IJTE, Vol. 10, No. 4, Spring 2023, pp. 1237-1252
Research Paper

Investigation of Porous Asphalt Surface Parameters Used in Traditional Texture Passages

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Received: 2022/02/20 *Accepted: 2023/01/10*

Abstract

Permeable pavement, including porous asphalt, is one of the best management practices in urban stormwater control, which is an effective way to protect brick and mud from rain runoff. The aim of this study is to investigate the relation between parameters related to the surface texture of porous asphalt with evaporation and permeability as two key properties of porous asphalt. For this purpose, laboratory samples were first made. By performing permeability and evaporation measurement tests in an innovative way, the amount of permeability and evaporation of porous asphalt with different gradations was determined. Then, with image processing and English pendulum device, parameters related to the surface texture of the samples such as surface porosity, fracture of surface aggregates and slip resistance were measured. Their effect on evaporation and permeability was investigated. The results of this study indicate that with finer gradation, the amount of surface porosity and angle and visible fractures of aggregates in the sample surface is reduced by about 27% and 48%, respectively. Also, the results of slip resistance test show that in dry state, the friction decreases by about 11% as the gradation becomes larger and in the wet state, the larger the texture, the slip resistance is about 32% higher. Based on the results presented in this study, the parameters related to the surface texture of the sample have a significant relationship with the rate of evaporation and permeability of porous asphalt; which is presented in this research. With the relationships presented in this study, it is possible to estimate the permeability and evaporation of porous asphalt by measuring the parameters related to the surface texture, which are relatively easier and faster to measure.

Keywords: Brick structures, Evaporation, Permeability, Porous asphalt, Surface texture

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1. Introduction

Brick and mud structures are important because they are one of the goals of historical tourism and since the tourism industry is one of the most important sources of income in the world (World Tourism Organization, 2017); preservation of antiquities, including old brick and mud structures, and preventing their destruction are of particular importance. Numerous factors cause the destruction of brick structures, and moisture is one of the main causes of the destruction of these structures. Accumulation of rainwater at the foot of clay and mud walls and high surface water level is the main cause of erosion and destruction of clay and mud walls, which eventually leads to their complete collapse (Figure 1). Therefore, water must be prevented from accumulating under the brick walls and reaching moisture to it (Shah et al., 2013).

Figure 1. A- Flooding of the traditional clay and mud texture passages B- Destruction of the brick walls due to moisture from runoff

One of the best ways to reduce rainwater runoff is porous pavement including porous asphalt (Suman & Kumar, 2022; Nazarinasab, Ghasemi, Marandi, 2018; Al-Busaltan et al., 2021). The reason is that when raining, water is prevented to penetrate the ground by the surface of sidewalks and streets often covered by impenetrable pavement. Thus, flooding occurs on city roads. However, rainwater is allowed to seep into the underlying layers by permeable surfaces to rainwater (Jusić et al., 2019a; Jusić et al., 2019b; Almássy & Joó, 2009); as a result, water will not collect along the clay and mud structures and ultimately prevent their destruction by rainwater runoff.

In general, porous asphalt with permeability and in some cases with evaporation prevents flooding (Yu et al., 2020; M. Hu et al., 2017, Shirgir, Mamdoohi, Hassani, 2015) in this regard, several studies have been conducted. For example, studies from 1999 to 2011 have shown that porous pavements reduce runoff by 50 to 93 percent (Ahiablame et al., 2012). Also, according to a 2019 study by Cheng et al., porous asphalt pavement can reduce runoff peak levels for severe floods and low-intensity floods by 16 and 55%, respectively (Cheng et al., 2019). Akhtar et al. In a study entitled "Stability and Permeability Characteristics of Porous Asphalt Pavement: An experimental case study" state that the use of porous asphalt in urban areas has positive consequences such as reducing the risk of floods and runoff as well as increasing safety (Akhtar et al., 2021). As mentioned, evaporation is another property of porous asphalt that helps reduce runoff (Tziampou et al., 2020) ; This is caused by the fact that more evaporation occurs than impermeable pavements by the high capacity of permeable pavements in keeping water in the considered way and connecting it through the pores to the surface. It was found that porous pavement has an evaporation property of approximately 16% higher than impermeable pavement (Starke et al., 2010). Also, in a study on the evaporation of porous asphalt, Brown & Borst states that if in an area of the city, it seeks to maximize the amount of evaporation through pavement and thus reduce subsurface moisture and runoff, the use of this pavement is recommended (Brown & Borst, 2015). In another study conducted in 2019, Aboufoul et al. emphasized the evaporation properties of porous asphalt and stated that the evaporation properties of porous asphalt are as important as the permeability properties in reducing runoff. There are two mechanisms for evaporation in a porous asphalt environment, drying the porous surface of the asphalt and rising water droplets through the pores by capillary action and its evaporation (Figure 2) (Aboufoul et al., 2019).

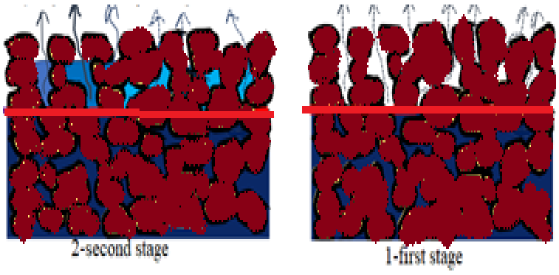


Figure 2. The evaporation phases in porous asphalt pavement

Gradation of stone materials is a key parameter in the porous asphalt mixing design; because the degree of permeability and evaporation of this pavement is strongly dependent on the degree of porosity, the degree of porosity is also strongly affected by gradation (J. Hu et al., 2020); numerous researchers have conducted studies in this field. For example, In 2004, Hamzah et al., modified the granularity of porous asphalt mixtures used in Korea to provide suitable granularity for porous asphalt for Malaysia (Hamzah et al., 2004). Also in 2021, Ren et al., presented a gradation with a strong aggregate structure by examining different gradations, that improves the performance of porous pavement (Ren et al., 2021). Above all, according to the climatic conditions of their country, the specialists and engineers in the field of pavement of each country have provided special gradation for the implementation of porous asphalt in the regulations. In general, it can be said that factors such as maximum aggregate, aggregates shape, aggregates dimension ratio and the arrays of aggregates are the most important and effective parameters on the rate of evaporation and permeability (J. Hu et al., 2020).

