

The Role of Cement and Fibers with Fatty-Arbocel for Improving Cold Emulsion Asphalt's Resistance against Fatigue and Rutting

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Abstract

Mounting environmental challenges and diminishing mineral and energy resources have led researchers to concentrate more on improving cold asphalt technologies. Despite its advantages, the cold asphalt mixtures' poor performance against permanent deformations and fatigue is the main reason they are not preferred in road construction projects in contrast to the typical hot asphalt mixtures. The effects of adding fibers with fatty-arbocel to a cold asphalt mixture were evaluated to overcome this weakness. Marshall Tests, static creep tests, and wheel track tests were applied to evaluate rutting and fatigue. The results showed that including cement and fibers with fatty-arbocel in a cold emulsion asphalt increases the mixture's stiffness, improves the load-bearing strength and modulus of elasticity, and enhances the load transfer. The results showed the best performance in samples containing 3% cement and 0.3% above fib ers. The results of physical and functional tests showed that combining cement and fatty fibers with arboreal can significantly reduce maintenance costs.

Keywords: Resilience modulus, Static creep, Dynamic creep, Rutting, Fatigue

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1. Introduction

Cold asphalts with emulsion bitumen offer significant environmental and logistics advantages since they are used without heating the materials and bitumen. However, it is less common in Iran due to its lower performance than hot asphalt [Behbahani, H et al. 2016]. In Spain, researchers show that the inclusion of emulsion bitumen in asphalt protects the environment [Potti, J.J et al. 2000]. The results have shown that up to 25% of energy is saved in the process of production, transportation, and distribution of cold asphalt in contrast to hot asphalt [Khweir, K et al. 1994]. Cold asphalts exhibit good recycling capability, which is essential for environmental and economic issues [Golchin, B et al. 2022]. However, the lab results show that cold asphalt suffers from failures like rutting and fatigue [Guo, M et al. 2014]. Studies prove that the inclusion of cement in asphalt can increase the asphalt's strength up to twice or thrice in some cases [Dardak, H. 1993]. The results show that cold asphalt's resistance against rutting with dense granulation is significantly higher than open granulation [Rezaei, M et al. 2017]. Studies show that including cement in asphalt increases the modulus of elasticity of the mixture [Li, R et al. 2020]. Recent studies indicate that the simultaneous use of cement as a filler and glass fibers as an additive plays a very useful role in enhancing the performance of cold mix emulsion asphalts against moisture-induced damage. [Verma, D. K et al. 2024]. Also, research shows that cold asphalt's performance reinforced with natural and synthetic fibers is improved against permanent deformation in contrast to cold mixtures without additives [Sun, Z et al. 2020]. Research indicates that by adding 0.15% carbon or nylon fibers, or cellulose fibers, the performance of cold asphalt mixes improves, thereby reducing the maintenance costs of these flexible pavements [Ferrotti, G and Pasquini, E 2014]. The effect of cement and

polyester fibers on the performance of cold-emulsified asphalt mixtures has been demonstrated. The use of 1.5% cement and 0.4% fibers significantly improves the resistance of these mixtures against fatigue cracking [Jiang, Y et al. 2023]. Increasing the hardness and modulus of the asphalt significantly reduces the transfer traffic loads to the lower layers of the pavement and, at the same time, increases their resistance to permanent and plastic deformations. However, this high hardness is a disadvantage since it reduces fatigue resistance and leads to pavement surface cracks, which minimizes pavement service life. So, the application of asphalt with high modulus is limited in cold regions. To overcome this challenge, this research concentrates on improving asphalt's mechanical performance with high modulus with additives. The combination of crumb rubber and acrylic fibers used in cold asphalt offered a good solution. Results show that these additives improve the mechanical behavior of cold asphalt with high elasticity modulus, resulting in higher performance of these mixtures [Moreno-Navarro, F et al. 2014]. Results on semi-hot asphalt show that nano bentonite and fatty arboreal increase semi-hot asphalt's hardness, and its application reduce semi-hot asphalt's permanent deformation and rutting [Saedi, S. and ORUÇ, Ş. 2020].

2. Materials and Method

2.1. Classification Models

In this study, the stone material is limestone, obtained from quarries in the outskirts of Tabriz. The ASTM standard is used to grade material [Saedi, S. and Oruc, S. 2022]. The grading curve in the figure 1, with the upper and lower limits in the Iranian Pavement Regulations, is given. In this study, grading 4 linings of the Iranian Road Paving Regulations, 234, is used. Mechanical tests were carried out based on common standards

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in Table 1 to determine the quality of aggregates.

