APPLICATION OF BASALT FIBERS AND CEMENT THROUGH FDR TECHNOLOGY IN THE KM 93+880 SECTION OF THE M2 YEREVAN–GORIS–MEGHRI HIGHWAY

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Abstract: *The maintenance and rehabilitation of road networks remain among the most critical challenges in the global road construction sector, as increasing traffic volumes and pavement deterioration demand efficient solutions. Road repair and maintenance are essential not only for ensuring traffic safety but also for optimizing economic expenditures. Full-Depth Reclamation (FDR) is a pavement rehabilitation method in which the existing pavement—comprising the asphalt concrete surface, the base layer, and in some cases, additional base and subbase layers—is uniformly pulverized and blended to a predetermined depth, producing an improved, homogeneous base material. FDR is carried out entirely on-site without the application of heat. The treatment depth depends on the structure of the existing pavement and typically ranges from 100 to 300 mm. Compared to other technologies for rehabilitating flexible pavements, FDR significantly reduces the need for importing new materials, lowers energy consumption, and decreases harmful atmospheric emissions. The implementation of FDR in road construction began several decades ago, initially involving various mechanisms for pavement treatment, including pulverizers, scarifiers, mixers, and a range of additives. However, the adoption of high-powered self-propelled reclaimers provided significant momentum to the use of FDR, enabling deeper processing, higher productivity, and more reliable control of the stabilization process when additives are introduced. This article examines the impact of applying Full-Depth Reclamation (FDR) technology with cement and basalt fibers as additives on the strength and crack resistance of road pavements. The km 93+880 section of the M2 Yerevan–Goris–Meghri highway in the Republic of Armenia was selected as the experimental test site.*

Keywords: *Basalt fibers, cement, additives, Full-Depth Reclamation (FDR) technology, asphalt concrete.*

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Introduction

The growing population, advancing economies, and increasing transport volumes have created significant challenges for the global road construction sector—challenges that underscore the urgent need to maintain and rehabilitate road networks. Over the past decades, a vast network of asphalt concrete roads has been developed; however, many of these roads are now nearing or have already exceeded their service life due to heavy loads, climatic conditions, and degradation. Implementing restoration works on time can substantially prolong road lifespan while minimizing financial costs [1]. Full Depth Reclamation (FDR) is one of the most effective methods for restoring asphalt concrete pavements, widely used for its resource efficiency and environmental benefits. This technology makes it possible to recycle existing road layers, thereby reducing the need for new materials, energy consumption, and emissions. FDR eliminates problems such as rutting and cracking, and it enhances the structural strength of the road through the use of stabilizing additives, including Portland cement, bituminous emulsion, or foamed bitumen [2-6]. In both developed and developing countries, the road network plays a vital role in economic and social development, and the application of FDR can offer a cost-effective and environmentally sustainable solution. Furthermore, the use of innovative materials—such as basalt fiber—is critically important for enhancing the quality of asphalt concrete mixtures. Basalt fiber is characterized by high mechanical strength, thermal stability, and resistance to cracking, all of which contribute to the greater durability of the road. Its use also reduces bitumen penetration and improves the properties of the mixture, which is particularly important in environments characterized by temperature fluctuations and heavy loads [7-10]. Given the climatic and geological conditions of Armenia, the integrated application of basalt fiber and FDR technology can considerably enhance pavement performance while reducing maintenance costs and environmental impact.