Although several studies have been conducted on the two properties of permeability and evaporation as well as gradation of porous asphalt; limited studies have been performed on the surface parameters of porous asphalt such as surface porosity and slip resistance and its relation with the degree of permeability and evaporation of porous asphalt; therefore, in this study, the offending granules of porous asphalt were considered and the mentioned parameters and their relation with the degree of permeability and evaporation were investigated. So far, no research has been done to investigate the evaporation and infiltration of water from the pavement together, this study emphasizes the innovation of this study.

2. Research Methodology

In the present work, by making the cubic samples first, the image processing, penetration, and evaporation tests were conducted. Then, the relationship between the parameters was determined by the results.

2.1. Preparing Samples

The materials used to make the samples in this study include aggregates with gradations according to Figure 3 and the characteristics presented in Table 1 and bitumen PG64-22 with specifications according to Table 2. According to the grain size diagram, grain size A is the largest grain size and grain size B is the smallest grain size, and grain size C is the average grain size of grain size A and B; also, grain size D is the average grain size of A and C and grain size E is the average grain size of grain size C and B. It should be noted that the porous asphalt granules studied in this study are the granules used for traditional texture in order to preserve old brick and mud structures; which is very important in terms of tourism.

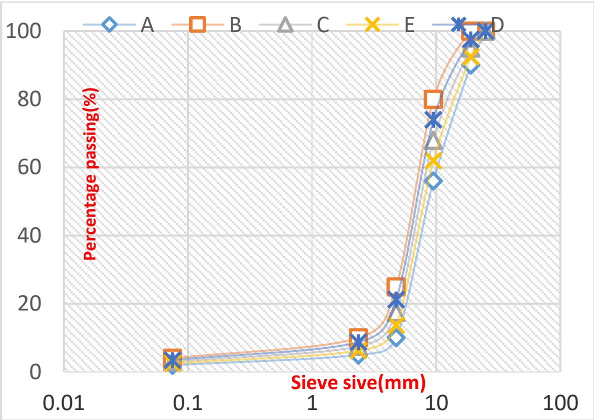


Figure 3. Grading diagram used

Due to the common asphalt binder used in Iran is 60-70 penetration grade, so it was used in this study. Different tests were conducted to survey the properties of asphalt binder among which penetration, softening point, rotational viscosity, ductility and Dynamic shear modulus. Dynamic shear modulus is the ratio of stress to strain under vibratory environments It is a property of viscoelastic materials as bitumen. Also, this mechanical characteristic, the dynamic shear modulus, is used in the design of road pavement structures made of viscoelastic materials such as asphalt.

Table 1. Specifications of stone materials

Type of experiment		Results of the experiment		
		Filler	Fine grain	Coarse grain
Sand Equivalent (AASHTO-T96)		-	63	-
-Percentage of weight loss versus Los Angeles wear (AASHTO-T96)			-	16
Atterberg Limits (AASHTO-T89)	Plastic Index (PI)	4	NP	-
	Plastic Limit (PL)	25	-	-
	Liquid Limit (LL)	29	Indeterminate	-
Percentage of fracture (ASTM-D5821)	On one front	-	-	86
	On two fronts	-	-	93
Elongation /flakiness (BS-812)	-Elongation		-	14
	-Flakiness		-	18
weight loss versus sodium sulfate AASHTOT104	Fine grain		1	-
	Coarse grain		-	1
The effect of boiling water on bitumen coated stone materials (ASTM-D3625)			The adhesion of bitumen to stone more than 95%.	

As mentioned, in this study, the samples made included a cubic sample with dimensions of 15 cm by 15 cm and 6-inch Marshall samples, according to Figure 4, with different gradations and a minimum percentage of fixed bitumen of at least 3%. It should be noted that since the purpose is to study different gradations, the percentage of bitumen in the whole study was kept constant. As mentioned, Gradding of stone materials actually forms the skeleton and main structure of the asphalt mixture and is one of the most important factors in creating resistance against pavement damage. Aggregate constitutes a large percentage of a hot mix asphalt. As a result, the characteristics of mixed stone materials have a significant impact on the characteristics of the mixture prepared from it.

Table 2. The physical properties of bitumen used in experiments

Type of experiment	**Experiment results**	**Standard**	**Unit of measurement**
Specific gravity at 25 °C	1.018	ASTM D792	gr/cm3
Penetration @25°C	63	ASTM D70	0.1 mm
Softening poin	51	ASTM D36	Degrees Celsius

Type of experiment	Experiment results	Standard	Unit of measurement
Ductility at 25 °C	110	ASTM D113	cm
flash point	292	ASTM 92	Degrees Celsius
Viscosity at 135oC	33	ASTM D4402	Pascal seconds
Dynamic shear modulus	174.1	ASTM D7175	KPa

Figure 4. A- Cubic asphalt samples B- 6-inch Marshall asphalt samples

3. Experimental Tests and Analysis

3.1. Permeability Test

In order to determine the permeability of porous asphalt in this study, a porous asphalt permeability measuring device with a rain simulator was used in which the permeability of raindrops is measured and is more consistent with reality (Yu et al., 2020). In the test, by placing the specimen in a special place under the shower, the faucet opens. It is essential to adjust the quantity of water to make the amount of water entering and leaving the sample the same to penetrate the inlet water completely. Then take a special container with a certain volume under the shower and measure and record the time it takes for the container to be filled with water with a stopwatch. Finally, by dividing the volume of the container in the measured time, the amount of flow and by dividing the flow by the surface of the sample, the amount of permeability is calculated (Figure 5-a) (Ma et al., 2020).

3.2. Evaporation Test

Since the amount of evaporation depends on several factors; the evaporation rate of the samples should be measured under the same and controlled conditions (Li et al., 2014). For this purpose, the device presented in Figure 5-b was used. To perform this test, the sample is placed in its special place and sealed with the special foam around the sample device. By closing the lid, the whole device is weighed and recorded. The device is placed in the right place and the fan turns on. It is essential to weigh the whole device again after 24 h. The minimum and maximum values of the thermometer and hygrometer need to be examined and recorded. The quantity of evaporation in a day is calculated by determining the device's weight difference within 24 h. The apparatus should be put in an appropriate place for the same environmental conditions, especially temperature and humidity. Moreover, the location of the device should be fixed for other specimens.