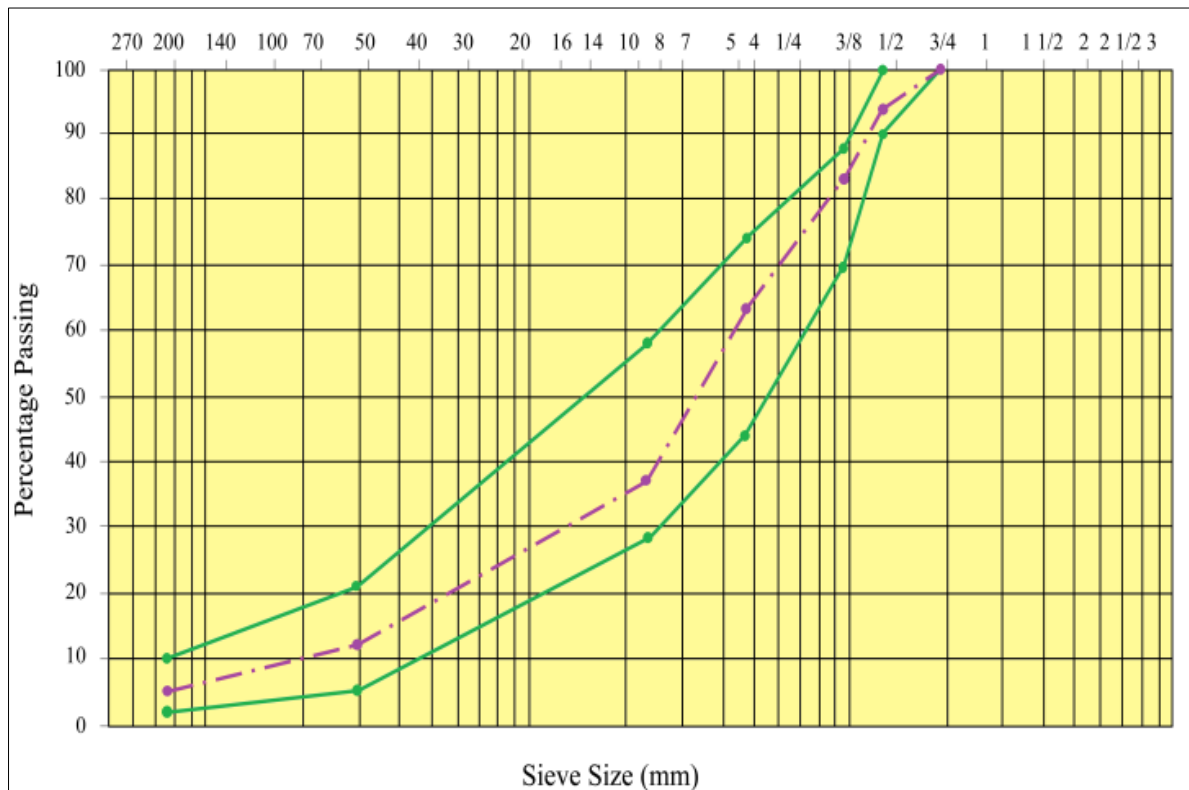


Figure 1. Aggregates gradation for making samples

2.1.1. Portland Cement

The cement in this research is Portland type-2 cement from the Soufian cement factory. The

physical, mechanical, and chemical features of this type of cement are described in Tables 2 and 3.

Table 1. Mechanical features of aggregates

Test	Method of testing	Unit	Values	Limits of the regulations
Specific weight of coarse aggregates	ASTMC-127-15	gr/cm ³	2.751	-
Specific weight of fine aggregates	ASTMC-128-15	gr/cm ³	2.787	-
Erosion Los Angeles	ASTMC-131	percent	19	Max 30
Water absorption percentage	ASTMC-127-15	percent	1.6	Max 2.8
Flakiness percentage	ASTMD-4791	percent	10.8	Max 15

Table 2. Physical and mechanical features of cement

Physical features	Results	Mechanical features	Results
Specific gravity in gr/cm ³	3.119	Minimum compressive strength N/mm ² at 7 days	31.1
The Blaine Fineness scale cm ² /gr	2991	Minimum compressive strength N/mm ² at 28 days	44.7

Table 3. Mechanical features of aggregates

Ingredients	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	So ₃	Na ₂ O	K ₂ O
Specific gravity in gr/cm ³	20.6	6.33	3.01	61.44	3.11	2.89	0.19	1.03

2.1.2. Portland Cement

In this research, emulsified bitumen is a slow-setting cationic type (CSS-1) manufactured by

Pasargad Oil Company. Results are given in Table 4.

