

Glass Grid vs. Fiber Reinforcement in Asphalt Pavements: Materials, Performance, Design Integration, and Field Applications

—A Critical Review

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How to cite this paper: Khatri, W.A., Al Gazlan, A.A. and Al Ubaidi, N.A. (2026) Glass Grid vs. Fiber Reinforcement in Asphalt Pavements: Materials, Performance, Design Integration, and Field Applications. *World Journal of Engineering and Technology*, **14**, 405-426.

<https://doi.org/10.4236/wjet.2026.142023>

Received: February 24, 2026

Accepted: April 10, 2026

Published: April 13, 2026

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Abstract

Asphalt pavements in hot-climate regions face accelerated deterioration due to rutting, thermal cracking, reflective cracking, and traffic-induced fatigue. Reinforcement technologies—specifically synthetic fibers incorporated within asphalt mixtures and glass fiber grids installed as interlayer systems—have gained widespread interest for their ability to improve structural performance and extend pavement service life. This review synthesizes global literature, laboratory performance evaluations, mechanistic analyses, and field observations to critically compare these systems. Fibers enhance internal mixture behavior by improving tensile strength, fatigue life, and rutting resistance, while glass grids function as high-stiffness interlayer membranes that suppress reflective cracking and improve overlay durability. Design implications, constructability considerations, and suitability for harsh climatic environments are evaluated, with specific reference to conditions common in Saudi Arabia. The review concludes with guidance on reinforcement selection and identifies research needs related to material calibration, long-term monitoring, and installation quality control.

Keywords

Asphalt Reinforcement, Fiber Asphalt, Glass Grid, Reflective Cracking, Rutting, Pavement Overlays, Saudi Arabia

1. Introduction

Asphalt mixtures remain the predominant material used for pavement construction due to their flexibility, ease of maintenance, and well-characterized material

behavior. However, pavements deteriorate over time through distresses such as rutting, fatigue cracking, reflective cracking, and oxidative hardening, all of which reduce service life and increase maintenance burdens [1] (Figure 1). These distresses result from traffic loading, binder aging, thermal cycling, and limitations in mixture composition.

To improve durability, various modifiers—including polymers, rubbers, and fibers—have been introduced into asphalt mixtures. Similarly, glass fiber grids have become a widely adopted interlayer reinforcement system for overlay applications, particularly in reflective crack mitigation. Both reinforcement methods offer promising results but operate through fundamentally different mechanisms.

Saudi Arabia's pavement network experiences severe environmental conditions, including high temperatures, rapid binder oxidation, and heavy industrial and airfield traffic. These factors intensify pavement deterioration and increase the need for reinforcement systems that enhance structural capacity and delay distress propagation.

This paper presents a structured review comparing fiber and glass grid reinforcement systems in terms of materials, mechanisms, performance characteristics, design considerations, and application suitability. A Saudi Aramco case study will be incorporated once detailed technical information is finalized.

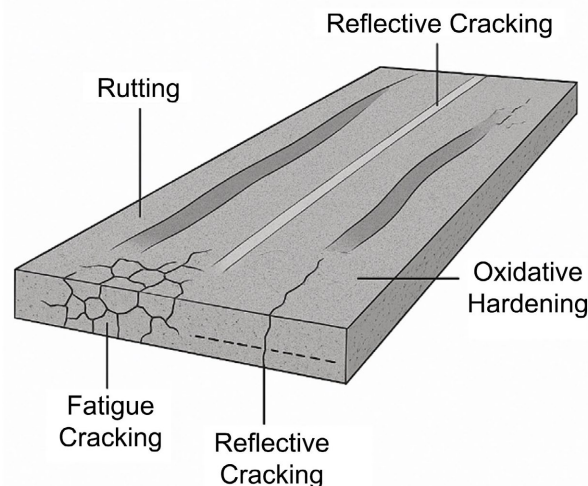


Figure 1. Common asphalt pavement distresses.

2. Review Method

This review was conducted using a structured narrative synthesis approach. Peer-reviewed journal articles were identified through database searches in Scopus, Web of Science, and Google Scholar using combinations of the following keywords: fiber-reinforced asphalt, aramid asphalt, polypropylene fiber asphalt, glass fiber grid asphalt, interlayer reinforcement, reflective cracking mitigation, and mechanistic-empirical pavement design.

In addition to academic literature, relevant technical reports (e.g., NCAT pub-

lications), design references, and manufacturer technical documentation were reviewed to capture both mechanistic understanding and practical implementation considerations.

Inclusion criteria focused on studies reporting laboratory performance metrics (Marshall stability, rutting, tensile strength, fatigue, resilient modulus), mechanistic interpretations, field validation data, or documented design integration approaches. Vendor documents were used strictly for material property ranges and installation descriptions, while performance claims were supported by peer-reviewed sources wherever available.

Studies lacking performance data, case documentation, or traceable methodology were excluded. Emphasis was placed on applications relevant to hot-climate pavements to ensure contextual applicability to Saudi Arabian conditions.

3. Reinforcement Materials and Mechanisms

3.1. Reinforcement Principles in Asphalt Systems

Reinforcement interaction within asphalt pavements occurs through two primary mechanisms:

- Internal reinforcement using fibers, which create a distributed three-dimensional network that increases tensile capacity, fatigue resistance, and deformation control [2].
- Interlayer reinforcement using glass grids, which introduce high-stiffness tensile restraint, improve interfacial shear transfer, and interrupt reflective crack propagation between pavement layers [3] [4].

These mechanisms underpin the different performance contributions of each system.

3.2. Fiber Reinforcement: Material Characteristics

A broad range of fibers has been explored for asphalt reinforcement, including cellulose, mineral fibers, natural plant fibers, fiberglass, and synthetic polymers [1] (Table 1). The most structurally effective fibers for modern pavement engineering are synthetic polymer fibers, particularly aramid and polyolefin blends.

3.3. Types of Fibers

- Fiberglass:

These have not been reported often in the literature but appear to have desirable properties, including high tensile modulus (~60 GPa), low elongation (3% - 4%), high elastic recovery (100%), and high softening point (815°C). They are, however, brittle and must be handled carefully during construction [5].

- Synthetic polymer fibers second

The most commonly used polymer fibers are polyester, polypropylene, aramid, and combinations of polymers. Other fibers include nylon, poly-para-phenylene terephthalamide (PPTA), and other less commonly used materials. Different polymers have different melt points, which need to be considered when adding to hot

mix asphalt. Production of synthetic fibers typically involves drawing a polymer melt through small holes. Fibers can be bundled together into yarn (although yarn is not typically used today in asphalt concrete). Reportedly, aramid fibers contract at high temperatures, which helps resist pavement deformation [2].

Table 1. Summary of Fiber types, advantages, and disadvantages.