3.3. Skid Resistance Test

Three factors that cause friction have always been of interest to researchers, the grading of aggregates, their type, and the mixing design. Grading is especially important in coarse aggregates. The sliding friction between the wheel and the pavement surface changes due to the presence, or absence, of water on the surface.In order to evaluate the skid resistance of the samples as a surface parameter depending on the type of gradation, the English pendulum device shown in Figure 5-c was used. The experiment was performed in dry and wet conditions of the samples (ASTM E303). An average of 5 consecutive readings is recorded as a pendulum number provided there is no difference of more than 3 units.

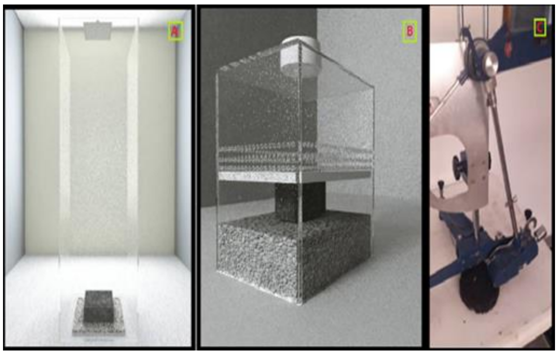


Figure 5. A - Permeability measuring device B- Evaporation measuring device C- Skid resistance test with a pendulum

3.4. Determining the Surface Porosity by Means of Image Processing

In this study, the surface porosity of porous asphalt samples, which represent the voids of porous asphalt, was measured using MATLAB software. For this purpose, with the mentioned software, the sample photo was converted into a photo with black and white pixels, where white pixels (Brightness) represent aggregates and black pixels indicate surface porosity. Then the number of white pixels in each image is divided by the total number of pixels in the image and the brightness value and then the porosity value is calculated. An example of a sample image processing image is shown in Figure 6. A summary of the program code of this software is as follows.Below is a summary of the MATLAB code brought to image processing:

```
;[inputImg s_img] =
ImageSerializer(inImgname, ext)
;[M,N]=size(thePoresBinary)
;Wight=sum(thePoresBinary(:)==1)
Bright=Wight/(M*N)
;Porosity=1-Bright
```

Figure 6. Sample photos converted to black and white photos in MATLAB

3.5. Surface Aggregates Fracture Valuation by Image Processing

Fractal dimension measurements are used to estimation and calculate the intricacy of form, Shape complexity, or texture of substances In order to study the shape of the aggregates and its effect on the surface porosity as well as the permeability and evaporation of porous asphalt, the shape and angularity of the aggregates were investigated using ImageJ software; thus, a constraint with the same area on the surface of the samples was considered and then the grain aggregate angle was determined by the software. as it mentioned, the shape of the aggregates is one of the most important parameters on which the quality of asphalt concrete depends (Tang, Huang, Peng, 2021); therefore, fractal analysis of aggregates forming asphalt concrete is of special importance. In fractal geometry as a branch of mathematics, irregular shape geometry is studied; which will be assessed in more detail below.

3.5.1. Basic Fractal Formula

It presents a more understandable interpretation of all the irregular geometry of natural phenomena including trees, clouds, mountains, and rocks compared to traditional geometry. Irregular shape geometry is studied in fractal geometry, which is the branch of mathematics. Mandelbrot (Stoyan, 1979) presented the basic concept of fractal geometry. It emerged as a robust instrument to evaluate the texture and irregular shape of objects. Fractal is determined based on fractal dimensions. The fractal analysis includes the procedure of observing the fractal dimensions of a body. To comprehend the fractals, examples of the middle third Cantor and von Koch curve can be used. The middle third Cantor set is one of the most easily constructed and best-recognized shapes displaying several fractal features. It can be constructed by a sequence of removal operations from a considered set (Singh, P., & Walia, 2014).

3.5.2. Fractal Dimension

By the fractal dimension index, the alterations in measured quantity are compared based on the measuring scale. The fractal dimension reveals the quantity of space filled close to each point in the set (Nonnenmacher et al., 2013).

To measure a given shape or set, the scale ∂ can be used, although all the irregularities smaller than ∂ are ignored and unnoticed. The scale effect on the measurement can be achieved as $\partial \longrightarrow 0$. For instance, when F is the curve, then Equation 1 can be used to obtain the length measured by scale ∂ in Nn numbers of linear steps.

$$M_O(F) = N_n \times \delta \quad (1)$$

This is consistent with classical geometry. Here, the determined value $M_\delta(F)$ is not dependent on the length of scale ∂. Though $M_\delta(F)$ holds power law if 0 ∂ (Eq. 2).

$$M_O(F)\ \alpha\ \delta^{-S} \rightarrow M_O(F)'\ C\ \times \delta^{-S} \quad (2)$$

In which F possesses the divider dimension s with c based on s dimensional length of F. It can be also explained as the fractal dimension decrement or increment from the Euclidean dimension. Indeed, when α is the fractal dimension, then s can be stated as Equation 3.

$$S = \alpha - 1 \quad (3)$$

Taking both side logarithms of Equation 2 yields Equation 4.

$$\log M_\delta(F) = \log\ c\ - s \times log\delta \quad (4)$$

By $\partial \longrightarrow 0$, the value of s is achieved as:

$$s = \lim \frac{\log M_\delta(F)}{-\log \delta} \quad (5)$$

Therefore, to obtain the value of s, Equation 2 is plotted in a log-log plot.

Based on Euclidean theory and model, by the magnification of a curve/area/volume through scale factor λ, then the multiple shapes of λ /λ^3/λ^2 are obtained respectively (Eq.6).

$$M(\lambda.A) = \lambda^K \times M(A) \quad (6)$$

By A as the taken shape and k as Euclidean dimension, then A is length, volume, or area, and k=1,2,3. For the case of the fractals, the shape will have a fractal dimension as α (Eq.7) (Singh, P., & Walia, 2014).

$$M^\alpha(A) = \lambda^\alpha M^\alpha(A) \quad (7)$$

3.5.3. Fractal Analysis

The fractal analysis can be utilized potentially in the field of irregular geometry as well as pavement engineering. It is always interesting for pavement engineers to assess the shape features of various objects such as aggregates, surface cracks, and pavement surfaces. There are huge possible uses of fractal analysis in this regard. This section deals with some key applications of FRA.