Table 4. Features of emulsion

Type of test	Method	Results	The specification limits of CSS-1 bitumen according to Code 234	
			Min	Max
Specific weight	ASTM D70	1.15	-	-
Curing at 25 degrees Celsius (s)	ASTM D2170	42	20	100
flash point (°C)	ASTM D3143	44	38	-
Stability in storage after 24 hours (%)	ASTMD244	0.77	-	1
residual bitumen from 360 (°C) distillation	ASTMD244	0.62	57	-
Residual bitumen ductility (cm)	ASTMD11370	101	40	-
Solubility of residual bitumen in trichloroethylene (%)	ASTMD D2042	98.08	97.5	-

2.1.3. Fibers with Fatty Arbocel

Fiber is a combination of cellulose fibers and bitumen, which is produced in the form of tablets for convenient application and long-term storage. These fibers can spread quickly and homogeneously in the asphalt, and including these fibers is 0.2-0.3% of asphalt's weight. Manufactured by the JCR German Company, cellulose fiber with fatty above was used.

Arbocel is a powdered or fibrillated cellulose additive used in the construction of chemical products. These additives are derived from cellulose, utilizing various renewable raw materials for cellulose production. Arbocel remains insoluble in water and preserves its natural state. It is manufactured with diverse characteristics (fiber length, thickness, purity, etc.) to suit various industrial applications. Arbocel cellulose fibers typically contain 6% to 8% moisture. They tend to clump together in this state, necessitating dry storage conditions. Arbocel's fiber structure and moisture-holding capacity contribute to its stability during formulation, enhancing its heat resistance. Arbocel maintains appropriate dimensions, preventing shrinkage. This means that it does not experience significant compaction. The use of Arbocel reduces internal stresses within formulations. Arbocel helps prevent crack formation, reducing energy associated with crack propagation. In many cases, Arbocel can be effectively used in thick layers. Arbocel performs well under the weather and natural

conditions, including freeze-thaw cycles and heat absorption from underlying layers. These properties make Arbocel particularly suitable for road construction and asphalt reinforcement [Arash Azma and Shams Javid]. Cellulosic fibers containing fatty-arbocel is shown in Figure 2.



Figure 2. Cellulosic fibers containing fatty-arbocel

Table 5. Fibers' Physical properties

amount of cellulose	%83
Bitumen percentage 50/70	%10
The percentage passing through the sieve is 3.55 mm	%7
flash point (°C)	500
Amino acid fat percentage	%7

2.2. Test Materials

2.2.1. Cold Emulsion Asphalt Mixture

This study uses the modified Marshall Method to determine the optimal bitumen percentage and mix design [Dibaj, S.M and Kavussi, A, 2012]. First, the stones with special granularity are placed at a temperature of 160-170 °C for 24 hours to evaporate the water in the aggregates. Then, the emulsion bitumen was heated to 60 °C, and five different percentages (4, 4.5, 5, 5.5, and 6) were added to the mixtures in proportion to the weight of the

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asphalt. Then, the mixture was poured into Marshall molds with a diameter of 15.2 and a height of 9.52 cm and was compacted by applying 75 blows of a 10.2 kg Marshall hammer falling from a height of 45 cm. In the modified Marshall mixing method, the optimal bitumen percentage is determined based on the average values of the bitumen percentage that form the highest Marshall endurance, the highest specific gravity, and the most appropriate amount of void space in asphalt concrete [Oruc, S et al. 2007].

2.2.2. Marshall Index

The Marshall index reflects the stiffness and resistance of the asphalt against permanent deformations, so by increasing the value of this index, asphalt's resistance against deformations is also improved [Sengul, C.E et al. 2013].



Figure 3. Marshall Index test

2.2.3. Static Creep Test

A static creep test measures the permanent deformation under the influence of static loads [Xiong, F et al. 2023]. To determine asphalt's strength, first load is applied on the sample and then removed, subjected to static loads [Tabasi, E et al. 2023].

$$E_{cq}(t) = \sigma / \epsilon(t) \quad (1)$$

Where $E_{cq}(t)$ is the creep modulus, σ denotes applied stress and $\epsilon(t)$ is the strain.