Fiber Type	Advantages	Disadvantages
Cellulose	<ul style="list-style-type: none"> • Stabilizes binder in open- and gap-graded stone matrix asphalt (SMA) mixtures. • Absorbs binder, allowing high binder content for more durable mixture. • Relatively inexpensive. • May be made from a variety of plant materials. • Widely available. • May be from recycled materials such as newsprint. 	<ul style="list-style-type: none"> • High binder absorption increases binder cost. • Not strong in tensile mode.
Mineral	<ul style="list-style-type: none"> • Stabilizes binder in open- and gap-graded SMA mixtures. • Not as absorptive as cellulose. • Electrically conductive fibers have been used for inductive heating for deicing purposes or to promote healing of cracks. 	<ul style="list-style-type: none"> • Some may corrode or degrade because of moisture conditions. • May create harsh mixes that are hard to compact and may be aggressive, causing tire damage if used in surfaces.
Polyester	<ul style="list-style-type: none"> • Resists cracking, rutting, and potholes. • Increases mix strength and stability. • Higher melting point than polypropylene. • High tensile strength. 	<ul style="list-style-type: none"> • Higher specific gravity means fewer fibers per unit weight added. • Cost-effectiveness not proven/varies.
Polypropylene	<ul style="list-style-type: none"> • Reduces rutting, cracking, and shoving. • Derived from petroleum, so compatible with asphalt. • Strongly bonds with asphalt. • Disperses easily in asphalt. • Resistant to acids and salts. • Low specific gravity means more fibers per unit weight added. 	<ul style="list-style-type: none"> • Lower melting point than some other fiber materials require control of production temperatures. • Begins to shorten at 300°F. • Cost-effectiveness not proven/varies.
Aramid	<ul style="list-style-type: none"> • Resists cracking, rutting, and potholes. • Increases mix strength and stability. • High tensile strength. • May contract at higher temperature, which can help resist rutting. 	<ul style="list-style-type: none"> • Slightly costly compared to conventional Hot Mix Asphalt (HMA).
Aramid & polyolefin	<ul style="list-style-type: none"> • Controls rutting, cracking, and shoving. • Combines benefits of aramid and polyolefin (polypropylene) fiber types. 	<ul style="list-style-type: none"> • Slightly costly compared to conventional HMA.
Fiberglass	<ul style="list-style-type: none"> • High tensile strength. • Low elongation. • High elastic recovery. • High softening point. 	<ul style="list-style-type: none"> • Brittle. • Fibers may break where they cross each other. • May break during mixing and compaction. • Cost-effectiveness not proven/varies.

- Mineral

Either naturally occurring fibers, such as asbestos (chrysotile), or manufactured

mineral fibers can be used. Mineral fibers (also called mineral wool or rock wool) are manufactured by melting minerals then physically forming fibers by spinning or extruding. Steel fibers have been used for research purposes, but because they corroded upon exposure to water, they were not effective in the long term. Asbestos fibers were the first type of fiber used in hot mix asphalt; they were used from the 1920s until the 1960s when environmental and health issues curtailed the use of asbestos.

- Cellulose

Cellulose fibers are plant-based fibers obtained most commonly from woody plants, although some are obtained from recycled newspaper. These fibers tend to be branching with fairly high absorption; it is this nature that helps cellulose fibers hold on to high binder contents in mixtures. Cellulose fibers can be provided in loose form or in pellets.

3.4. Key Characteristics Include

- High tensile strength (typically 2800 - 3600 MPa for aramid fibers, depending on grade and test method) [1] [5].
- Thermal compatibility with hot-mix asphalt production.
- Chemical inertness.
- Capability to increase binder viscosity and elasticity.
- Creation of a 3D reinforcement network that delays crack propagation [5].

Fiberglass fibers have a high modulus but are brittle and prone to breakage during mixing, limiting their applicability [5].

3.5. Glass Grid Systems: Material Characteristics

Glass grids consist of continuous glass fibers formed into a grid structure and coated with a polymer-modified adhesive for improved bonding (Figure 2). Typical engineering properties include:

- Tensile strength: 50 - 200 kN/m.
- Elastic modulus: >70 GPa.
- Low elongation (3% - 4%).
- Exceptional thermal stability (-40°C to $+200^{\circ}\text{C}$).
- Strong resistance to chemical exposure and creep [3].
- **Thermal Stability (-40°C to $+200^{\circ}\text{C}$).**
- Glass grid systems exhibit strong resistance to common roadway chemicals, including de-icing salts, oils, and fuel contaminants, owing to the inert nature of glass fibers and the protective polymeric coating applied to enhance durability and bonding performance [3].

When installed within an asphalt overlay system, glass grids act as a high-stiffness tensile reinforcement layer positioned near the bottom of the overlay. This configuration reduces tensile strains at the base of the overlay and intercepts upward crack propagation originating from underlying pavement layers. The grid redistributes localized stresses along the plane of reinforcement, encouraging hor-

horizontal crack deflection and reducing stress concentration at existing discontinuities. As a result, crack reflection into the overlay is delayed, contributing to improved durability and extended service life, provided adequate interlayer bonding is achieved [3] [4] (Figure 3).

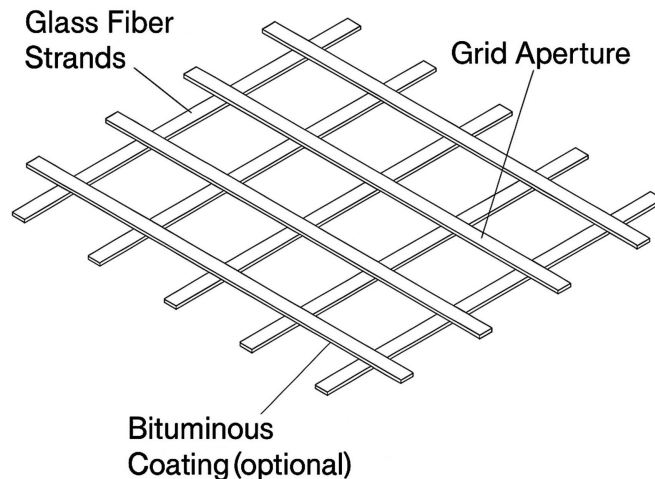


Figure 2. Schematic of a typical glass fiber grid used as an asphalt reinforcement interlayer.

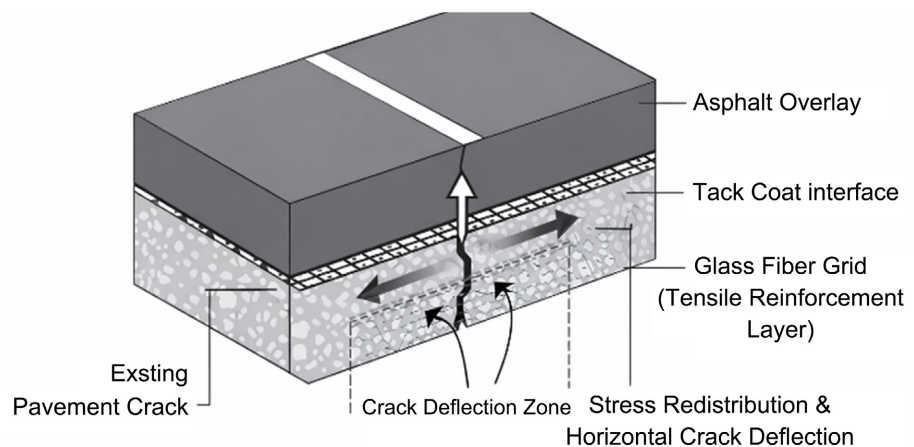


Figure 3. Schematic of a typical glass fiber grid used as an asphalt reinforcement interlayer.

