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Performance evaluation of porous asphalt mixtures modified with basalt fiber

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Abstract: Porous pavement applications, which is environmentally friendly, especially for residential areas, allow rainwater to remain clean and to feed groundwater through infiltration. Porous asphalt pavements, in which are among the pavement types used in porous pavements systems, also reduce environmental noise pollution. On the other hand, there is a need to improve the performance of these asphalt pavement mixtures, which have a short service life due to their porous structure. It has been considered to improve the performance of the pavement mixtures by using basalt fiber without compromising the hydraulic permeability level. The waste slag material released during the ferrochrome production process was used as aggregate in the porous asphalt mixture design. Thus, it is aimed to benefit from the economic and environmental aspects with the recycling of ferrochrome slag in an area suitable for its properties. In the study, the design performances of porous asphalt mixtures were determined with tests such as volume analysis, permeability, Cantabro particle loss, indirect tensile strength and moisture susceptibility. Basalt fiber was added at 0.2%, 0.4%, 0.6% and 0.8% of the mixture weight. It has been determined that the mixtures of basalt fibers at 0.2% significantly improve the mechanical performance.

Keywords: porous asphalt, basalt fiber, ferrochrome slag, fly ash, permeability.

1. Introduction

Applications for protecting the environment and natural resources also stand out in the road pavement. The studies on the development of asphalt pavement mixtures are ongoing (Akdaş et al., 2018). Porous road pavements are considered environmentally friendly due to the following benefits. In crowded cities, rainwater is collected on impervious surfaces and is mostly prevented from leaking into groundwater. Porous pavement applications allow rainwater that remains clean to infiltrate and feed the groundwater (Claytor, 2000; Mullaney & Lucke, 2014; Ndon & Al-Manaseer, 2017). Due to the porous structure of the pavement, it reduces environmental noise pollution (Raaberg et al., 2001; Vaitkus et al., 2017). According to the results of the study conducted on a test track where three types of asphalt pavement layers, namely porous asphalt, stone mastic asphalt and dense-graded, it was determined that porous asphalt significantly reduced noise compared to other pavements. It has been determined that 25% - 50% of the noise is absorbed by its porous structure (Hwee, 2008). It has been observed that as the thickness of the porous asphalt pavement increases, the degree of noise reduction also increases (Smit, 2008). On the other hand, waste recycling and sustainability have become more important day by day in terms of protecting natural resources and reducing the environmental pollution. From this point of view, it is thought that it will be suitable for use as aggregate in the production of porous asphalt mix, which is more suitable for the properties of waste ferrochrome slag.

Porous asphalt is a bituminous mixture with an open gradation containing a small fine material compared to coarse aggregate. Due to the high void ratio in its structure, it has good drainage properties (Mallick et al., 2000; Moore et al., 2001). Together with the environmental contributions provided by these pavements, it reduces the risk of accidents that may occur due to skidding caused by the water film that cannot be drained from the pavement surface, headlight reflections which may occur during night driving, restriction of visibility distances caused by splash and spray. In addition, it provides solutions in terms of pedestrian disturbances caused by water splashes (Afonso et al., 2019; Pancic, 2017).

In addition to the reduction in construction costs and time, porous asphalt is less expensive in comparison to other porous pavements and has an overall lower life cycle cost. Porous asphalt is generally 20-50% higher in unit material costs than conventional asphalt. While unit material costs for porous asphalt are slightly higher than for conventional impermeable asphalt, porous asphalt can lead to cheaper project costs due to the costs of stormwater drainage system items. Although the costs may vary according to the characteristics of the courses used in the construction of porous asphalt pavement, the construction of porous asphalt pavement section is approximately $123.77 per square meter. Also, unit costs for a porous asphalt course range from about $2 to $3.5 per square foot for asphalt courses. For a permeable concrete layer, it ranges from $2 to $6 per square foot (Eisenberg, 2015).