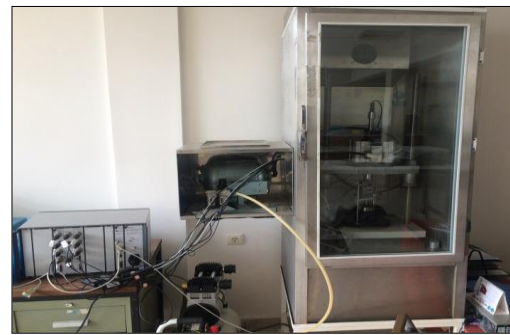


Figure 4. Static creep test

2.2.4. Static Creep Test

The mixture with the optimal percentage of bitumen was placed inside the slab molds of the roller compaction to measure the amount of rutting by the French Method. Samples with 500 mm length, 180 mm width, and 50 mm height were prepared. Twelve hours before the test, the sample's temperature was increased to 60 °C, and the LCPC machine was adjusted so that each wheel applied 5000 N to the samples. The tire pressure was set to 6.5 MPa, and the samples were condensed to 98%. Then, the measurements were carried out at 1000, 3000, 5000, 10000, 30000, and 50000 rpm. Finally, using the equation, the amount of rutting settlement is determined [Shanbara, H.K et al. 2018].

$$Y = A \left[\frac{N}{1000} \right]^B \quad (2)$$

Where Y is N cycle settlement (mm), A is a settlement at 1000 rpm, and B is the slope of the linear line in logarithmic coordinates. It is worth mentioning that rutting is usually considered after passing 30,000 rpm based on the standard by the French Road Laboratory.



Figure 5. wheel track test

2.2.5. Fatigue Test

Road pavement materials are loaded for a short period by each vehicle. Repeated loadings reduce rigidity and eventually cause small cracks, and accumulating these cracks leads to a general failure in the pavement [Wang, Z et al. 2024].



Figure 6. Fatigue test

In the indirect tensile fatigue test, the asphalt sample is subjected to repeated loading until

failure. In this test, samples are tested under the influence of different stresses. The fatigue life (N_f) is calculated based on the amount of stress leading to failure from logarithmic diagrams or the following equation [Saedi, S et al. 2018].

$$N_f = K_1 \left(\frac{1}{\sigma}\right) K_2 \quad (3)$$

Where, N_f is the number of cycles of failure (fatigue life), K_1 and K_2 are constants, and σ is the tensile strain.

3. Results and Discussion

3.1. Calculations of Asphalt Mix Design

Modified Marshall Method was applied for mixing procedure and the optimal bitumen percentage was determined. Results are given in Table 6.

Table 6. Fibers' Physical properties

Optimum bitumen (%)	Specific gravity of the mixture bitumen (gr/cm ³)	Theoretical specific gravity of the mixture (gr/cm ³)	Void space in percentage	Voids in the mineral aggregate (%)	Voids filled with bitumen (%)
5.6	2.301	2.399	4.08	16.77	75.63

Results showed that 5.6% bitumen was determined as the optimal bitumen of the mixtures. Other parameters of the samples used in this bitumen were very close to the standard conditions of hot asphalt mixtures.

3.2. Analysis of Marshall Index Results

The comparison chart of the Marshall Index for samples is shown in Figure 7.

Marshall Index is one of the parameters representing the mixture's resistance against permanent deformation [Abdel-Wahed, T et al. 2022].