4. Performance of Fiber-Reinforced Asphalt Mixtures

4.1. Marshall Stability

As shown in Figure 4, Marshall stability results indicate that fiber reinforcement enhances mixture strength without adversely affecting volumetric properties. Both laboratory- and plant-produced fiber-reinforced mixtures exceeded minimum stability requirements, with stability values consistently higher than corresponding unmodified and Polymer-Modified Asphalt (PMA) mixtures. The observed improvement is attributed to enhanced internal load transfer and crack-bridging effects provided by the fiber network, confirming the contribution of fibers to mixture-level structural integrity under monotonic loading conditions [6].

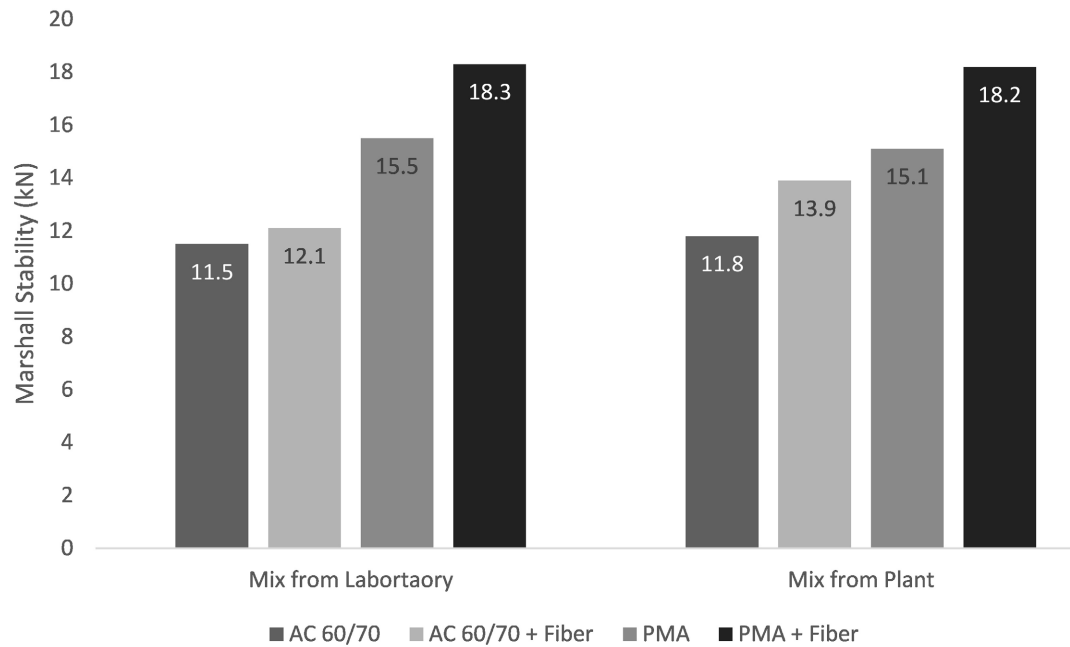


Figure 4. Marshall stability test results (adapted from Takaikaew *et al.* [6]).

4.2. Rutting Resistance

Fiber-reinforced asphalt mixtures exhibit significantly improved rutting resistance (Figure 5). Experimental studies reported 36% - 40% reductions in rut depth when aramid-polyolefin fibers were used in AC60/70 and Polymer Modified Asphalt (PMA) mixtures [6]. This positions fiber reinforcement as a cost-efficient alternative to full PMA modification.

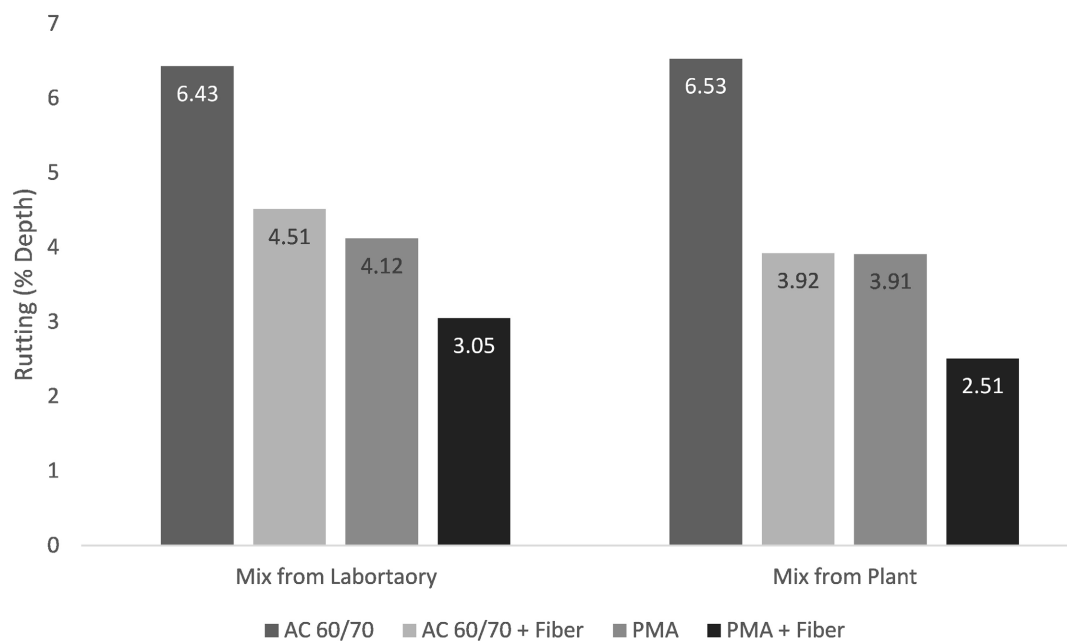


Figure 5. Pavement rutting test results (adapted from Takaikaew *et al.* [6]).

4.3. Tensile and Fracture Behavior

Indirect tensile strength (ITS) tests consistently demonstrate higher tensile resistance in fiber-modified mixtures relative to controls (**Figure 6**). The improvement is attributed to enhanced binder-fiber mechanical interaction and crack-bridging effects. Higher tensile capacity contributes directly to extended fatigue life.