Materials and Methods

Properties and Manufacturing of Basalt Fibers

FDR technology is a pavement restoration method in which the existing surface—typically the full depth of the asphalt concrete layer, along with the base and, in some cases, additional subbase and subgrade layers to a specified depth—is thoroughly pulverized and mixed to produce a homogeneous, improved base material. FDR is performed entirely on-site without the use of thermal processing. The processing depth depends on the existing road structure and generally ranges from 100 to 300 mm. Compared to other flexible pavement restoration methods, the use of FDR significantly reduces the need for new materials, lowers energy consumption, and minimizes the emission of harmful substances into the atmosphere. From a structural standpoint, FDR technology used in the restoration of flexible pavements effectively addresses all issues related to rutting and reflective cracking on the road surface [11]. Various additives—such as basalt fibers, cement, and others—may be used during the implementation of FDR technology to enhance the strength and crack resistance of the reclaimed material. In recent decades, basalt fibers have been considered a strengthening agent for composite materials. Basalt is a volcanic rock widely distributed across the world. Basalt fibers are produced by melting natural basalt at temperatures ranging 1300–1700°C, followed by fiber formation through high-speed rotating rollers. The chemical composition of basalt includes SiO_2 (45–55%), Al_2O_3 (15–20%), Fe_2O_3 (5–15%), CaO (5–10%), and other oxides, all of which contribute to its high durability [12-14]. Tensile strength: Basalt fibers exhibit tensile strengths ranging from 3000 to 4000 MPa, which is 20–30% higher than that of glass fibers (2500–3000 MPa) and steel (3500–4500 MPa). Modulus of elasticity: Their elastic modulus ranges from 85–100 GPa providing sufficient rigidity to resist deformation under heavy loads. Density: With a density of 2.6–2.8 g/cm^3— three times lighter than steel (7.8 g/cm^3)— basalt fibers are advantageos in handling and application due to their lightweight nature. Heat resistance: Basalt fibers can withstand temperatures up to 700°C without undergoing structural degradation, unlike synthetic fibers, which typically melt at 200–300°C. Corrosion Resistance**:** Basalt is chemically stable in both alkaline (pH 12–14) and acidic (pH 2–4) environments, in contrast to steel, which is vulnerable to rust [15-18]. Extensive research conducted by numerous scientists and experts has clearly demonstrated that the use of basalt fibers significantly enhances the crack resistance and overall strength of asphalt concrete mixtures. Their experimental findings indicate that a fiber content of 0.4% is considered the most effective and optimal amount for asphalt concrete mixtures, ensuring maximum performance and stability [19-21]. Cement (primarily Portland cement) is used in FDR as a binding agent, enhancing the stiffness and load-bearing capacity of the mixture. The chemical composition of cement includes CaO (60–65%), SiO_2 (20–25%), Al_2O_3 (5–7%), and Fe_2O_3 (2–4%). It exhibits a compressive strength of 5–10 MPa, stiffness of 10–15 GPa, and moisture resistance of 80–90% [22].

Results and Discussion

Preliminary assessment and Planning

The Full-Depth Reclamation (FDR) process begins with a comprehensive assessment of the existing pavement condition. At this stage, the extent of surface deterioration, the structure of the base layer, and the properties of the constituent materials are carefully examined. The purpose of this assessment is to determine the appropriate reclamation depth and to select the types of binding agents required for the process (Fig.1).

Fig. 1. *Section of road under reclamation*

For this purpose, samples taken from the designated road section are sent for laboratory testing. The analyses make it possible to determine the type and quantity of binding agents, as well as the particle size distribution (gradation) of the road materials. This stage is particularly important in the mountainous areas of Armenia, where roads are exposed to harsh climatic conditions and heavy mechanical loads. Figure 2 illustrates the determination of the particle size distribution of the road pavement under laboratory conditions.

