynthetic-reinforced asphalt concrete with the aid of monotonic cross-shear test. Two layers of 19 mm thickness of asphalt concrete with geosynthetic in between were considered for testing. The test results of unreinforced and geosynthetic-reinforced asphalt specimens were compared. It was revealed that the geosynthetic had enhanced the cracking resistance of the asphalt concrete. Jaskula et al., 2023 [18] investigated the impact of a multiaxial geocomposite on the delay of crack propagation, using the four-point bending tests. The impact of reinforcement on shear resistance was investigated. It was observed that the reinforced system was able to bear loads over a longer period and increase the fatigue life, as compared to the unreinforced system. Roodi et al., 2023 [19] tested the unreinforced and geosynthetic-reinforced asphalt concrete subjected to monotonic and cyclic cross-shear. The results show that the adopted geosynthetic reinforcements exhibited a significant improvement in the performance of asphalt concrete. All reinforced asphalt concrete specimens exhibited superior performance against the control specimens. Wang et al., 2023 [20] assessed a full-scale field study using two types of geosynthetics installed in the asphalt binder course. The test results indicated that geosynthetic-reinforced pavements were able to maintain pavement resilience during construction.

The aim of the present work is monitoring the changes in the viscoelastic behavior of asphalt concrete after the implication of two types of geosynthetic as a reinforcing membrane, the load carrying capacity and the stiffness of the control and reinforced asphalt concrete samples will be evaluated and compared through the unique testing setup for the experimental program.

2. Materials and Methods

2.1. Geotextile

Two types of non-woven polyester continuous fibers geotextile have been implemented as reinforcement; Table 1 illustrates their properties. such geotextile types are commercially available at the local market.

Table 1. Geotextile reinforcement's properties (as supplied by the manufacturers)

Type of geotextile	Typer BM 41Textile	Geofalt Textile	ASTM Designation
Unit weight	140 gm./ m^2	200 gm./ m^2	ASTH D-5261
Tensile strength	4.9 kN/ m^2	4.0 kN/ m^2	ASTM D-4595
Elongation at max. load	45 %	50%	ASTM D-4632
Thickness	0.7 mm	0.6 mm	ASTM D-5199
Melting temperature	165˚C	260 ˚C	ASTM D-4355
Polymer nature	Polypropylene	100% Polyester	Not applicable

2.2. Asphalt concrete

Fine and Coarse aggregates were obtained from Al-Nubai, north of Baghdad; the physical properties of the aggregates are illustrated in Table 2. Mineral filler was Caco3 powder, it was obtained from Karbala quarry; its physical properties are illustrated in Table 3. Asphalt cement binder was obtained from Dorah refinery; the properties are as illustrated in Table 4. The testing was conducted as per the ASTM, 2015 [21] procedure.

Table 2. Physical properties of aggregates according to ASTM, 2015 [21] testing procedures

Property	Coarse aggregate	Fine aggregate	ASTM Designation
Specific gravity	2.680	2.620	ASTM C-127 and C-128
Absorption (%)	0.4	0.7	ASTM C-127 and C-128
Percent Wear (Los-Angeles Abrasion)	19.6	Not applicable	ASTM C-131

Table 3. Physical properties of mineral filler according to ASTM, 2015 [21] testing procedures

Property	Test results	ASTM Designation
Specific gravity	2.640	ASTM D-845
Percent passing sieve No. 200	95	ASTM D-546

Table 4. Properties of Asphalt cement according to ASTM, 2015 [21] testing procedures

Property	Test results	ASTM Designation
Penetration (0. 1 mm)	48	ASTM D-5
Softening point (˚C)	49	ASTM D-36
Ductility (cm)	+100	ASTM D-113
Specific gravity	1.024	ASTM D-70

2.3. Preparation of asphalt concrete mixture

Aggregates were dried, separated to different sizes by sieving, and stored in plastic containers; the required amount of aggregate from each size was weighted, and combined to fulfill the overall gradation of job mix formula requirement as per the SCRB, 2003 [22] specification for binder course pavement layer. The selected combined gradation falls within the lower and upper limits of the SCRB specifications. The combined aggregate gradation and the asphalt cement were heated to 160 ˚C to comply with the viscosity requirements of the binder as per SCRB, 2003 [22] then mixed using mechanical mixer for a minimum of 120 seconds. Table 5 presents the properties of the design asphalt concrete implemented. Figure 1 exhibits the combined aggregates gradation. The maximum size of aggregate was 19.5 mm, and the nominal maximum size was 12.5 mm which was implemented for the mix design. The mixing temperature was maintained to 160 ˚C.