Due to the short service life of porous asphalt pavements, there is a need to improve their strength properties. Studies show that this improvement can be achieved by improving aggregate properties and gradation, bituminous binder modification, as well as reinforcing the mixture with fiber (Gupta et al., 2019). According to the revised German regulations, the minimum binder content was increased to achieve a longer structural life in porous asphalt mixes and only modified binder was allowed to be used. Mineral and synthetic fibers can be used in the modification to improve the binding of bitumen (Serfass & Samanos 1996; Afonso et al., 2017). Thus, mixtures resistant to moisture, aging, fatigue, permanent deformation and cracking can be prepared. The fiber types commonly used for bitumen stabilization are cellulosic and mineral fibers. These are added to the mixtures at a rate of 0.2% to 0.5% of the total weight of the mixture (Cooley et al., 2009). The bituminous binder becomes brittle in cold climates and the wearing and particle loss experienced in porous asphalt increase. Binder and mixture modification is applied to prevent this situation (Jacobson et al., 2017).

Senior-Arrieta & Córdoba-Maquilón (2017) investigated the effects of asphalt binder modified with fatty acid amides on the mechanical characterization and performance of porous asphalt mixtures. Cantabro particle loss test was performed on samples prepared with bitumen binder modified with 2% fatty acid amides by weight of bitumen. In the experiment applied in dry and wet conditions, it was determined that fatty acid amides improved the performance of the porous asphalt mixture. Radzi et al. (2019) laboratory tests such as cantabro abrasion, modulus of elasticity, Marshall stability and density were performed on porous mixtures containing different percentages of steel fiber. The results show that 0.6% steel fiber additions give the lowest wear value, while 0.5% fiber content contributes to the highest Elasticity Modulus and Marshall Stability value, respectively. It is concluded that asphalt mixes containing steel fibers can increase the stability and strength of the mixture. Gupta et al. (2021), the effect of four different fibers, (a) normal aramid fiber (RegAR), (b) latex coated aramid fiber (ARLat), (c) polyurethane coated aramid fiber (ARPoly), (d) aramid fiber length 12 mm (AR12) was evaluated for wear resistance and toughness of porous mixtures. Permeability tests for functional performance, Cantabro test for mechanical performance and indirect tensile strength tests were applied. Based on the analysis of the results, it was concluded that the addition of ARLat fibers improves the abrasion resistance of the mixtures. In terms of indirect tensile strength tests, ARPoly and RegAR positively affected the mixtures under dry conditions.

In the study performed to improve the performance of porous asphalt, high viscosity binder (HVB), PG76-22 and PG70-22 binder and fiber, hydrated lime and (dodecylbenzene sulfonate) DBS polymer samples prepared with cantabro abrasion, moisture damage, strength tests have been applied. According to the data obtained, HBV significantly improved the strength of porous asphalt. The DBS additive has increased the high temperature performance but reduced the low temperature cracking resistance and durability. On the other hand, fiber increases its durability and low temperature cracking performance. Hydrated lime increased the resistance to moisture damage while weakening its durability (Ma et al., 2018).

In a study investigating the effects of different types of fibers added to porous asphalt, it was found that all three of the polypropylene, polyacrylonitrile and cellulose fibers added to the mixture increased Marshall stability and indirect tensile strength compared to the control sample prepared without additives. The addition of fiber to the mixture significantly reduced the Cantabro part loss test (Pasetto, 2000). While Cantabro part loss is 25% in samples prepared with unmodified bitumen; It has been determined that this value decreases up to 16% in samples prepared with bitumen modified with 2% Licomont Bs-100 additive (Arrieta & Maquilon, 2014).

In the study, ferrochrome slag recycled aggregate was used, and the effects of basalt fiber on the improvement of porous asphalt mixture performance were investigated. According to the highway's technical specification (THTS, 2013), type-3 gradation and polymer bituminous binder are used. The mixtures were prepared in 6.0% and 6.5% bitumen, which are in the range of optimum bitumen for the selected aggregate gradation. Basalt fiber was added at 0.2%, 0.4%, 0.6% and 0.8% of the total mixture weight. Permeability, cantabro part loss, indirect tensile strength, and moisture sensitivity tests on the compacted mixture samples. Considering the test results, the design values of porous asphalt mixtures and the effects of basalt fiber on the performance of the mixture were determined.