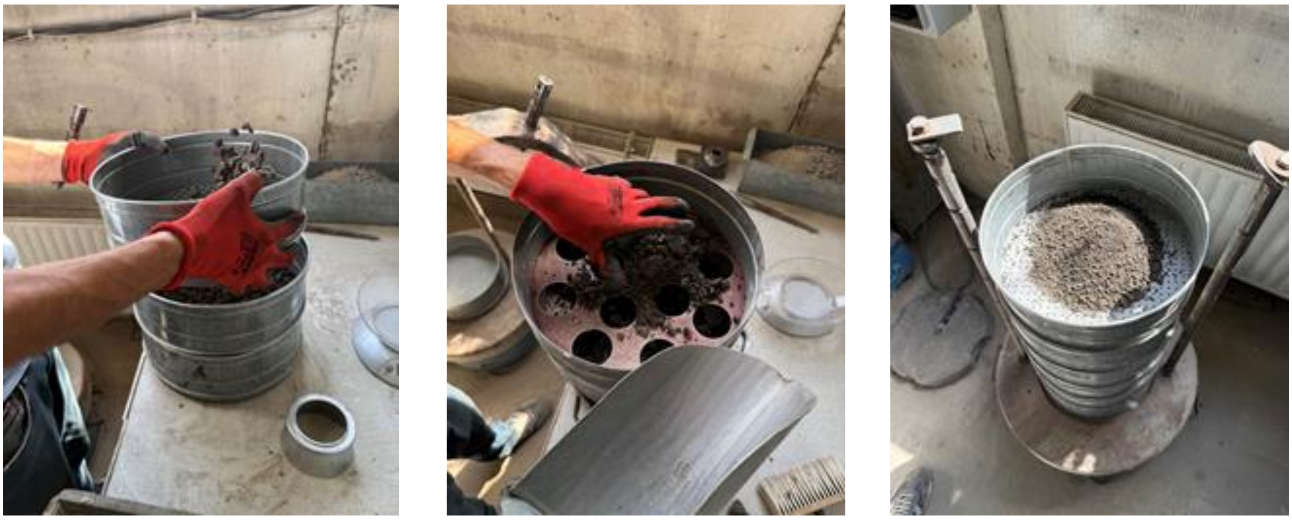

Fig. 2. *Determination of the particle size distribution of milled asphalt concrete*

Based on the analysis of the grain-size composition of the road pavement, four separate experimental sections were selected to evaluate the effectiveness of different binding materials and their combinations. The additives used in the experiments were sourced from “ARMBASALT” CJSC, which supplied basalt fibers, and from “ARARATCEMENT” CJSC, which provided the cement. A different approach is applied in each test section (Figs. 3,4):

1. Section 1: FDR is performed without adding any binding agents to assess the reclaimed material’s natural strength and stability in the absence of additives.
2. Section 2: Basalt fibers measuring 20 mm in length are added at a content of 0.4%.

Fig. 3. *First and second test sections*

3. Section 3: 4% cement is used as the binding agent.
4. Section 4: basalt fibers (20 mm in length, 0.4% content) are combined with 4% cement as binding agents.

Fig. 4. *Third and fourth test sections*

Execution of FDR

The FDR process begins with the pulverization of the existing pavement and base layer to a depth of 25 cm. This depth is determined by considering the condition of the existing pavement. Pulverization is carried out using specialized equipment such as reclaimers, which process the asphalt concrete layer and base material into a uniform granular mixture. This process enables the reuse of existing road materials, reducing the need for new materials and promoting environmental sustainability. After pulverization, the selected binding agents are added to each test section in accordance with the plan outlined above. The binding agents are mixed with the pulverized material using on-site mixing equipment. This process ensures the uniform distribution of materials, which is essential for achieving a homogeneous and stable base. After mixing, the mixture is compacted using a roller to reduce air voids and enhance the structural strength. Compaction is performed in multiple stages to achieve a smooth and stable surface. Subsequently, profiling is carried out to shape the road surface with the required gradient and smoothness (Fig.5).