Table 5. Properties of the design Asphalt concrete mix prepared

Properties of asphalt concrete mixture	Test results
Optimum asphalt content (%)	4.6
Maximum theoretical specific gravity (Gmax)	2.446
Marshall stability (kN)	8.3
Marshall flow (mm)	3
Specific gravity at optimum asphalt content	2.270
Volume of voids (%)	4.6
Voids filled with bitumen (%)	72

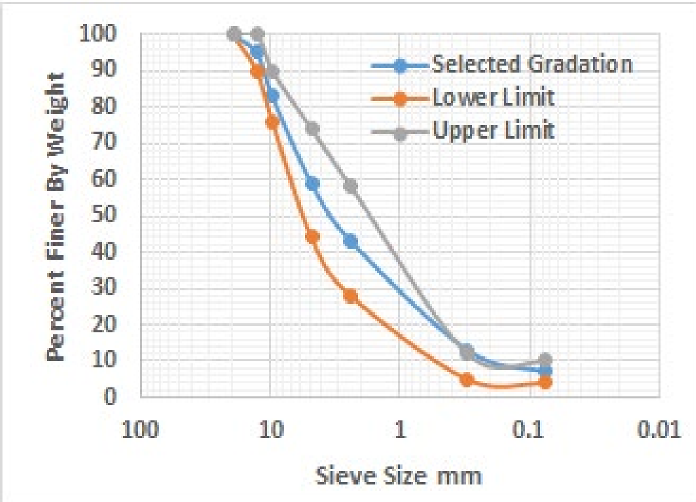

Figure 1. Combined gradation of asphalt concrete

2.4. Preparation and testing of asphalt concrete specimens

Asphalt concrete specimens of 152.4 mm diameter and 38.1 mm thickness were constructed using the traditional CBR mold and spacers, the required amount of hot Asphalt concrete mix (at 160 ˚ C) which gives the predetermined density of (2.270 gm / cm^3) at optimum asphalt content of 4.6 % was weighted, spread into the preheated mold, and subjected to initial compaction through a 50 spatula strikes, then the specimens were subjected to static compaction using Versa compression machine until the required specimen thickness was obtained at the target density, a total load of 5000 kg was required. The specimens were compacted to 93 % of the maximum theoretical density. Filter papers have been introduced at the top and bottom faces of the specimens to prevent sticking to the spacers. Specimens were kept overnight to cool then withdrawn from the mold using hydraulic jack. For control specimens, the material required to construct the upper layer which represent the overlay (when it was loose at 160 ^{0} C) was compacted over the pre compacted lower layer specimen which represent the existing pavement layer, this could simulate the field condition when constructing an overlay over existing pavement layer. The expected bonding between the upper and lower specimens is expected to occur due to the high compaction temperature rather than the need for a tack coat. However, for reinforced system, the material required to construct the upper layer (when it was loose at 160 ^{0} C) was compacted over the pre compacted lower layer specimen after inserting the geotextile in between. The expected bonding between the upper and lower specimens and the geotextile is expected to occur due to the high compaction temperature of 160 ^{0} C rather than the need for a tack coat. A total of 12 asphalt concrete specimens have been constructed and tested in duplicate. Figure 2 exhibits the preparation and compaction of asphalt concrete cylindrical specimens with the aid of CBR molds and spacers.

Figure 2. Preparation and compaction of asphalt concrete cylindrical specimens with the aid of CBR molds and spacers

Figure 3 shows the preparation of geotextile reinforced specimens with various types of reinforcements. The compaction temperature was maintained to 150 °C.