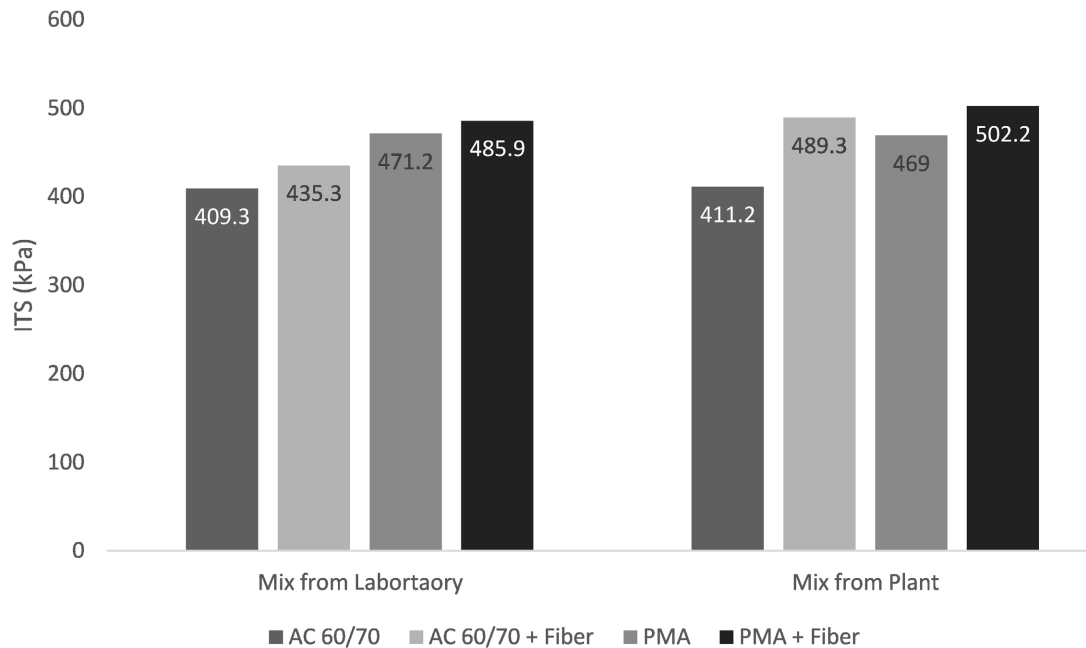


Figure 6. Indirect tensile strength test results (adapted from Takaikaew *et al.* [6]).

4.4. Resilient Modulus (MR)

Fiber-reinforced mixtures show MR values equivalent to or higher than PMA mixtures and substantially higher than unmodified HMA [6] (**Figure 7**). Comparable performance between plant-mixed and laboratory-mixed samples indicates good field production consistency.

4.5. Fatigue Performance

Fiber reinforcement increases fracture energy, post-peak residual strength, and fatigue resistance. These benefits result from the fiber network's ability to absorb strain energy and dissipate crack growth [6] [7].

4.6. Structural Coefficient Improvement

Mechanistic-Empirical Pavement Design Guide (MEPDG) simulations show the asphalt layer coefficient can be increased from 0.44 (standard HMA) to 0.52 - 0.62 for fiber-reinforced mixtures, equating to 19% - 41% structural improvement [8] (**Table 2**). This enhancement enables reductions in asphalt thickness without compromising performance.

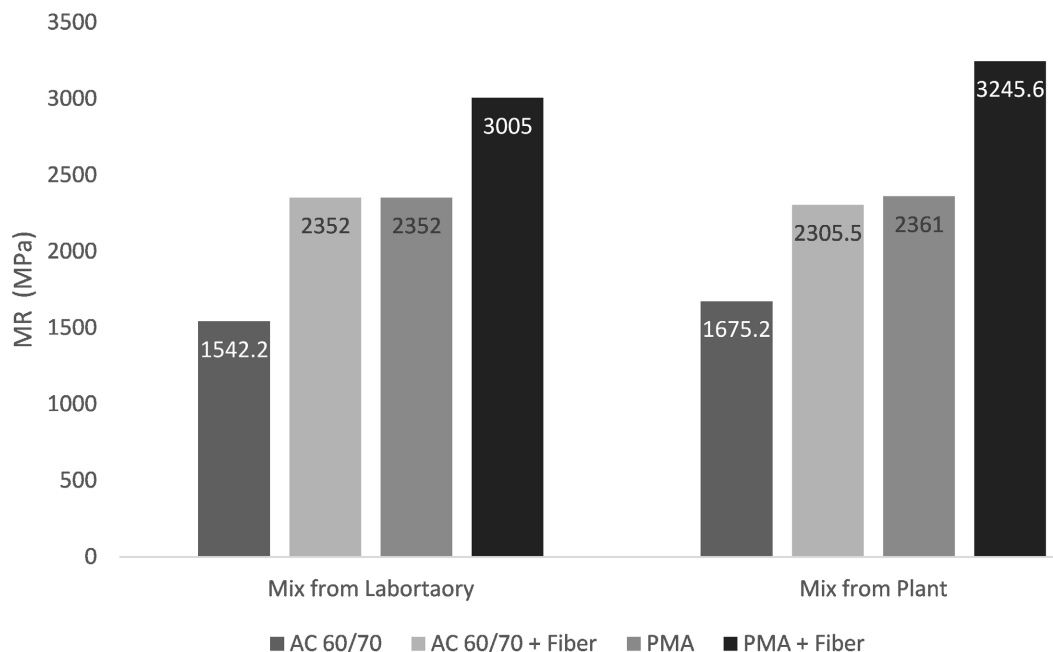


Figure 7. Resilient modulus test results (adapted from Takaikaew *et al.* [6]).

Table 2. Asphalt layer coefficient (a_1) versus required AC thickness based on MEPDG-derived structural capacity adjustments [8].

Layer Coefficient (a_1)	AC Thickness (inches)
0.44	11
0.52	9

5. Performance of Glass Grid Reinforcement Systems

5.1. Reflective Crack Mitigation

As shown in **Figure 8**, glass grid systems have demonstrated exceptional performance in delaying reflective cracking. Long-term monitoring of reinforced overlay sections on Korean national highways showed crack ratios dropping from 30%-60% before overlay to 0% - 4% after reinforcement [9].

5.2. Roughness and Rutting Performance

Grid-reinforced sections generally exhibited equal or lower IRI values compared to adjacent unreinforced sections under similar traffic exposure (**Figure 9**). Rutting depth was also reduced, except in cases influenced by lane-specific heavy loading [9].

5.3. Interlayer Bonding and Shear Benefits

Core sampling showed that grid-reinforced overlays achieved approximately 30% higher interlayer shear strength relative to controls, improving shear transfer and reducing the potential for slippage or delamination [9].