2. Experimental study

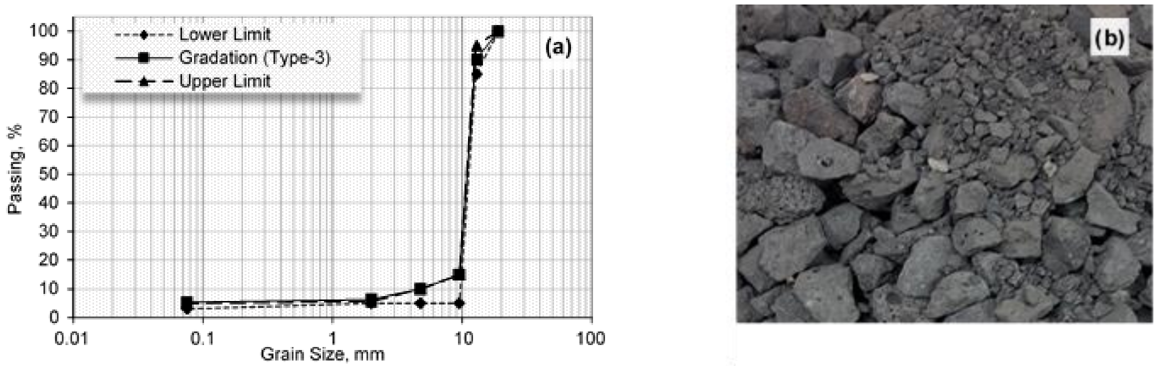
This study has assessed the effects of basalt fiber on the performance of PA mixtures, waste ferrochrome slag aggregate was also used. The Turkish highway technical specifications have been considered for the porous asphalt mixture requirements. In preparing the mixtures, type-3 mix aggregate gradation and polymer bituminous binder (PMB 76-16) were used. In addition, fly ash (F type) and cellulosic fiber were used as additional filler materials to provide bitumen stabilization in the mixtures. The mixture samples were prepared with a Marshall compactor. The void analyses of samples prepared in different bitumen ratios (6.0% and 6.5%) with basalt fiber additive (0.2%, 0.4%, 0.6% and 0.8% of the total weight of the mixture) have been made. The design tests such as permeability, Cantabro loss, and indirect tensile and moisture sensitivity tests were conducted to determine the effects of basalt fiber concentration on the PA mixture's performance.

3. Materials

In this study, ferrochrome slag aggregate and polymer bituminous binder were used as the base material. In addition, cellulosic fiber and F-type fly ash were used as substitute materials. Basalt fiber has been added to improve the performance properties of the mixtures.

3.1. *Aggregate*

In this study, slag material obtained from the Elazig ferrochrome plant was used as coarse aggregate, fine aggregate and filler material (Figure 1). Some physical properties belonging to ferrochrome slag are given in Table 1. As the porous asphalt mix aggregate gradation, the type-3 gradation in the 417 section of the Turkish highways technical specification (THTS) shown in Figure 1 has been selected (THTS, 2013). In the mixtures, fly ash (F type) obtained from the Catalagzi thermal power plant was used as an additional filler (4.45%). The specific gravity and water absorption values of the aggregate of ferrochrome slag determined according to TS EN 1097-6 are given in Table 2.



(a) (b)

Figure 1. Ferrochrome slag aggregate (a) particle size distribution (b) image.

Table 1. Physical properties of ferrochromium slag aggregate.

Characteristics	Test method	Values
Los Angeles abrasion (%)	TS EN 1097-2	18
Sodium sulfate soundness (%)	TS EN 1367-1	0,85
Crushing value (%)	TS EN 933-5	100
Flakiness index (%)	TS EN 933-3	7,8

Table 2. Specific gravity and water absorption values of ferrochromium slag aggregate.