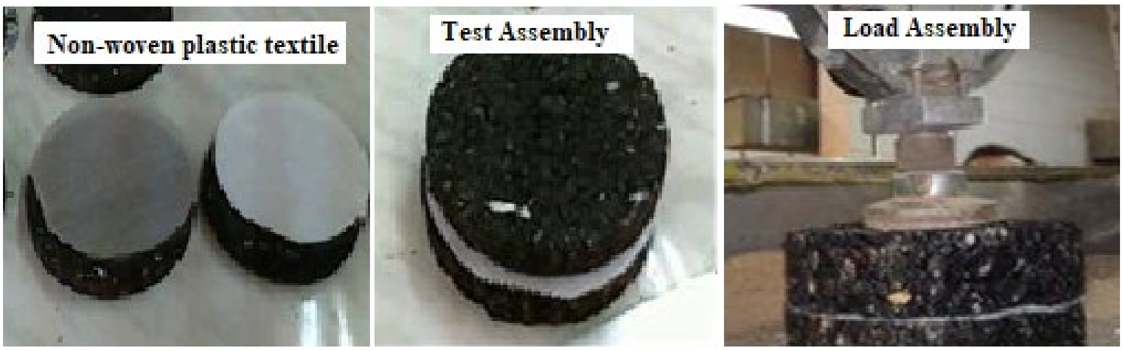

Figure 3. Preparation of geotextile reinforced asphalt concrete samples

2.5. Testing of reinforced asphalt concrete

The coupled specimens were transferred, centered, and seated into the testing box model of 50 x50 x70 cm dimensions on a layer of loose sand of 40 cm depth. The loose sand condition has been selected so that it could simulate compressible and poor subgrade, so that the reinforcing effect of asphalt concrete could be clearly detected. The loose sand was added into the model box by raining method. It was poured from height not exceeding 20 cm in layers, 100 mm for each layer until the desired height of sand was reached, and the layer was leveled with a straight edge. The sand is classified as poorly graded sand with a coefficient of uniformity (C_u)= 1.57 and coefficient of curvature (C_C) = 1. The maximum and minimum dry unit weight of sand are 17.4 kN/m^3 and 14.7kN/m^3 respectively and the specific gravity value of the used sand is 2.65. The load was applied through a circular metal plate of 10 mm thickness and 40 mm diameter using a strain-controlled system. An initial seating load of 10 Newton was applied consistently for all the tested specimens to ensure perfect contact between the plate and asphalt concrete top surface, also such contact was insured between the sub-grade sand and the bottom face of Asphalt concrete. The thickness of the overlay and the size of the loading plate were modelled to represent 50 % of the real field size (60 mm is the typical overlay thickness and 80 mm is the tire print). The load was applied and maintained at a rate of 2 mm / minutes and the load – deformation data were recorded until failure. The adopted failure criteria of asphalt concrete specimens were the drop in load and the punching deformation which is monitored by visual observation. Figure 4 shows the versa testing machine of 50-Ton capacity used for static compaction of the specimens and the model box used for testing the specimens.

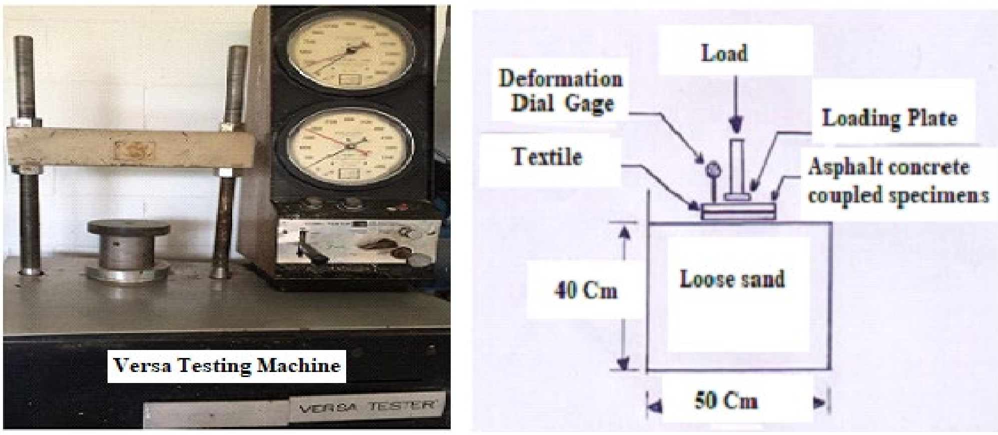

Figure 4. Compaction and Testing assembly of geotextile reinforced asphalt concrete specimens