To characterize the shape of an aggregate, fractal analysis can be used. Area perimeter approaches can be used to simply assess the aggregates' fractal dimension. The proportion of fractal linear extents is again a fractal. To express the roughness fractal dimension (DR) of the aggregate in terms of its area (A) and perimeter (P), we have:

$$C = \frac{P^{DR}}{A^{0.5}} \quad (8)$$

In which c is constant for similar fractals. Taking the Logarithm reduces Equation 8 to Equation 9.

$$D_R = 2 \times \frac{\log P}{-\log A} = \frac{2}{m} \quad (9)$$

In which m represents the slope coefficient achieved by plotting the perimeter and area on a log–log scale. To measure the perimeter and area of the aggregates, image processing can be performed via any image processing algorithm or software package like ImageJ software. The fractal dimension can be determined with the help of these measured parameters and areas

(Singh, P., & Walia, 2014). Figure 7 shows an example of the studies performed.

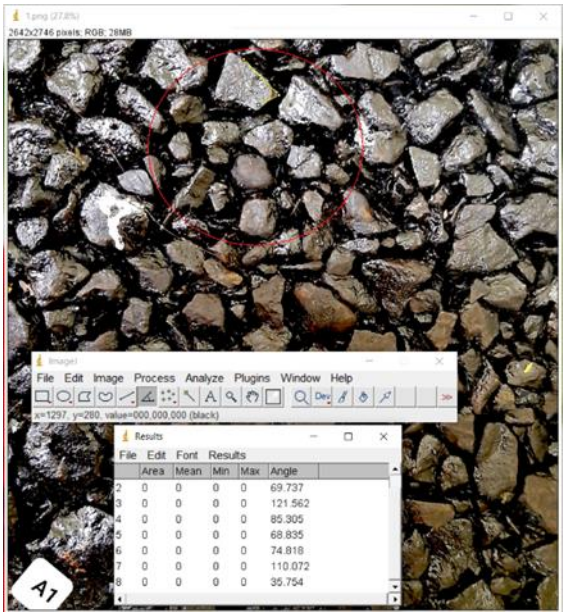


Figure 7. An example of fractal analysis in ImageJ software

4. Results and Analysis

4.1. Permeability and Evaporation Tests Results

The results of permeability and evaporation test of porous asphalt samples are as shown in Figure 8. It is quite clear that as the grading becomes finer (from grading A to grading B), the rate of evaporation and permeability decreases due to the decrease in the percentage of empty space; which is also consistent with previous research (Zhu et al., 2021; Aboufoul et al., 2019).

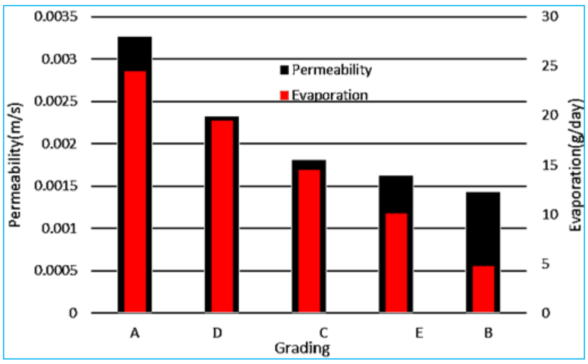


Figure 8. Results of permeability and evaporation tests

4.2. Skid Resistance Test Results

The friction force for brake vehicles is mainly provided by the texture of paving surface, since skid resistance indicates surface roughness; this test was performed to determine the skid resistance of different types of grading and compare it on 6-inch Marshall samples with a constant percentage of 3% bitumen in both dry and wet conditions; the results are presented in Figure 9. The numbers provided are the skid resistance values of BPN.

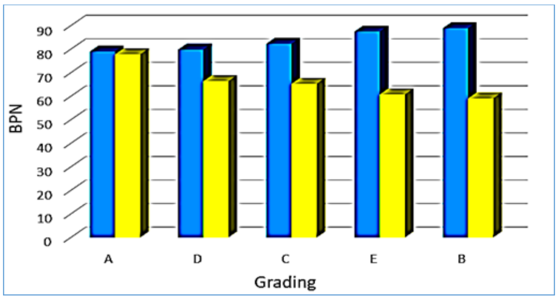


Figure 9. Results of the English pendulum test in the dry and wet condition

In the dry condition, the amount of friction decreases as the gradation thickens. As the gradation becomes larger, the surface porosity increases and the surface area of the aggregates that come in contact with the rubber or the pendulum shoe decreases, resulting in less friction and the finer the sample, the less porosity of the surface and the tire is more in contact with the aggregates and increases the friction; however, in wet conditions, the larger the texture, the greater its drainage properties, and in wet conditions, it has a more skid resistance due to the rapid drainage of water on the pavement surface. Smaller gradation, on the other hand, require longer (compared to coarse gradation) drainage due to reduced permeability after wetting the surface. In this case, the pendulum shoe is stretched on the wet surface, which has less friction. But in general, the skid resistance is less in wet mode than in dry condition.

In a study entitled “Characterization of the Skid Resistance and Mean Texture Depth in a Permeable Asphalt Pavement”, Afonso et al., found that skid resistance increases with coarser gradation and texture depth (Afonso et al., 2019). Also, in a study conducted by Mayora and Piña to evaluate the effect of the skid resistance effect on traffic safety under wet-pavement conditions, it was found that wet pavement reduces skid resistance and safety and thus increases accidents. Therefore, permeable pavements are of special importance (Mayora & Piña, 2009). The results of these studies are consistent with the results of this study.

4.3. Image Processing Results

This experiment was performed to investigate and compare the effect of porous binder gradation on the pores of the sample surface and its surface texture, on cubic samples with a fixed bitumen content of 3%, the results of which are presented in Figure 10. According to this Figure, the larger the grain size, the more pores on its surface. Because the finer the mixture, the finer the grains are placed between the coarse grains so that the empty space between them is less than the coarse grains; however, the larger the grain size, the fewer fine grains in the mixture that are placed between the large grains. As a result, there is a gap between the coarse grains, resulting in more surface pores.

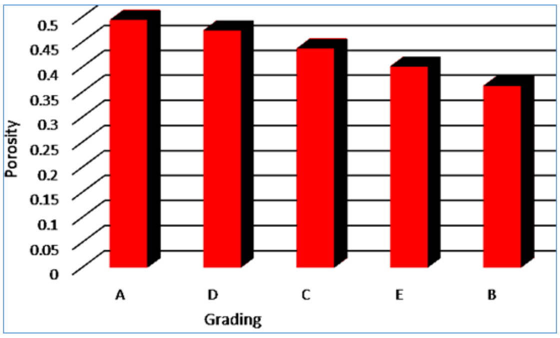


Figure 10. The amount of surface porosity of the sample resulting from image processing

Ahmed et al. in a study stating that in order to fully understand the properties of porous asphalt, research should be done from different perspectives examined the microstructural properties and performance of porous asphalt with image processing. The results show that this method is a suitable method to study porosity. Also, gradation of porous asphalt mixture has a special effect on porosity and permeability (Ahmad et al., 2019).