	Coarse aggregate	Fine aggregate	Filler
Apparent specific gravity	2.998	2.781	3,209
Bulk specific gravity	2.903	2.616	-
Water absorption (%)	1.09	2.27	-

3.2. *Bituminous binders*

Since it is stated that a polymer binder should be used in porous asphalt mixtures according to Turkish highway's technical specifications and the effect of fiber modification was investigated in the study, a type of polymer binder was used. The modified bitumen was produced in 120 minutes in a high shear mixer at 180°C and 2000 rpm. İstanbul Asphalt Industry and Trade Inc. Some properties of the provided polymer bituminous binder (PMB 76-22) are given in Table 3.

Table 3. Characteristics of the polymer bitumen.

Characteristics	Test method	Values
Penetration, 25ºC, 100 g, 5 s (0,1mm)	TS EN 1426	39
Softening point (ºC)	TS EN 1427	76,4
Flashpoint (ºC)	TS EN ISO 2592	316
Elastic recovery 25ºC (%)	TS EN 13398	91
Specific gravity	TS EN 15326	1,026

3.3. *Basalt fiber*

Basalt fiber shown in Figure 2 was used in the modification that constitutes the subject of the study. Basalt fiber was added to the mixtures 0.2%, 0.4%, 0.6% and 0.8% of the total weight of the mixture. It was dry mixed with aggregate for 2 minutes to ensure a homogeneous distribution of the fibers in the mixture. Some technical properties of basalt fiber are given in Table 4.

Figure 2. Image of the basalt fiber.

Table 4. Basalt fiber specifications (Dostkimya, 2021).

Specifications	Values
Tensile strength (MPa)	4840
Elastic modulus (GPa)	89
Service temperatures (°C)	- 260 ± 982
Melting temperature (°C)	1450
Density (g/cm^3)	2.6-2.8
Fiber diameter (μm)	9-23
Fiber length (mm)	12

3.4. *Cellulosic fiber*

The bitumen-absorbed cellulosic fiber with a thermal resistance above 250 °C was added at 0.03% of the total mixture weight to prevent the leaching of bituminous binder from porous asphalt mixtures. The aggregate was mixed with dry for 2 minutes since the granular material in the form of pellets of 7 mm diameter and 20 mm length (Istanbulteknik, 2021) was distributed homogeneously in the mixture.

4. Test methods and results

This section explains the procedures and results of void analysis, permeability, cantabro particle loss, indirect tensile strength and moisture susceptibility tests performed on compacted samples.

4.1. *Mixture design and preparation of samples*

Mix samples were prepared in 6% and 6.5% bitumen for Type-3 porous asphalt mixture gradation according to Turkish highways technical specifications (THTS, 2013). It was dry mixed with aggregate for two minutes to ensure that cellulosic fiber and basalt fiber were homogeneously dispersed in the mixtures. After the bitumen was added, the mixture was mixed for three minutes at about 175-180 °C and allowed to cool down to 115-120 °C. The mixtures were continuously mixed with a spatula to accelerate cooling and prevent bitumen from leaching. The mixtures placed in the heated mold were compacted with 50 blows on both sides of the sample with the Marshall compactor. Samples allowed to cool to room temperature were removed from the molds.

4.2. *Void analysis and permeability test*

The void ratio is one of the basic parameters used in the design of PA mixtures. Since PA mixtures have a high void ratio, unlike conventional pavements to calculate specific gravity and void ratios, samples must be coated with parafilm to prevent water from entering. In performing the void analysis, it is necessary to determine the specific gravity of the compacted mixture samples (AASHTO, T275) and the theoretical specific gravity of the bituminous mixture (ASTM D2041, 2019). The void analysis and permeability test results are presented in Table 5. The calculated values naturally decrease in the void ratios of the samples as the bitumen and fiber ratio increases, as can be seen in Figure 4a. It provides a minimum limit value of 18% in all fiber ratios except for samples with 0.8% and 1.0% fiber in 6.5% bitumen and 1.0% fiber samples in 6% bitumen.