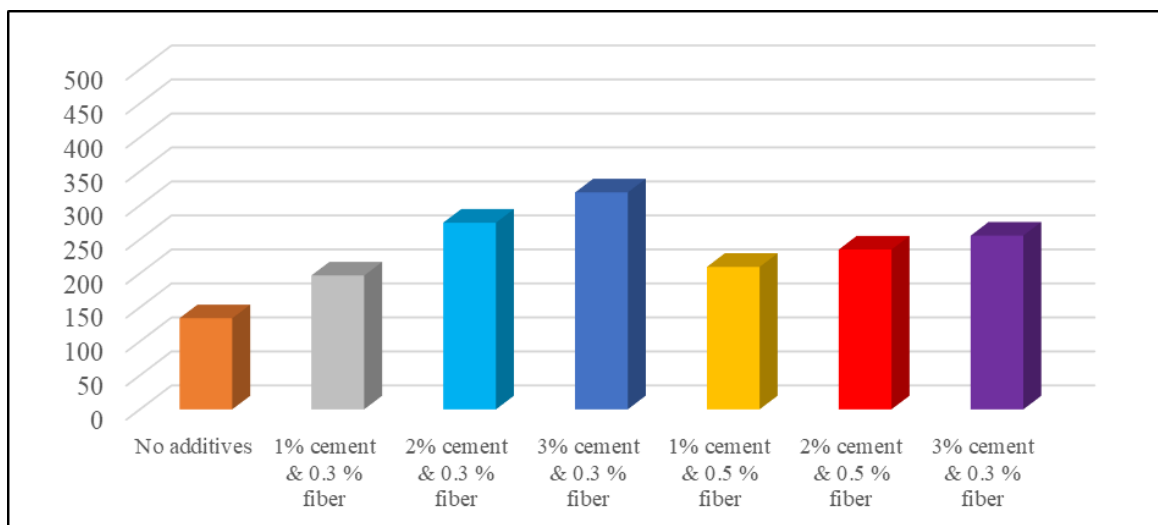


Figure 7. Marshall Index comparative curve

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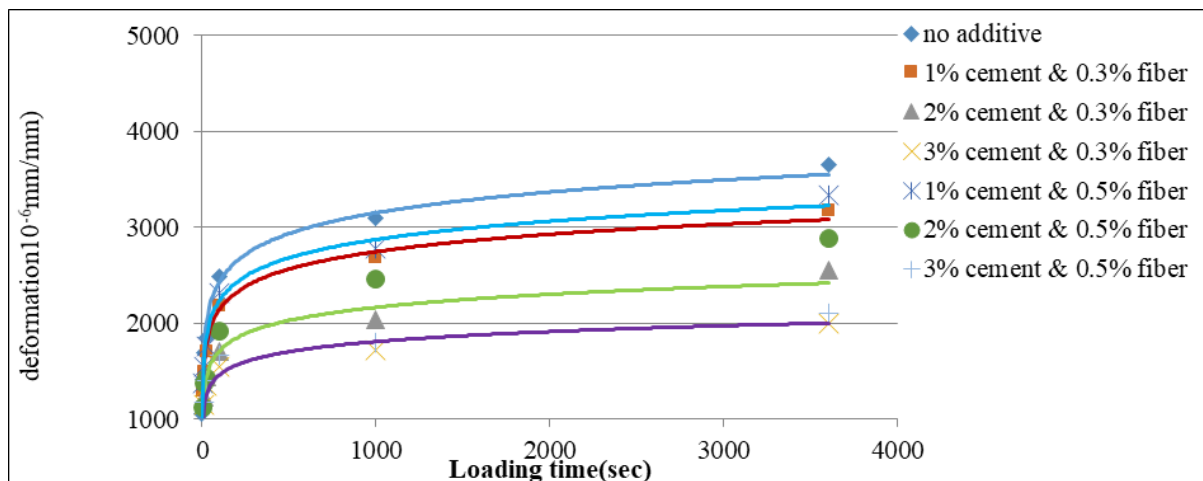


Figure 8. Results of deformations of different compounds based on loading time

As the percentage of cement increases, the samples' Marshall resistance value increases, and the flow value decreases. These changes are shown in the Marshall Index chart. The chart shows that the samples with 3% cement and 0.3% fibers with fatty arboceol have reached their maximum value. In fact, the samples' Marshall Index shows a 237% significant increase in contrast to samples without additives.

3.3. Static Creep Test Results

Prepared samples for the Marshall Test, without additives and with cement and fibers with fatty arboceol, were subjected to a uniaxial static creep test at 25 degrees. Permanent deformation results by static loading are shown in Figure 8, and the values of static creep modulus were calculated based on the results of permanent deformation, and the results are shown in Figure 9. This Figure shows that after applying the load to the sample, an increase in deformation.