4.4. Image Processing Results to Investigate the Fracture of Surface Aggregates

The results of ImageJ software are shown in Figure 11; according to the presented results, because the finer the gradation, the locking and the entanglement of the aggregates are better, the angle of the aggregates on the surface is less visible and measurable. In other words, it can be said that with finer gradation and also reducing the angle and visible fractures of aggregates on the surface, the amount of surface porosity as well as permeability and evaporation decreases. It should be noted that the vertical axis of the diagram presented in Figure 11 represents the sum of the angles of the aggregates in the range specified in the surface of the porous asphalt samples and the horizontal axis represents the samples with different gradation.

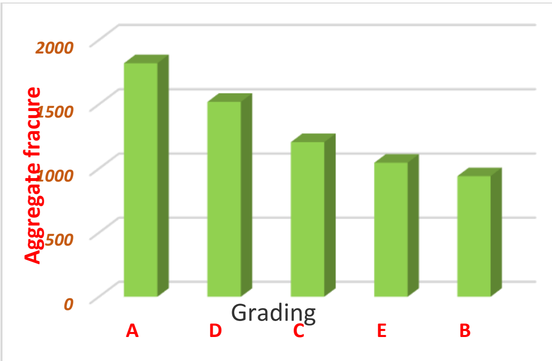


Figure 11. Image results to investigate the fracture of surface aggregates

4.5. Statistical Analysis of Results

In order to investigate the effect of surface porosity, fracture of surface rock materials and slip resistance as a surface parameter on permeability and evaporation, the relationships between surface porosity and permeability and evaporation were determined with SPSS software (Figure 12). Also, the relationships between surface porosity with the amount of friction and for different gradations with 3% bitumen were determined, which are show in Table 3 of these relationships.

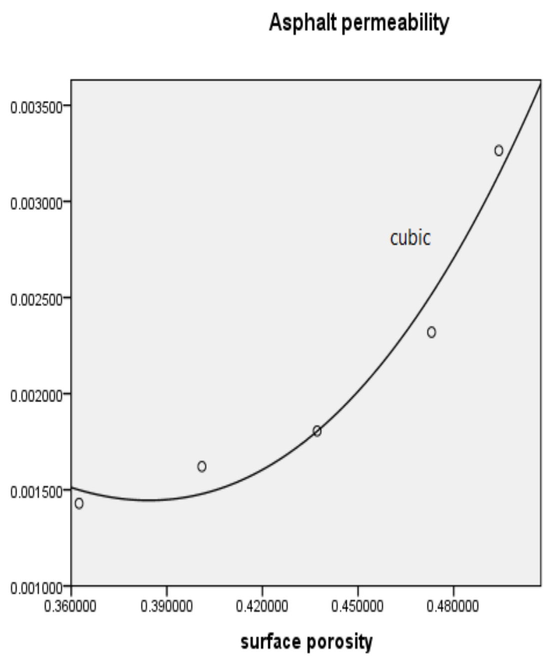
Then, with the help of Design – Expert software, three-dimensional diagrams related to the evaporation and permeability of porous asphalt were drawn, which are shown in Figure 13. Also, Equations 10 and 11, respectively, are the relationships of permeability and evaporation with the surface parameters of porous asphalt extracted from this software.

Table 3. Relationships between parameters

Independent variable	Best relation	Dependent variable	Equation	R square
Surface porosity	cubic	Permeability	$y = 0.011 - 0.03x - 0.045x^2 + 0.146x^3$	0.963
	quadratic	Evaporation	$y = 3.424 - 98.086X + 282.659x^2$	0.995
	linear	Friction (dry)	$y = 119.275 - 82.511X$	0.96
	cubic	Friction (wet)	$y = -1.7E^{-3} + 1.281E^{-4}x - 3.105E - 4x^2 + 2.511E - 4x^3$	0.897
Friction (dry)	quadratic	Permeability	$y = 0.242 - 0.006x + 3.238E - 5 * x^2$	0.884
	quadratic	Evaporation	$y = 827.443 - 17.75x + 0.96 * x^2$	0.941
Fracture of stone materials of sample surface	Permeability	quadratic	$y = 0.002 - 2.151E - 6x + 1.507E - 9 * x^2$	0.995
	Evaporation	quadratic	$y = -41.298 + 0.065x - 1.591E - 5 \times x^2$	0.941

$$\text{Permeability} = -6.6536E^{-3} - 6.0636\text{E}^{-4} \times \text{ porosity} + 6.359\text{E}^{-0.05} \times \text{ Dry friction} + 2.8284\text{E}^{-0.06} \times \text{ Angled} \quad (10)$$

$$\text{Evaporation} = -80.91 + 135.7135 \times \text{ porosity} + 0.3496 \times \text{Dry friction} + 5.781\text{E}^{-0.03} \times \text{ Angled} \quad (11)$$



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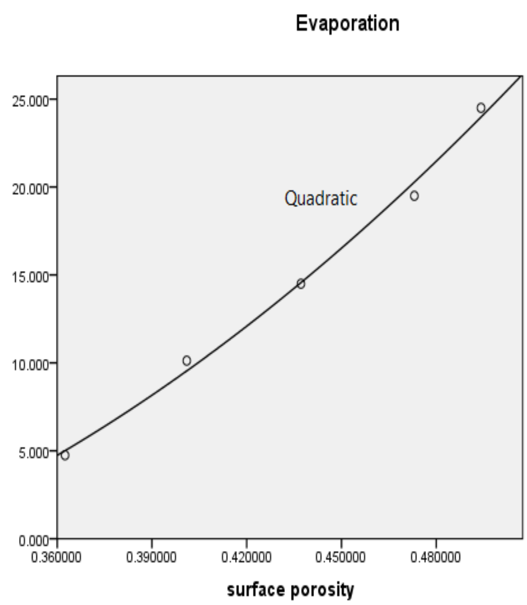