Fig. 5. *Full-Depth reclamation and profiling of road pavement*

Quality Control

After the addition of binding agents and compaction, the road base is left to undergo the curing phase. In the case of cement, the curing process may last between 3 and 7 days, depending on humidity and weather conditions. In the case of basalt fibers, the curing time may be shorter; however, when combined binding agents are used (e.g., cement and basalt fibers), the curing duration depends on the cement hardening process. During the curing period, it is necessary to maintain a moist environment to ensure proper cement hardening. Core samples are extracted from each test section one week after completion of the works, for laboratory analysis. However, as shown in Figure 6, core samples could only be taken from the section where cement alone was used—with core lengths ranging from 10 to 12 cm—and from the section where both cement and basalt fibers were used—with core lengths ranging from 22 to 24 cm. No binding occurred in the other sections.

Fig. 6. *Core sample extraction*

The extracted core samples are tested under laboratory conditions to evaluate their strength and crack resistance, providing insight into which combination of binding agents yields the most effective results. Test results are evaluated against established standards to verify that the reclaimed road meets the technical requirements. Upon completion of the curing period, the samples underwent thorough compression testing to precisely assess their compressive resistance and strength properties. Before compression testing, each sample—maintained under strictly controlled conditions—is weighed for data recording. Subsequently, the samples were placed into the compression testing device, as illustrated in Figure 7.

Fig. 7. *Compressive strength test of core samples*

The following indicators were obtained from the test, as presented in the Table.

Table. Compressive Strength Results of Cement and Cement–Basalt Fiber Specimens

№	Description	Mass (g)	Maximum compressive strength (MPa)
1.	Sample 1 from cement section	1322	3.2
2.	Sample 2 from cement section	1337	3.3
3.	Sample 3 from cement section	1334	3.2
4.	Sample 1 from cement and basalt fiber section	1352	3.75
5.	Sample 2 from cement and basalt fiber section	1412	3.7
6.	Sample 3 from cement and basalt fiber section	1345	3.79

The average compressive strength of samples from the cement section is 3.2 MPa, while the average compressive strength of samples from the cement and basalt fiber section is 3.75 MPa. Technical specifications and experimental methods were carried out in accordance with the standards in force in the Republic of Armenia, namely GOST 9128-2013, GOST 12801-98, RABC 32-01-2022, and SP 78.13330.2012

Economic analysis

The calculations are based on official data from the Republic of Armenia.

- FDR with cement as an additive
  - Implementation cost of FDR technology per 1 m²: 2,670 AMD
  - Cost of adding 4% cement (16 kg) per 1 m²: 960 AMD
  - Total cost per 1 m²: 3,630 AMD
  - Service life: 20 years

- **FDR with cement and basalt fibers as additives**
  - Implementation cost of FDR technology per 1 m²: 2,670 AMD
  - Cost of adding 4% cement (16 kg) per 1 m²: 960 AMD
  - Cost of adding 0.4% basalt fibers (1.6 kg) per 1 m²: 500 AMD
  - Total cost per 1 m²: 4,130 AMD
  - Service life: 24 years

Conclusion

Full-Depth Reclamation (FDR) is an effective technology for road rehabilitation. For this study, the section at Km 93+880 of the M2 Yerevan–Goris–Meghri road was examined. Test results indicate that the combination of basalt fibers (0.4% by content, 20 mm in length) and 4% cement significantly improves the physico-mechanical properties of asphalt concrete mixtures, including compressive strength and crack resistance. This proportion yields more optimal results compared to using only 4% cement. The tests conducted on the km 93+880 section of the M2 Yerevan–Goris–Meghri road confirm that the road pavement produced with such mixtures outperforms traditional asphalt concrete in terms of performance indicators. The obtained results indicate that the service life of the road increases by 17–18%, while the cost rises by 13–14%, which is justified from a financial perspective. These results are of significant importance for the road construction sector of the Republic of Armenia, where the quality and long-term durability of road infrastructure play a vital role in the country's economic advancement and social development. The test results indicate that the use of basalt fibers and cement through FDR technology has a significant positive effect on asphalt concrete pavement. It enables the construction of roads with enhanced capacity to withstand heavy loads and to ensure long-term stability.

Conflict of Interest

The author declares no conflicts of interest.

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