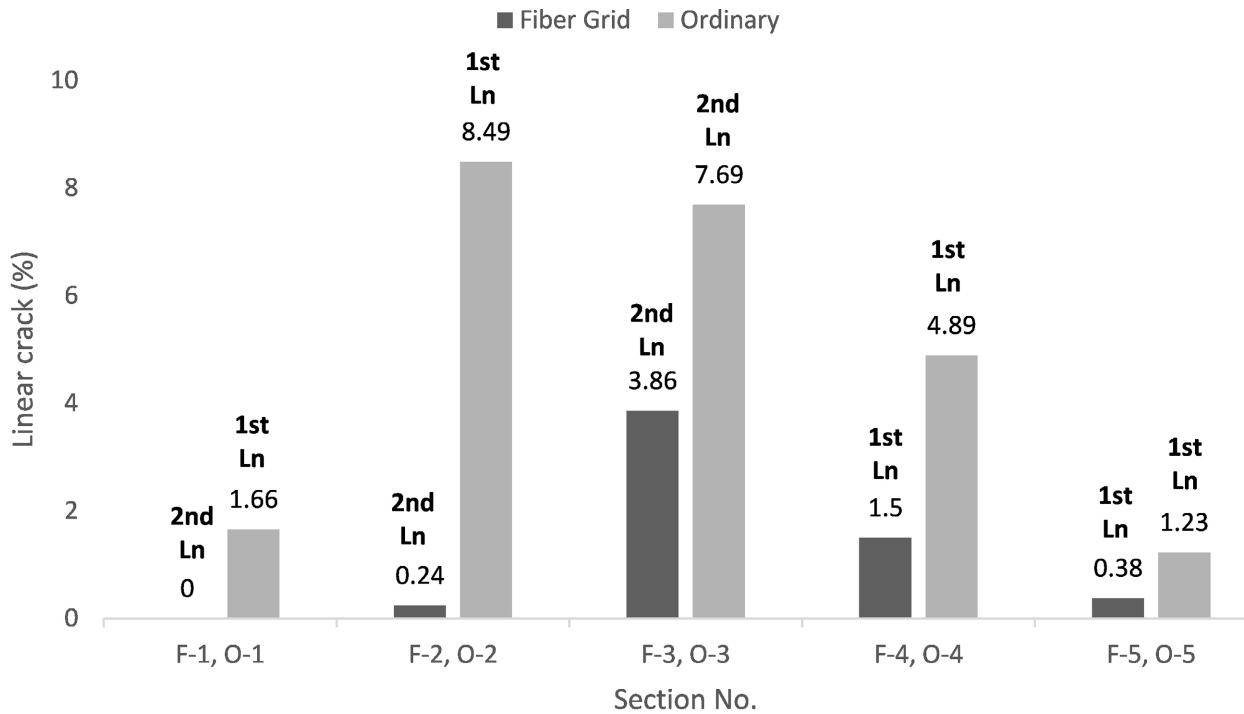


Figure 8. Comparison of crack ratios before overlay and after glass-grid-reinforced overlay [9].

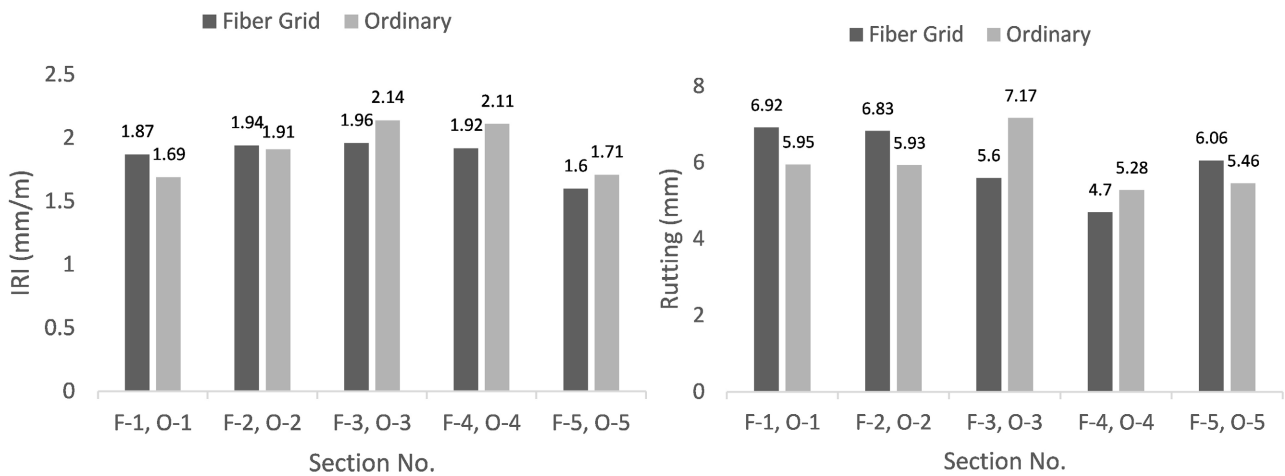


Figure 9. Comparison of IRI and rutting depth for reinforced and unreinforced sections [9].

5.4. Other Distresses

Grid-reinforced sections displayed fewer potholes, no alligator cracking, and reduced patching needs relative to non-reinforced overlays [9].

6. Design Considerations

6.1. Integration into Mechanistic-Empirical (M-E) Design

Fiber-reinforced asphalt mixtures modify intrinsic mixture-level properties and may therefore be incorporated directly into mechanistic-empirical (M-E) pave-

ment design frameworks [7] [8]. Depending on available laboratory characterization, fiber addition may influence the following design inputs:

- Dynamic modulus ($|E^*|$),
- Fatigue resistance parameters (e.g., strain-life transfer functions),
- Fracture energy or tensile strength parameters,
- Permanent deformation coefficients associated with rutting models.

In practice, implementation within mechanistic-empirical pavement frameworks (e.g., AASHTO MEPDG) may involve substituting laboratory-measured dynamic modulus values for fiber-reinforced mixtures or adopting calibrated layer-coefficient adjustments derived from validated performance correlations [8]. These modifications directly affect predicted bottom-up fatigue life and rutting progression.

Glass fiber grid interlayers, by contrast, do not alter mixture properties but modify interlayer mechanics. Their structural contribution is associated primarily with improved tensile restraint and stress redistribution at cracked interfaces. Within mechanistic-empirical frameworks, grids are typically represented indirectly through:

- Improved interlayer shear or bond assumptions,
- Reflective-cracking delay factors derived from field performance studies,
- Or calibrated performance modifiers based on long-term monitoring data [4] [9].

Thus, fiber reinforcement is integrated at the material-property level, whereas grid reinforcement is integrated at the structural-interface level within the pavement system.

6.2. Environmental Considerations

For high-temperature climates typical of Saudi Arabia:

- Fibers improve internal stiffness and rutting resistance.
- Glass grids maintain mechanical integrity across wide temperature ranges due to high thermal stability.

Synthetic fibers consist of proprietary blend of polypropylene and aramid fibers. The fiber composition designed to work with hot mix asphalt. **Table 3** shows the main physical properties of both fibers.

Table 3. Physical characteristics of used fibers [1].

Fiber Material	Aramid	Polyolefin
Specific Gravity	0.91	1.44
Tensile Strength (MPa)	2800 - 3600	-
Length (mm)	19.0	19.0
Color	Yellow	Yellow
Acid/Alkali Resistance	Inert	Inert
Decomposition Temperature (°C)	-73°C to 427°C	N/A

Based on equivalent structural number assumptions, the improved layer coefficient associated with fiber-reinforced asphalt mixtures enables a reduction in asphalt concrete thickness while maintaining structural capacity. For a conventional asphalt layer coefficient of 0.44, typical of unmodified HMA, the corresponding fiber-reinforced coefficient ranges from 0.52 to 0.62 depending on climate and subgrade conditions. This represents a structural improvement of approximately 19% - 41%, supporting thickness optimization strategies for reinforced pavement designs [8].

Table 4. Summary Fiber-Reinforced Asphalt Concrete (FRAC) Layer Coefficients and Percent Changes for Different Climate and Subgrade Conditions.