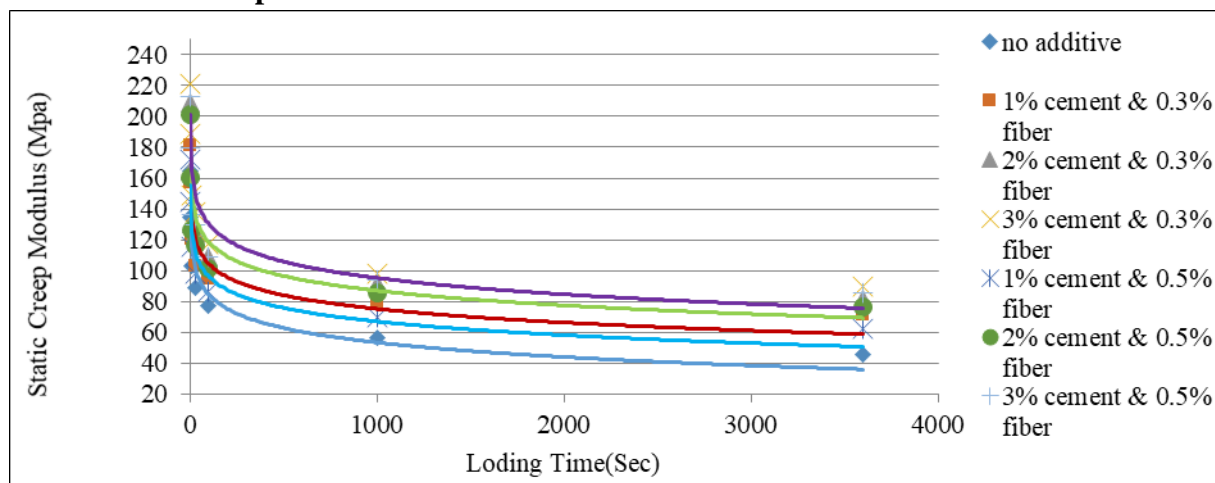


Figure 9. Variations of static creep modulus of mixtures based on loading time

gradually occurs in the samples. Samples with cement and fiber additives show a more gradual increase in instant deformation than those without additives. The degree of deformations in samples with additives, in contrast to those without additives, at the end of 3600 seconds, shows a decrease of about

13%, 30%, 46%, 8%, 21%, and 42%, respectively. Therefore, it is concluded that in the combination of cement and fibers with fatty arboceol, the resistance of cold emulsion asphalt mixtures increases against rutting caused by heavy static loads. When the creep modulus values are evaluated based on the

changes in the graph in Figure 4, the static creep modulus values suddenly decline by 200 seconds, and the degree of this decline from the beginning until the end of the test reduces. Creep modulus values increase as the amount of additives increases. Therefore, combining cement and fibers with fatty Arbocel improves cold emulsion asphalt mixtures' resistance against permanent deformation.

3.4. Results of Evaluation of Rutting Performance

Slab samples prepared for different compositions are compacted under 1000 passes before 60°C temperature. The results of the rutting test are presented in Figure 10. Results showed that the highest amount of rutting, with 8.95% in 30,000 passes, was

observed in samples without additives. Samples with 3% cement and 0.3% fibers with fatty arbocel showed the lowest amount of rutting with 4.99% in 30,000 passes, and it could achieve below the 6% limit test standard. Results showed that the increase of soft fibers leads to more softness of the mixture at high temperatures, and the mixture becomes more prone to rutting.

3.5. Fatigue Test Results

Three Marshall samples of cold emulsion asphalt mixture underwent a fatigue test. Different combinations underwent the load repetition curves, resulting in 4 ten thousandths of a millimeter of deformation, as shown in Figure 11.