3. Results and Discussion

3.1. Influence of geotextile on load sustainability of asphalt concrete

The aim of the implemented geotextile is to increase the structural capacity of the flexible pavement overlay. Figure 5 demonstrates the influence of geotextile on the Load-deformation relationship of asphalt concrete. The data indicated that implementation of geotextile exhibits higher load sustainability of reinforced asphalt concrete as compared with the control (unreinforced) mixture. A sharp increase in the deformation could be detected through the visco-elastic stage of loading. The viscoelastic stage of failure ends after a deformation of 5 mm while it ends after 2.5 mm for control mixture. The end point of the viscoelastic stage is figured when the slope of the load-deformation changes its trend to flatter state. The viscoelastic stage of loading is referred to the changes in condition of the specimen due to loading which can be eliminated under unloading conditions. For the geotextile reinforced asphalt concrete mixture, the load sustaining capacity at the end of the viscoelastic stage increased by 116 % as compared with the case of control mixture regardless of the type of geotextile. This may be attributed to the enhanced stiffness generated by the geotextile in the asphalt concrete. Significant variation in the load sustainability of asphalt concrete could be observed after implementation of reinforcements throughout the visco-plastic stage of failure. The deformation increases gently through the viscoplastic stage of loading. At failure, the load sustaining capacity of reinforced asphalt concrete mixtures is higher than that of the control mixture by (29, and 35.4) % for Geofalt and Typer reinforced asphalt concrete mixtures respectively. This could be related to the higher tensile property of the (typer) as compared with that of (Geofalt)as demonstrated in Table 1. The viscoplastic stage of loading refers to the changes in condition of the specimen due to loading which cannot be eliminated under unloading conditions. Significant permanent deformation was observed, likely due to the plastic yielding of the asphalt concrete layers. Such behavior may be attributed to the increased tensile strength of reinforced asphalt concrete as compared with the control mixture. Similar findings were reported by Zornberg, 2017 [23], and Fleury et al., 2023 [11]. The accepted standard deviation between the strength and deformation values of each couple of specimens was 5 % and the average value of a minimum duplicate specimens was considered for the analysis for each testing condition.

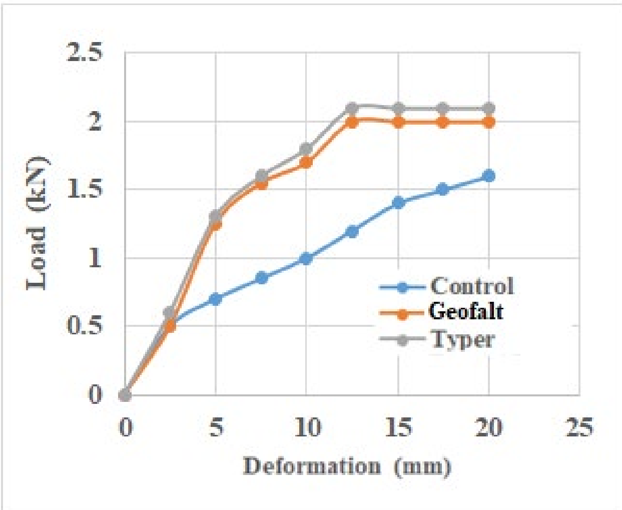

Figure 5. Influence of Geotextile on Load-deformation Relationship

3.2. Influence of geotextile on stiffness of asphalt concrete

The stiffness of asphalt concrete specimens was calculated by dividing the sustained load at failure by the deformation at failure for control and geotextile reinforced asphalt concrete specimens. As demonstrated in Figure 6, implementation of either type of geotextile reinforcement can restrict the lateral flow of the mixture and provide higher stiffness as compared with the control mixture. The stiffness of asphalt concrete mixture at failure had increased after implementation of geotextile reinforcement by (25, and 31.2) % for Geofalt and Typer reinforced mixtures respectively as compared with control mixture. Such finding agrees with the work reported by Sudarsanan et al., 2018 [3]; and Silva et al., 2024 [16].

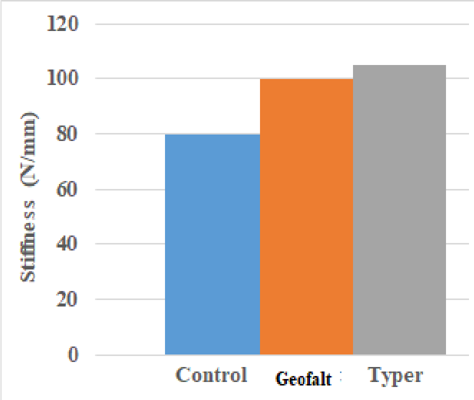

Figure 6. Influence of Geotextile on the Stiffness of Asphalt Concrete

4. Conclusions

Based on the limited testing program and limitations of materials, the following remarks may be addressed:

- The visco-elastic stage of failure of geotextile reinforced asphalt concrete ends after a deformation of 5 mm while it ends after 2.5 mm for control mixture.
- The load sustaining capacity of geotextile reinforced mixture at the end of the visco-elastic stage increased by 116 % as compared with the case of control mixture regardless of the type of geotextile.
- At failure, the load sustaining capacity of reinforced asphalt concrete is higher than that of control mixture by (29, and 35.4) % for Geofalt and Typer reinforced asphalt concrete respectively.
- The stiffness of asphalt concrete mixture at failure had increased after implementation of geotextile reinforcement by (25, and 31.2) % for Geofalt and Typer reinforced mixtures respectively as compared with control mixture.
- Geotextile can enhance the sustainability of asphalt concrete and increase its fatigue life.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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