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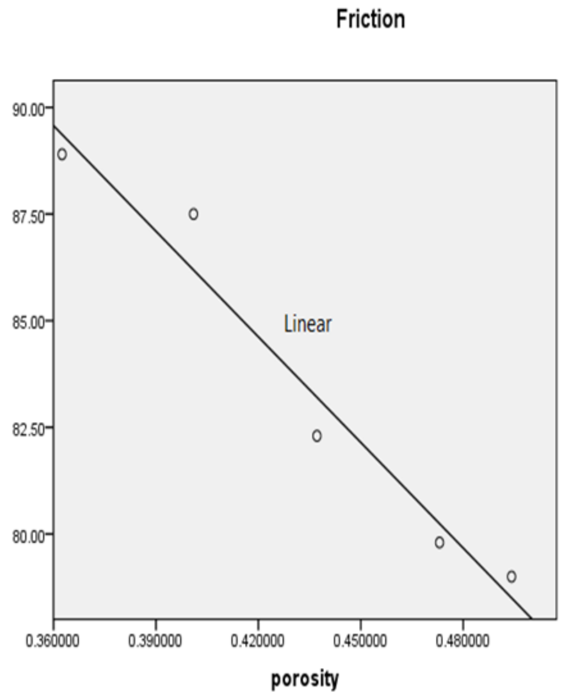

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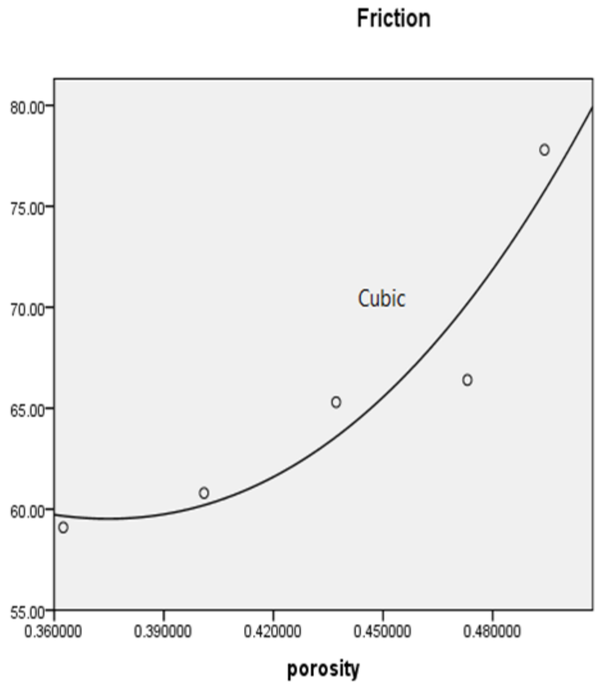

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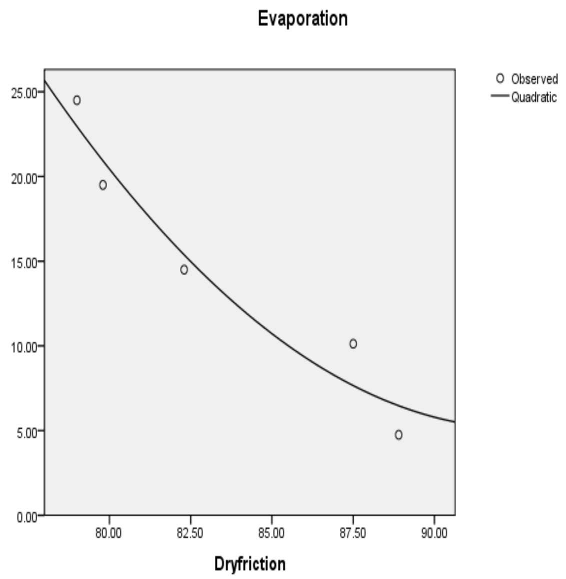
Figure 12. Diagram of different parameters in terms of surface porosity a) Permeability b) Evaporation rate c) Skid resistance in dry condition d) Skid resistance in wet condition



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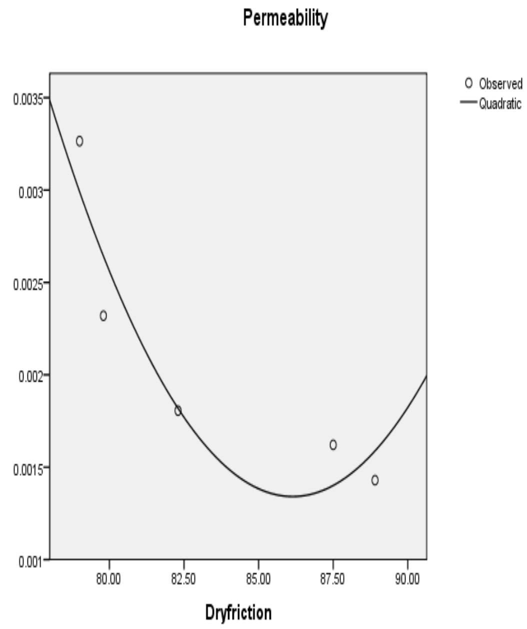

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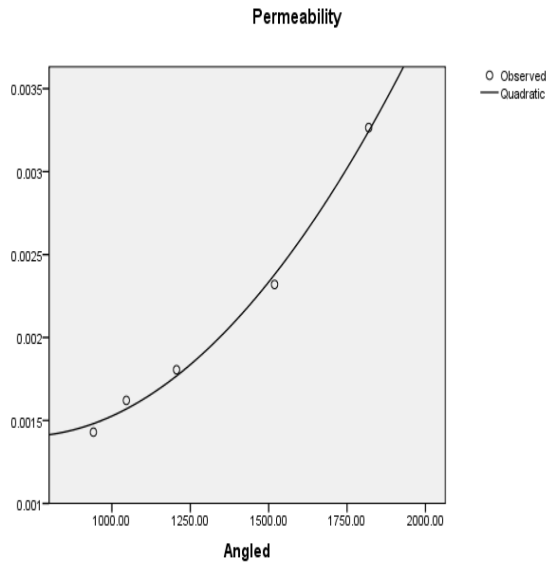
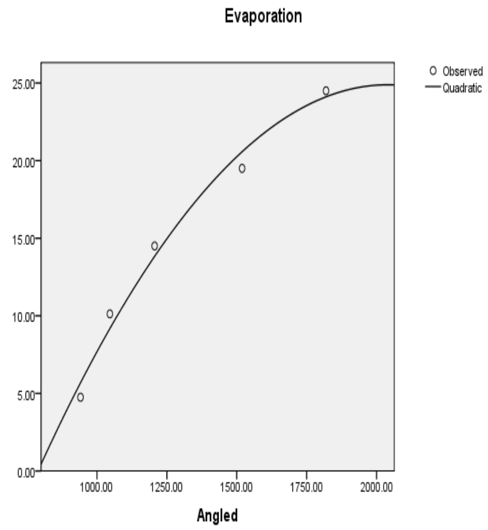
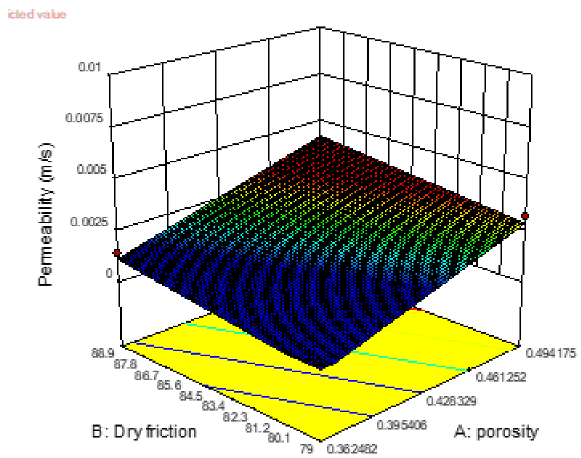