Climate	Subgrade Strength	Control Layer Thickness (inch)	FRAC Layer Thickness (inch)	Control AC Layer Coefficient	FRAC Layer Coefficient	Percent Change (%)
Phoenix, AZ	Low	5	3.85	0.44	0.57	29.87
	Medium	5	3.75	0.44	0.59	33.33
	High	5	3.55	0.44	0.62	40.85
Raleigh, NC	Low	5	4.15	0.44	0.53	20.48
	Medium	5	4.20	0.44	0.52	19.05
	High	5	3.90	0.44	0.56	28.21

The comparative thickness outputs presented in **Table 4** are based on mechanistic-empirical simulations conducted under the following assumptions:

- Traffic levels representative of moderate to high-volume roadway classifications,
- Reliability levels consistent with standard U.S. design practice (typically 90% - 95%),
- Climate files corresponding to Phoenix, AZ (hot-dry) and Raleigh, NC (moderate),
- Subgrade classifications categorized as low, medium, and high strength,
- Fatigue cracking and rutting as governing performance criteria.

These assumptions reflect the original modeling framework reported in NCAT analyses [8]. Transferability of the resulting thickness-reduction factors to Saudi Arabian conditions therefore requires local calibration of traffic spectra, climatic inputs, reliability targets, and distress thresholds before adoption in design practice.

6.3. Constructability and Quality Control Requirements

6.3.1. Fiber-Reinforced Asphalt Mixtures

Fiber-reinforced asphalt mixtures can be produced using conventional hot-mix asphalt plants without modification to the approved job mix formula, provided that dosing, mixing sequence, and temperature control are carefully managed.

Field and laboratory experience indicates that fibers should be introduced early in the mixing process and allowed to blend with heated aggregates prior to full binder addition to minimize agglomeration and promote uniform dispersion. In pug-mill mixing systems, dry mixing of fibers with aggregates for approximately 10 - 15 s has been reported as sufficient to distribute fibers before binder introduction, followed by a wet-mixing period of at least 30 s to ensure complete coating and homogeneity [6] [10].

Mixing and compaction temperatures should remain within the normal operating ranges for the selected binder type. For conventional asphalt binders, fiber-reinforced mixtures are typically produced at mixing temperatures in the range of 139°C - 163°C, consistent with standard hot-mix asphalt practice. For polymer-modified asphalt (PMA), the appropriate mixing temperature should be established through binder-specific testing to ensure adequate workability without compromising polymer integrity or fiber performance [6] [10]. Quality control procedures should therefore verify fiber dosage, mixing time, temperature consistency, and uniformity of distribution, as these parameters directly influence the repeatability of mechanical performance gains observed in fiber-reinforced mixtures [6] [7].

6.3.2. Glass Grid Installation Considerations

Glass grid reinforcement is substantially more sensitive to installation quality because performance depends on interlayer bonding and correct placement. Surface preparation, tack coat selection and application rate, grid alignment and tensioning, overlap detailing, and installation temperature are key determinants of bond development and long-term effectiveness. Inadequate bonding or improper placement can reduce reinforcement efficiency and may contribute to slippage, debonding, or premature crack reflection. Field-oriented literature emphasizes that consistent construction practices and inspection controls are essential for achieving durable interlayer performance in grid-reinforced overlays [3] [4] [10].

7. Comparative Assessment: Fiber vs Glass Grid Reinforcement

7.1. Performance-Based Comparative Analysis

A direct comparison between fiber reinforcement and glass grid interlayers highlights fundamental differences in their reinforcement mechanisms, performance contributions, and field applicability. Published research shows that fibers primarily enhance the internal mechanical behavior of asphalt mixtures, improving rutting resistance, tensile strength, and fatigue performance [5]-[8], whereas glass grids function as high-stiffness interlayer systems that suppress reflective cracking and improve overlay durability [3] [4] [9] (Table 5). Constructability considerations and installation sensitivity also differ between the two technologies, influencing their suitability for specific pavement conditions [3] [4] [10]. The following table synthesizes these distinctions to clarify where each reinforcement type provides the greatest engineering value:

Table 5. Comparative summary of fiber reinforcement and glass grid interlayers [1] [3]-[10].

Criterion	Fiber Reinforcement	Glass Grid Reinforcement
Mechanism	Internal, 3D reinforcement	Interlayer, tensile membrane
Best For	Rutting, fatigue, thermal cracking	Reflective cracking, overlays
Structural Coefficient	Increased (0.52 - 0.62)	Not applicable
Installation Sensitivity	Low	High
Thickness Optimization	Yes	No
QC Requirements	Mixing uniformity to avoid balling, dosage typically 1 pound/Tonnes of AC	Tack coat, fixing bonding, surface preparation
Crack mitigation	Within the mix to prevent formation of cracks	Mitigates bottom-up crack propagation
Applications	Heavy-duty pavements	Overlay above glass grid layer to prevent reflective cracking
Suitability for KSA	Excellent for heavy traffic & high heat	Excellent for overlays & trench repairs

7.2. Performance-Based Comparative Analysis

Selection between fiber reinforcement and glass grid interlayers should begin with identification of the governing distress mechanism.

When rutting, fatigue cracking, or structural deficiency dominate, fiber-reinforced mixtures are generally more appropriate. In such cases, mixture-level properties should be incorporated into mechanistic-empirical inputs, and production quality control must verify fiber dosage and dispersion [5]-[8].

When reflective cracking governs performance in overlay applications, glass grid interlayers are typically more suitable. In these cases, structural adequacy of the existing pavement must be confirmed, and strict attention should be given to tack coat rate, surface preparation, grid alignment, and bonding [3] [4] [10].

In both cases, final selection should be validated through mechanistic design checks and construction quality assurance measures.

8. Application Case Studies

Field applications of fiber and glass grid reinforcement provide essential evidence on how these systems perform under real construction practices, climatic conditions, and traffic loading—factors that cannot be fully replicated in laboratory environments. International case studies demonstrate how reinforcement effectiveness is influenced by installation quality, pavement structure, interlayer bonding, and dominant distress mechanisms such as reflective cracking or rutting. Reviewing these applications allows for a clearer understanding of long-term durability, maintenance implications, and the operational contexts in which each reinforcement type delivers the greatest engineering value. The following subsections summarize representative international findings before relating them to local observations within Saudi Arabia.

8.1. International Applications

International field applications show that reinforcement systems deliver the greatest benefit when selected based on the governing distress mechanism and executed under controlled installation conditions. Glass grid interlayers have been widely used in asphalt overlays to mitigate reflective cracking where existing pavements contain joints, trench reinstatements, or advanced cracking. Long-term monitoring of reinforced overlays on Korean national highways demonstrated substantial reductions in crack ratio and improved surface condition indicators relative to adjacent unreinforced sections under comparable traffic exposure [9].

Airfield rehabilitation provides another documented application where reinforcement is used to extend overlay service life under combined thermal cycling and operational loading. A runway rehabilitation undertaken at Inyokern Airport, operated by the Indian Wells Valley District airport authority in California's Mojave Desert, reported severe pre-rehabilitation cracking attributable to large temperature swings and long-term thermal stresses (Figure 10). In that case study, the reinforced overlay approach was selected as a cost-controlled alternative to a substantially thicker overlay, and field reporting indicated only minor cracking after extended service exposure [3]. These observations align with the reinforcing role of stiff interlayers in reducing tensile strain concentration and slowing crack propagation when adequate interlayer bonding is achieved [4].