The volume and velocity of water passing through the PA pavement are expressed by the hydraulic conductivity coefficient determined in permeability tests. In the study, "rigid wall permeability" was developed based on constant head permeability used to determine this parameter. This system in Figure 3 is called the "balloon tube fixed head permeability system.” This system significantly reduces sidewall infiltration and is suitable for very low hydraulic gradients. It also provides the ability to test materials with high flow rates such as porous asphalt pavements (Cetin et al., 2014). The sample is placed in the testing system without removing it from the mold, and the tester is placed in a water bath to keep the water level constant. When the water level in the system becomes stable, it is recorded (Hstart) and the test starts. At the end of the test, the water level in the reservoir (Hfinish) and flow time (t) is recorded. The height difference between the lower end height of the balloon tube (H1) and the height of the water in the water bath (H2) where the system is placed, the sample height (L) and the total level loss (H) are determined. The hydraulic conductivity coefficient (k) is calculated by the formula in equation (1), using Darcy's law. It is recommended that the minimum permeability coefficient should be 102 cm / s (~ 100 m / day) in porous pavement structures (Mallick et al., 2000; FDOT, 2012).

$$k = \frac{(H_{start} - H_{finish})}{\frac{(H_2 - H_1)}{L} \times t} \quad (1)$$

Table 5. Average air void contents and permeability coefficients of PA mix.

Mixture types	Bitumen content (%)	Specific gravity, ρ_m	Theoretical specific gravity, ρ_T	Air void ratio, V_a (%)	Coefficient of permeability, k (m/day)
0% control	%6.0	2.134	2.701	21.9	138.3
0% control	%6.5	2.121	2.694	21.3	131.0
0.2% Fiber	%6.0	2.086	2.596	19.8	130.0
0.2% Fiber	%6.5	2.098	2.594	19.1	116.3
0.4% Fiber	%6.0	2.090	2.585	19.1	113.0
0.4% Fiber	%6.5	2.125	2.581	17.8	102.0
0.6% Fiber	%6.0	2.102	2.574	18.3	103.0
0.6% Fiber	%6.5	2.140	2.575	16.8	77.6
0.8% Fiber	%6.0	2.103	2.567	17.9	91.0
0.8% Fiber	%6.5	2.141	2.564	16.5	61.4

As seen in Figure 4b, as the amount of bitumen and fiber in the mixture increased, a decrease was observed in the permeability coefficient. It was determined that the samples with 0.2%, 0.4% and 0.6% fibrous in 6.0% bitumen and 0.2% and 0.4% fibrous in 6.5% bitumen were above the limit permeability value.

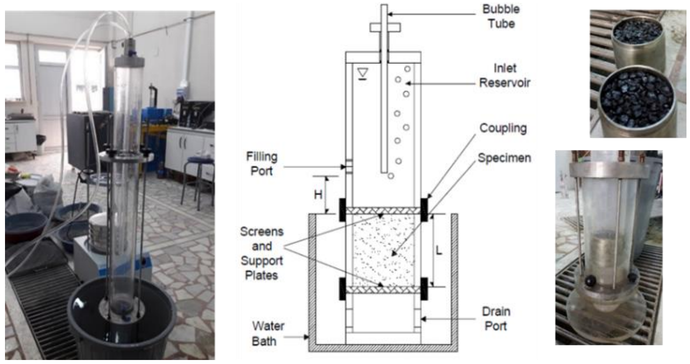


Figure 3. Bubble tube constant head permeability test setup.