G

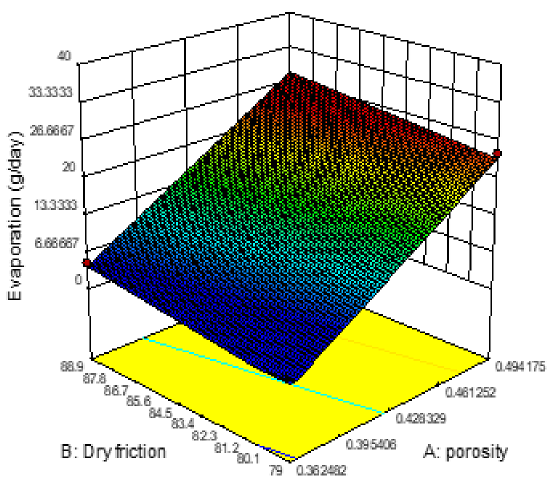


H

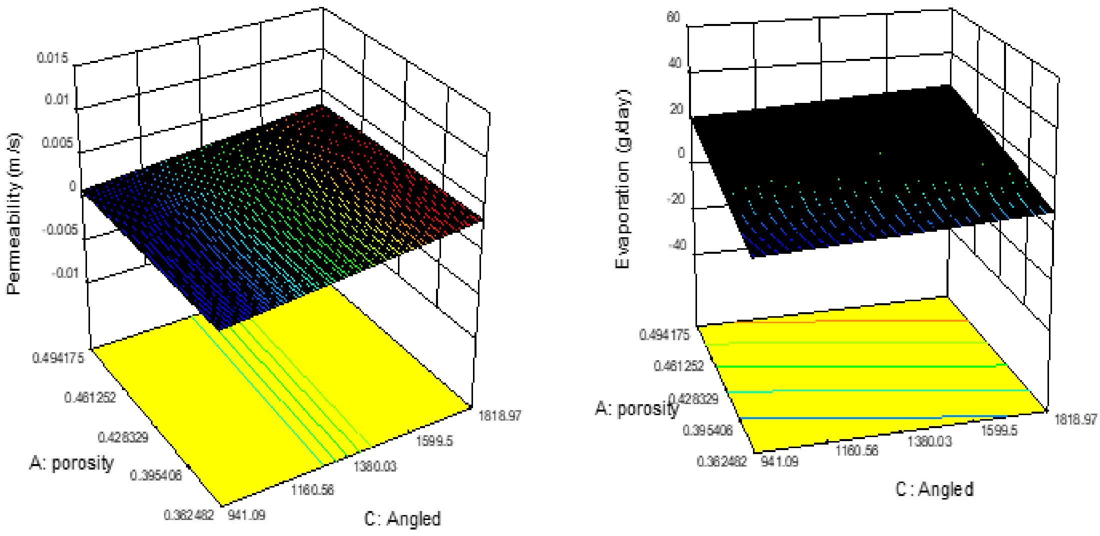
Figure 12(Continuation). e- Diagram of permeability in terms of friction f- Diagram of evaporation rate in terms of friction g- Diagram of the amount of permeability in terms of the amount of fracture of rock materials on the sample surface h- Diagram of evaporation rate in terms of fracture rate of sample rock materials



A



B



C D

Figure 13. Three-dimensional diagram of the relationship between evaporation and permeability with the surface parameters of porous asphalt

According to the presented materials, there is a significant relationship among the parameters that indicate the surface texture of porous asphalt (surface porosity and skid resistance) and the parameters of evaporation and permeability, which are the key characteristics of porous asphalt. Because evaporation and permeability measurement tests are time consuming and require a special device; the amount of evaporation and permeability of porous asphalt can be predicted by performing image processing or performing skid resistance tests, using the provided relationships.

5. Conclusion

Since today porous asphalt is known as one of the best methods of flood control and is an effective method to reduce runoff next to brick and mud structures and it can be used as a way to protect old clay and mud structures from destruction, the study of effective parameters related to two important characteristics of asphalt, namely the degree of permeability and evaporation, is of particular importance. In the present work, by making experimental samples and conducting evaporation and permeability tests innovatively, the quantity of evaporation and permeability of porous asphalt with various gradations was calculated. Then, by processing the image as well as the English pendulum device, the parameters related to the surface texture of the samples such as surface porosity and skid resistance were measured and their effect on evaporation and permeability was investigated. Fractures of porous asphalt surface aggregates were also investigated by image processing. The results of this research are as follows.

- The results of skid resistance test show that in the dry condition, the friction decreases by 11% as the gradation becomes larger, while in the wet condition, the larger the texture, the greater its drainage properties and as a result, the skid resistance increases by 32%.
- The results of image processing to investigate the surface porosity of the samples show that the larger the grain size, the greater the pores on its surface, or in other words, the greater the surface porosity, and vice versa; So that with finer gradation from gradation A to B, surface porosity is reduced by 27%.
- Also, the results of image processing to investigate the fractures of the aggregates on the surface of the samples show that with finer gradation, the angle and visible fractures of the aggregates on the surface of the sample

decreases, which decreases from A to B to 48%.