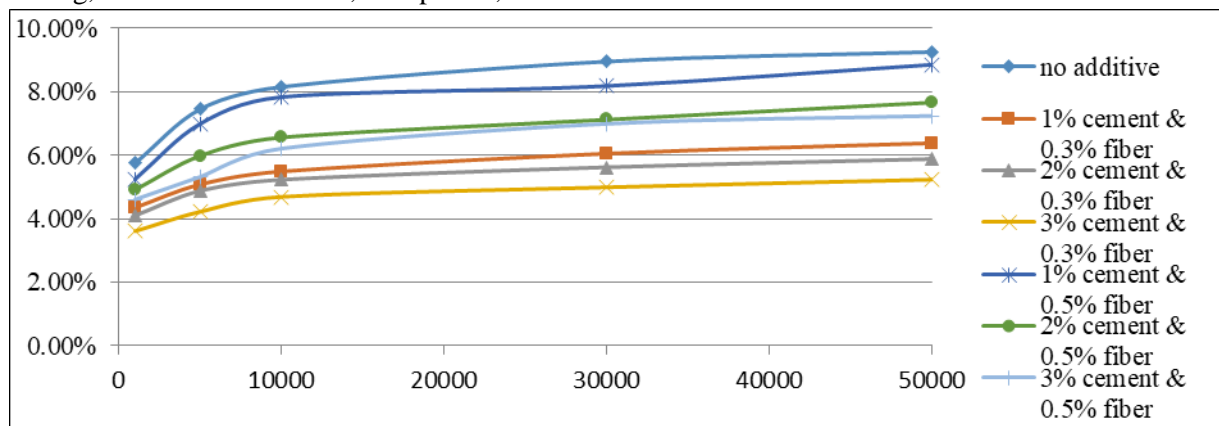


Figure 10. Results of Evaluation of Rutting Performance

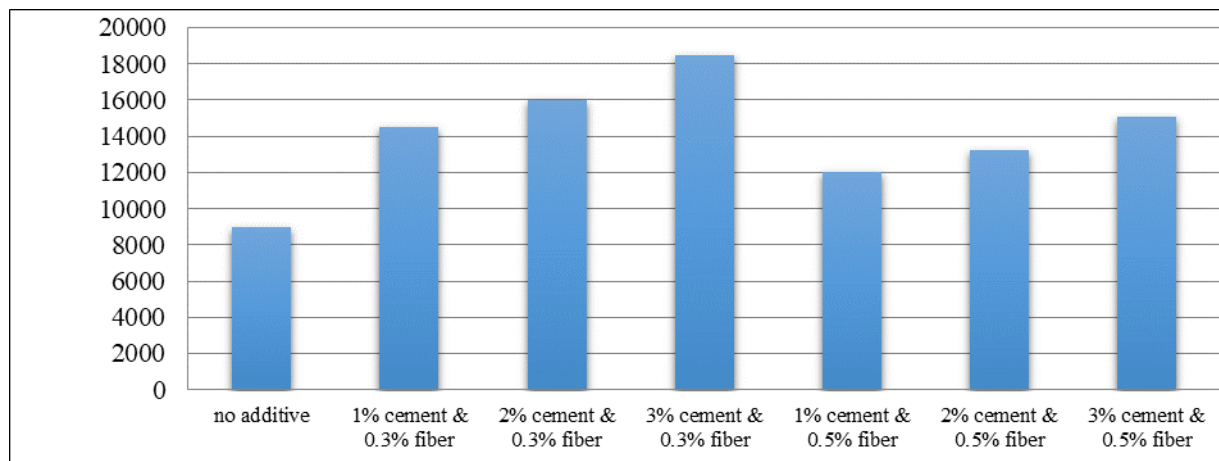


Figure 11. Comparative diagram of fatigue by load repetition

Figure 6 revealed that samples' fatigue resistance with additives had increased significantly by 61%, 78%, 100%, 33%, 47%,

and 68%, respectively, in contrast to samples without additives, and is consistent with standard criteria for fatigue resistance in hot

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asphalt mixtures. Cracks by fatigue are the leading cause of damage to pavement. With an increase of 30% in damage, the performance of the asphalt surface layer will be significantly affected and require repair and protection methods. Therefore, increasing fatigue resistance can be crucial in minimizing maintenance costs.

4. Conclusion

This research examined the effect of cement and fibers with a fatty arbocel combination on cold emulsion asphalt mixture's fatigue and rutting features. The results are as follows:

1. Combining cement and fibers with fatty arbocel as an additive of cold emulsion asphalt mixture improves the Marshall Index parameter. This can improve the behavior of cold emulsion asphalt mixtures against permanent changes.
2. The results indicate that combining cement and fibers with fatty arbocel increases cold emulsion asphalt mixture's resistance against rutting by heavy static loads.
3. The rutting test showed that the highest rutting was observed in the samples without additives and the lowest in the samples with 3% cement and 0.3% fibers with fatty arbocel. This sample could meet the 6% limit set for hot asphalt mixtures in the LCPC method.
4. Fatigue cracks are the most severe causes of pavement failure. The performance of the asphalt surface layer is strongly affected by an increase of 30% of that failure. Results revealed that combining cement and fibers with arboreal in cold emulsion asphalt mixtures improves the resistance of these types of mixtures against fatigue and meets hot asphalt mixtures' standards.
5. The results of physical and functional tests showed that combining cement and fatty fibers with arboreal can significantly reduce maintenance costs.

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