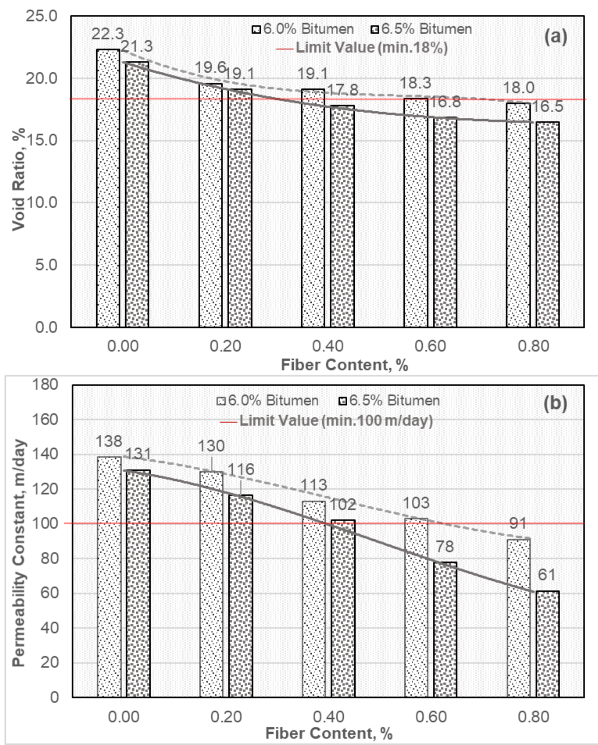


Figure 4. (a) Void contents, and (b) permeability coefficients of PA at different fiber concentrations.

4.3. *Cantabro particle loss test*

In porous asphalt pavements, raveling based on its porous structure is more common with the effect of environmental conditions and traffic. Raveling resistance which is one of the performance properties taken as a basis in the design is also important to identify the expected positive effect of FCS. The Cantabro loss test used to determine raveling resistance was conducted on at least three samples for each mixture type and bitumen rate. The limit value is generally accepted as a maximum of 20% for the test. In Figure 5, it is seen that although the part rupture loss improved in 6.0% bitumen samples with 0.2% and 0.4% fiber, the results could not provide the maximum limit value. It can be said that this is due to the fact that the desired bitumen film thickness cannot be achieved in mixtures.

At the rate of 6.5% bitumen, the best result is obtained at a 0.2% additive rate, and it is seen that it is very close to the limit value at 0.4% fiber. In general, it has been determined that particle rupture is significantly reduced with the addition of fiber. It was determined that 0.2% and 0.4% fibers had values close to each other, and at rates greater than 0.4%, the abrasion loss increased as the fiber increased and remained above the maximum limit value.

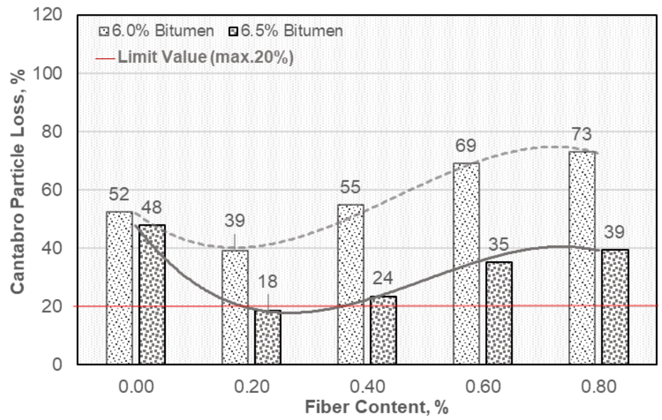


Figure 5. Cantabro particle loss of PA at different fiber concentrations.

4.4. *Indirect tensile strength test*

The indirect tensile strength test is widely used to determine the tensile strength necessary for porous asphalt mixtures. In this method, due to the difficulty of applying the direct tensile test, the sample is subjected to tensile force indirectly in the horizontal direction by applying a vertical load. It was applied to determine the bitumen film thickness, especially the fiber effect. This test was carried out by ASTM D6931 (2017) procedure with a 50 mm/min deformation rate and a temperature of 25 ° C with a Marshall stability test machine. Tensile stress occurring perpendicularly against the load exerted (σ_t) is calculated with the formula in Eq. (4), taking into account the ultimate load causing fracture of the sample (P), sample height exposed to the load (h) and diameter of sample (d).

$$\sigma_t = \frac{2 \cdot P}{\pi \cdot h \cdot d} \quad (2)$$

In 6.5% bitumen, indirect tensile strength values were higher than 6.0% bitumen (Figure 6a). The best results are obtained at 0.2% fiber, and 0.4% fiber results are close to 0.2% bitumen for both bitumen ratios. It is seen that indirect tensile strength decreases in bitumen concentrations greater than 0.4% bitumen.