Fiber reinforcement has been applied internationally to improve mixture-level performance—particularly rutting resistance, tensile capacity, and fatigue durability—without requiring fundamental changes to conventional plant production. Multiple studies report that properly dispersed synthetic fibers improve resistance to permanent deformation and cracking mechanisms under repeated loading, supporting their use on heavily trafficked pavements and industrial routes [6]-[8]. Overall, field experience reinforces that fibers are most suitable when rutting and fatigue dominate, while glass grids are most suitable for overlay systems where reflective cracking governs long-term performance [4] [9].



Figure 10. Reinforced runway overlay at Inyokern Airport, California (Mojave Desert) [3].

8.2. Regional Experience: Saudi Arabia

Saudi Arabia's pavement network is exposed to severe thermal gradients, rapid

binder oxidation, and heavy industrial traffic loading—conditions that accelerate rutting, fatigue cracking, and premature surface failures. These challenges make the Kingdom an important test environment for evaluating reinforcement technologies such as fiber-modified asphalt mixtures and glass grid interlayers. Recent pilot work conducted within Saudi Aramco facilities provides early insight into the field constructability and short-term behavior of fiber-reinforced asphalt mixtures under local climatic and operational conditions.

A pilot implementation of Fiber Reinforced Asphalt Concrete (FRAC) was executed at one of Saudi Aramco's bulk plant facilities in the Western Province. The trial involved constructing a 70-mm thick bituminous surface course on a truck lane with a total area of approximately 180 m², using a FRAC surface mixture designed in accordance with the FRAC Guide Specification for Highway Construction. The constructed layer is shown in **Figure 11(a)**. Approximately 30 tons of fiber-reinforced asphalt mixture were produced for the pilot, incorporating 15 kg of synthetic fibers, consisting of a polyolefin-aramid blend dosed at 0.5 kg per metric ton of asphalt during batching. A representative sample of the produced mixture is presented in **Figure 11(b)**, while **Figure 11(c)** illustrates the fiber introduction process during mixing.

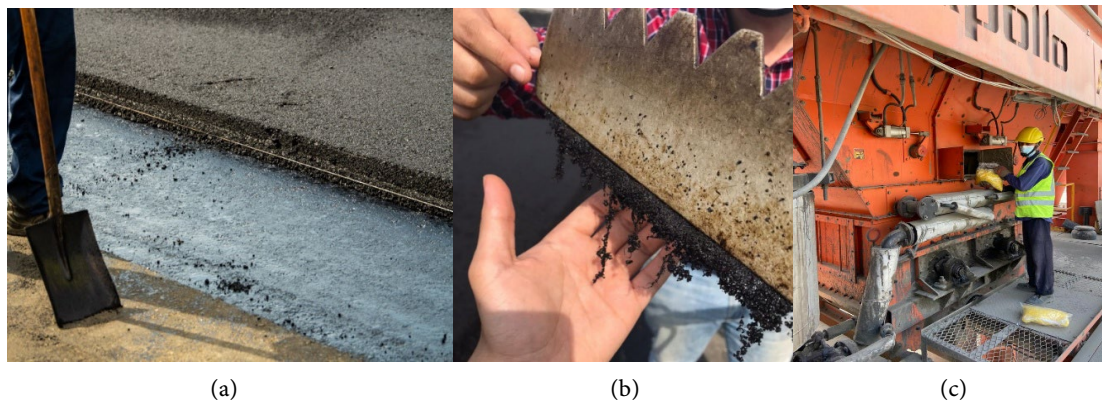


Figure 11. (a) FRAC 70 mm thick surface course layer, (b) Used FRAC mix, (c) Introducing the synthetic fibers to the mix.

The fiber blend used in the pilot is engineered to enhance mixture toughness, improve crack resistance, and reduce susceptibility to fatigue and thermal cracking—attributes aligned with the performance improvements documented in international research [6]-[8]. The selected dosage rate corresponds to typical field applications of structural synthetic fibers and is intended to create a three-dimensional reinforcement network within the asphalt matrix without necessitating changes in the plant's production process.

Laboratory testing of the FRAC mixture, including Marshall stability, flow, volumetric properties, and maximum theoretical specific gravity, confirmed compliance with the project specification limits and demonstrated adequate mixture density, air void structure, and stability levels for field placement. Extraction and gradation results also verified that the job mix formula remained within tolerance,

with a measured asphalt content of 5.2% and aggregate gradation consistent with the approved design.

The objective of the pilot is to evaluate the constructability, short-term performance, and comparative durability of fiber-reinforced asphalt under real operational loading from bulk plant truck movements. The section went through one-year performance monitoring, with measurements of rutting, cracking initiation, and surface texture to be compared against adjacent conventional asphalt lanes. This dataset will help determine whether synthetic fiber reinforcement offers a viable solution for enhancing pavement service life in high-temperature and high-load Saudi environments.

A second regional trial involved the use of a fiberglass grid interlayer to control reflective cracking arising from a utility trench reinstatement. The selected site exhibited recurrent cracking after trench backfilling operations, making it a suitable location to evaluate the grid's ability to stabilize differential movement between reinstated and existing pavement sections.

The distressed asphalt was removed down to the Bituminous Base Course (BBC), after which both the BBC and underlying

Aggregate Base Course (ABC) were reconstructed and compacted in accordance with Saudi Aramco standards. The reinstated bituminous base is shown in **Figure 12(a)**. A 50-m long and 1.2-m wide fiberglass grid was then installed over the prepared surface. The grid was tensioned and fixed mechanically using nails to ensure proper seating and to prevent displacement during paving (**Figure 12(b)** & **Figure 12(c)**). A tack coat was applied at a controlled rate not exceeding 0.25 Liters/m², following ASTM D2995 recommendations to achieve uniform film thickness. The bituminous wearing course was subsequently placed and compacted over the grid, as illustrated in **Figure 12(d)** and **Figure 12(e)**.



Figure 12. (a) Trench -Compaction of the sub grade, (b) & (c) Laying of Fiberglass grid and application of primer, (d) & (e) Laying of AC layer and compacted pavement.

The reinforced section has now undergone multiple field inspections, including a detailed assessment approximately three years after construction. As shown in **Figure 13**, the trial continues to perform well, with no notable reflective cracking or layer separation despite exposure to daily loading from service vehicles and

significant thermal cycling. The retention of interlayer integrity and absence of horizontal debonding indicate that the fiberglass grid fulfilled its intended mechanical function under the site's operating conditions.



Figure 13. The section after 3 years.

This pilot contributes supplementary regional evidence that grid reinforcement, when installed with proper tensioning, bonding, and tack coat application, can effectively mitigate trench-related reflective cracking in Saudi climatic and traffic conditions.