4.5. *Moisture susceptibility*

Water penetrating the asphalt mixture accelerates deterioration in the pavement by harming the bonds between bituminous binder and aggregate (Shen et al., 2008). The surface area contacting water is more extensive in the PA mixture due to its structure. The most common procedure adopted to detect the size of damage likely to occur in pavement mixtures is AASHTO T 283-17 (2014) standard. In this procedure, indirect tensile strengths of the compacted samples divided into two groups were determined. One group of the samples was wetted and appropriately coated with a plastic film layer and put into plastic bags each containing 10 ml of water were conditioned by being kept in deep freeze at -18 °C for 16 hours and in a water bath at 60 °C for 24. Finally, indirect tensile strengths of conditioned and unconditioned samples kept in a water bath at 25°C for 2 hours were determined. The numerical index of the resistance to water effect (ITR) is expressed as the ratio of strength after freeze-thaw conditioning (σ_c) to the original strength (σ_{uc}) (Eq. (3)).

$$ITR = {}^{\sigma_c}/_{\sigma_{uc}} \quad (3)$$

According to the THTS and Superpave specification, the calculated indirect drawing ratios should not be below 80% of the minimum value (THTS, 2013). According to the graph given in Figure 6b, it is seen that the results are above this value for all fiber concentrations except 0.6% and 0.8% fiber in 6.0% bitumen. It was determined that the indirect tensile ratios

(ITR) in 6.5% bitumen are better than in 6.0% bitumen.

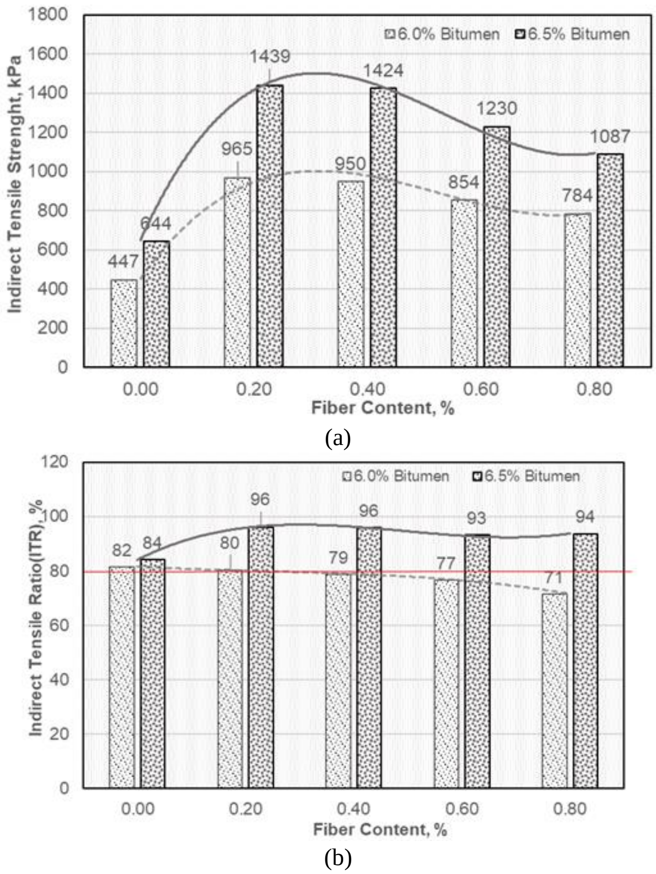


Figure 6. (a) Indirect tensile strength values, and (b) moisture susceptibility (ITR values) of PA at different fiber concentrations.

4.6. *Mixture design results*

When the results of the performance tests are evaluated, the optimum mixture design has been determined by considering the bitumen and fiber concentrations. While the air void ratio and permeability values naturally decrease with the increase in bitumen volume and fiber concentration, the highest air void and permeability coefficient values were obtained at 6.0% bitumen. It is seen that the void ratio and permeability values meet the required specification limits at 0.2% and 0.4% fiber additive ratios. In the Cantabro abrasion loss test, the results remained above the 20% limit value for all fiber additives in 6.0% bitumen. The specification limit value is provided only in 6.5% bitumen and 0.2% fiber. The best results were obtained in the indirect tensile strength test at 6.5% bitumen percentage. It is seen that the maximum values obtained in the addition of 0.2% basalt fiber in both percentages of bitumen increased about two times compared to the control samples. Although all results were higher than the control samples, it was determined that the indirect tensile strength values decreased at the additions greater than 0.2% fiber. The water damage test determined that the results are above the limit value (min.80%) for all fiber concentrations except 0.6% and 0.8% fiber in 6.0% bitumen. ITR in 6.5% bitumen is better than in 6.0% bitumen.