9. Discussion

The preceding sections have shown that fiber reinforcement and glass grid interlayers improve asphalt pavement performance through different mechanisms and under different boundary conditions. Laboratory and field data indicate that both systems can be effective when correctly selected and installed, but their benefits are highly distress-specific and sensitive to constructability and climatic factors [3] [4] [6]-[10]. This section synthesizes the key findings with a focus on practical selection criteria, relevance to Saudi conditions, sustainability implications, and remaining technical gaps.

9.1. Suitability by Distress Type

The evidence consistently shows that fibers are most effective for improving mixture-level performance, especially rutting resistance, tensile behavior, and fatigue life [6]-[8]. By forming a three-dimensional reinforcement network within the asphalt matrix, fibers increase fracture energy and residual strength, reducing the rate of crack initiation and propagation under repeated loading. This makes them particularly suitable for heavy-traffic corridors, industrial roads, and airfield pavements where structural capacity and deformation control govern performance.

Glass grid interlayers, in contrast, are primarily effective in mitigating reflective cracking in overlay systems [3] [4] [9]. Their high tensile stiffness redistributes stresses at existing crack locations and reduces strain concentration in the overlay, thereby slowing crack reflection from underlying layers to the new overlay construction. Field observations from long-term monitoring clearly show that crack ratios and repair needs are markedly lower in grid-reinforced overlays than in conventional overlays when reflective cracking is the dominant distress mechanism [9]. Consequently, grids are best viewed as a targeted structural tool for overlays and utility or other trench reinstatements, rather than a general-purpose reinforcement.

9.2. Relevance to Saudi Arabia

Pavements in the Kingdom of Saudi Arabia are subject to extreme temperatures, accelerated binder aging, and in many cases heavy axle loading from industrial traffic. Under such conditions, rutting and fatigue are critical design drivers on highway roads and access corridors, while reflective cracking is a major concern in rehabilitation of older pavements and utility cuts.

Given this context, fiber reinforcement is technically attractive for new construction and structural rehabilitation where the objective is to enhance mixture stiffness, rutting resistance, and fatigue life without major changes to existing mix designs. The increase in layer coefficient reported for fiber-reinforced mixtures can achieve thickness optimization and life-cycle cost savings for structurally critical pavement sections [8]. Glass grids, on the other hand, align well with overlay construction, to improve the stiffness of pavement layer and trench repair applications, particularly where existing pavements exhibit advanced cracking but the base structure is still structurally sound. Their demonstrated performance in delaying reflective cracking and maintaining serviceability indicates promising applicability for rehabilitation of cracked national highways, airfield pavements, and high-value industrial routes [3] [4] [9].

However, the success of both systems in Saudi Arabia will depend on rigorous construction quality control, especially for grid installations where surface preparation, tack coat rate, and bonding are critical, and for fiber-modified mixtures where dosing, sequence of mixing and time of mixing and dispersion must be verified during production [3] [4] [6] [10].

9.3. Sustainability and Economic Considerations

From a sustainability and life-cycle perspective, reinforcement systems contribute primarily by extending pavement life and potentially reducing required asphalt thickness, thereby lowering material consumption, transport, and construction frequency. Fiber-reinforced mixtures, through improved structural capacity and fatigue resistance, may enable reductions in asphalt thickness or extended resurfacing intervals, leading to measurable life-cycle cost and CO₂ savings when properly quantified [1] [6] [8]. Glass grid interlayers, by delaying reflective cracking

and reducing the need for premature overlay replacements or intensive patching, also reduce cumulative material use and associated emissions over the pavement life [3] [4] [9].

These benefits are consistent with broader sustainability objectives such as Saudi Vision 2030 and corporate net-zero strategies, but they should be quantified rigorously rather than assumed. Life-cycle assessment and life-cycle cost analysis are required to translate performance gains into credible environmental and economic metrics, particularly when reinforcement materials themselves may have higher unit costs than conventional asphalt mixtures.

9.4. Technical Gaps

Despite positive findings, several technical gaps remain before reinforced systems can be fully optimized for Saudi practice. First, the structural coefficients and performance models used in M-E design have largely been derived from international data; local calibration is needed to reflect Gulf climatic conditions, traffic spectra, and material sources [8]. Second, there is a need for standardized QC procedures for glass grid installation, including acceptance criteria for tack coat application, bonding, overlaps, and surface preparation, as field performance is highly sensitive to these parameters [3] [4] [10]. Third, long-term monitoring of fiber-reinforced and grid-reinforced sections in Saudi conditions is required to validate performance assumptions and refine design factors over time [3] [4] [6] [9].

Finally, future research should examine combined effects of reinforcement with other emerging technologies—such as modified binders, recycled materials, and alternative base treatments—to ensure that reinforcement is integrated into a coherent, system-level pavement design strategy rather than applied as an isolated add-on. Addressing these gaps will enable more reliable, cost-effective, and sustainable use of fiber and glass grids in the region.

10. Conclusions

Fiber reinforcement and glass grid interlayers each provide distinct and measurable benefits to asphalt pavements, but their effectiveness depends on the distress mechanisms being addressed and the conditions under which they are applied. Fiber-reinforced mixtures consistently demonstrate improvements in rutting resistance, tensile capacity, fracture behavior, and fatigue life. These enhancements translate into meaningful structural gains and can support reductions in asphalt thickness or extended resurfacing intervals [6]-[8]. Their ease of integration into standard production processes and compatibility with high-temperature environments make them a practical option for heavily trafficked pavements, industrial routes, and airfield facilities.

Glass grid interlayers, by contrast, function as a tensile reinforcement membrane within overlay systems, delivering substantial reductions in reflective cracking and improving the long-term condition of rehabilitated pavements. Field evidence shows marked improvements in crack control, surface roughness, and ser-

vice life when installation practices ensure proper bonding and alignment. Their value is most evident in overlays constructed over cracked asphalt, trench reinstatements, and pavements where crack propagation governs functional performance.

Both reinforcement types contribute to sustainability objectives through extended pavement life and reduced material demand, although the magnitude of these benefits depends on accurate life cycle and cost-benefit assessments rather than assumptions. Their performance in hot climates underscores the importance of selecting reinforcement strategies that align with environmental and traffic conditions, recognizing that constructability and quality control remain critical determinants of field success.

Continued refinement of structural models, local calibration of performance parameters, and long-term monitoring will strengthen the reliability of reinforcement strategies and support their integration into regional pavement design and rehabilitation practices. As pavement demands increase and environmental pressures intensify, reinforcement systems such as fibers and glass grids offer a technically sound and operationally viable pathway to improving durability, optimizing material use, and achieving higher performance standards across diverse pavement networks.

Authors' Contributions

Waseem Khatri developed the initial concept and established the overall scope of the review. Abdullah Al Gazlan led the manuscript preparation and expanded each section through detailed technical analysis and contextual case-study integration. Nawaf Al Ubaidi contributed to the development of the design considerations and the comparative assessment of glass grid and fiber reinforcement systems. All authors reviewed and approved the final version of the manuscript.

Acknowledgements

The authors wish to express their appreciation to all internal collaborators who supported this work through discussion and feedback.

Conflicts of Interest

The authors declare no competing interests.

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