Considering all the design test results, it showed that the best values were obtained at the rate of 6.5% bitumen. When the basalt fiber concentrations were evaluated, it was determined that the highest tensile strength was obtained at the rate of 0.2% fiber, providing the maximum Cantabro abrasion value. Even though the air void and permeability results meet the specification criteria at 0.4% fiber, the results at 0.2% are at a better level. The ITS value determined for water damage at 0.2% fiber remains above the minimum limit value. Therefore, the optimum mixture values were determined as 6.5% bitumen and 0.2% basalt fiber. Optimum mixture values are given in Table 6.

Table 6. Design results of porous asphalt mixture with basalt fiber.

Design parameters	Design values	Spec. value
Optimum bitumen (%)	6.5	-
Opt. fiber (%)	0.2	-
Air void (%)	19.1	Min. 18
Cantabro loss particle (%)	18.5	Max. 20
Coefficient of permeability, k (m/day)	116	Min. 100
Ind. tensile strength (kPa)	1439	-
Ind. tensile ratio, ITR (%)	96.1	Min. 80

5. Conclusions and discussion

The study investigated the effects of basalt fiber on the mixture performance. The performance tests such as void analysis, Cantabro abrasion loss, permeability, indirect tensile strength and resistance to water damage have been conducted. The following inferences were made from these test results:

1. As the amount of bitumen and fiber in the mixture increased, the air void and permeability of the mixtures decreased. While samples prepared with only 0.2% and 0.4% fiber for both bitumen provide the limit value, the void ratio and permeability at the rate of 6.0% bitumen are more than 6.5% bitumen;
2. In the Cantabro particle loss test, none of the samples prepared with 6.0% bitumen could achieve the limit value (25%). The specification limit value is provided only in 6.5% bitumen and 0.2% fiber. It was observed that the addition of basalt fiber significantly improved the loss of Cantabro particles compared to the pure samples;
3. It was determined that the tensile strength values of the basalt fiber samples increased about two times compared to the control samples. Although all results were higher than the control samples, it was determined that the indirect tensile strength values decreased at the additions greater than 0.2% fiber. Indirect tensile test results support the Cantabro particle loss test results;
4. Considering the results obtained in both the Cantabro abrasion test and the indirect tensile test, it was observed that the results obtained in 0.2% and 0.4% fiber were close to each other, but the strengths were reduced at higher additive rates. This can be explained as the increased fiber volume weakens the cohesion in the bitumen matrix and the adhesion between bitumen and aggregate;
5. The water damage test determined that the results are above the limit value (min.80%) for all fiber concentrations except 0.6% and 0.8% fiber in 6.0% bitumen. ITR in 6.5% bitumen is better than in 6.0% bitumen. The effect of basalt fiber addition on the water damage of the mixtures was not noticeable;
6. The study results significantly improved the strength properties of basalt fiber addition compared to the control samples. While the void and permeability values naturally decrease with the increase of the basalt fiber, it was determined that the specification limit value was achieved at 0.2% fiber;
7. Fiber modification to be made in porous asphalt mixes at small additional costs will provide significant improvements in the service life of the mixes by improving the strength the mixes. Thus, the use of porous asphalt pavements will be made more economical and widespread;
8. This study demonstrated the positive effects of basalt fiber on the performance of porous asphalt pavement mixes. Different fiber types may be the subject of research to improve the performance of porous asphalt mixes. In addition, studies on modified bitumen can be expanded;
9. In addition, ferrochrome slag aggregate and fly ash are used as additional fillers in the study. In this respect, porous asphalt mixture design contributes to the environmental and economic aspects of recycling waste materials.

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