• Based on the results presented in this study, the parameters related to the surface texture of the sample have a significant relationship with the rate of evaporation and permeability of porous asphalt; therefore, since determining the permeability and evaporation of porous asphalt is time consuming and requires special equipment, with the relationships presented in this study, it is possible to estimate the permeability and evaporation of porous asphalt by measuring the parameters related to the surface texture, which are relatively easier and faster to measure.

6. Acknowledgement

This research has been carried out with the support of "Giti Gostar Khavaran Company" with contract number 05@14,9,2020, and their participation is appreciated. This article is extracted from the first author's thesis, in Yazd University, and the relevant research and laboratory managers are hereby respected. This study was conducted with the opinion and suggestion of the university professor, Zeini, to whom he is sincerely grateful.

7. References

- Aboufoul, M., Shokri, N., Saleh, E., Tuck, C., & Garcia, A. (2019). Dynamics of water evaporation from porous asphalt. Construction and Building Materials, 202, 406–414. doi.org/10.1016/j.conbuildmat.2019.01.043

- Afonso, M. L., Dinis-Almeida, M., & Fael, C. S. (2019). Characterization of the skid resistance and mean texture depth in a permeable asphalt pavement. IOP Conference Series: Materials Science and Enfile:///C:/Users/SamRayaneh/Downloads/Scholar_948.Bibgineering, 471(2), 22029. doi:10.1088/1757-899X/471/2/022029

- Ahiablame, L. M., Engel, B. A., & Chaubey, I. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. Water, Air, & Soil Pollution, 223(7), 4253–4273. doi:10.1007/s11270-012-1189-2

- Ahmad, K. A., Hassan, N. A., Abdullah, M. E., Bilema, M. A. M., Usman, N., Hainin, M. R. Bin, & others. (2019). Image processing procedure to quantify the internal structure of porous asphalt concrete. Multidiscipline Modeling in Materials and Structures, 3(7), 4253–73. doi:10.1108/MMMS-08-2017-0073

- Akhtar, M. N., Al-Shamrani, A. M., Jameel, M., Khan, N. A., Ibrahim, Z., & Akhtar, J. N. (2021). Stability and permeability characteristics of porous asphalt pavement: An experimental case study. Case Studies in Construction Materials, 15, e00591. doi.org/10.1016/j.cscm.2021.e00591

- Al-Busaltan, S., Kadhim, M. A., Nile, B. K., & Alshama, G. A. (2021). Evaluating Porous Pavement for the Mitigation of Stormwater Impacts. IOP Conference Series: Materials Science and Engineering, 1067(1), 12052. doi:10.1088/1757-899X/1067/1/012052

- Almássy, K., & Joó, A. L. (2009). Special materials in the road building--Grids and netts application terms for improving the pavement structures. Budapest Iss. 2, pp. 55–59. doi:10.14382/epitoanyag-sbcm.2009.10

- Brown, R. A., & Borst, M. (2015). Quantifying evaporation in a permeable pavement system. Hydrological Processes, 29(9), 2100–2111. doi.org/10.1002/hyp.10359

- Cheng, Y.-Y., Lo, S.-L., Ho, C.-C., Lin, J.-Y., & Yu, S. L. (2019). Field testing of porous pavement performance on runoff and temperature control in Taipei City. Water, 11(12), pp.2635. doi.org/10.3390/w11122635

- Hamzah, M. O., Samat, M. M., Joon, K. H., Muniandy, R., Tech, D., & Bangwha2-dong, G. (2004). Modification of aggregate grading for porous asphalt. Proceedings of the 3rd Eurasphaly and Eurobotume Congress, Vienna, Austria, pp.1-10.
doi: worldcat.org/isbn/9080288446

- Hu, J., Qian, Z., Liu, P., Wang, D., & Oeser, M. (2020). Investigation on the permeability of porous asphalt concrete based on microstructure analysis. International Journal of Pavement Engineering, 21(13), 1683–1693.
doi.org/10.1080/10298436.2018.1563785

- Hu, M., Sayama, T., Zhang, X., Tanaka, K., Takara, K., & Yang, H. (2017). Evaluation of low impact development approach for mitigating flood inundation at a watershed scale in China. Journal of Environmental Management, 193, 430–438.
doi.org/10.1016/j.jenvman.2017.02.020

- Jusić, S., Hadžić, E., & Milišić, H. (2019a). Stormwater management by green roof. ACTA Sci. Agric, 3, 57–62.
doi:10.14382/epitoanyag-sbcm.2009.10

- Jusić, S., Hadžić, E., & Milišić, H. (2019b). Urban Stormwater Management--New Technologies. International Conference "New Technologies, Development and Applications," 790–797.
doi:10.14382/epitoanyag-sbcm.2009.10

- Li, H., Harvey, J., & Ge, Z. (2014). Experimental investigation on evaporation rate for enhancing evaporative cooling effect of permeable pavement materials. Construction and Building Materials, 65, 367–375.
doi:10.14382/epitoanyag-sbcm.2009.10

- Ma, Y., Chen, X., Geng, Y., & Zhang, X. (2020). Effect of clogging on the permeability of porous asphalt pavement. Advances in Materials Science and Engineering, 367–375.
doi:10.14382/epitoanyag-sbcm.2009.10

- Mayora, J. M. P., & Piña, R. J. (2009). An assessment of the skid resistance effect on traffic safety under wet-pavement conditions. Accident Analysis & Prevention, 41(4), 881–886.
doi.org/10.1016/j.aap.2009.05.004

- Nazarinasab, A., Ghasemi, M., Marandi, S. (2018). Performance Improvement of Porous Asphalt Mixtures using Crumb Rubber and Steel Slag Powder. International Journal of Transportation Engineering, 6(2), 99-110.
doi: 10.22119/ijte.2017.52978

- Nonnenmacher, T. F., Losa, G. A., & Weibel, E. R. (2013). Fractals in biology and medicine. Birkhäuser, pp.881–886.

- Ren, J., Xu, Y., Huang, J., Wang, Y., & Jia, Z. (2021). Gradation optimization and strength mechanism of aggregate structure considering macroscopic and mesoscopic aggregate mechanical behaviour in porous asphalt mixture. Construction and Building Materials, 300, 124262.
doi: org/10.1016/j.conbuildmat.2021.124262

- Shah, A., Khan, H. M., & Qazi, E. U. (2013). Damage assessment of flood affected mud houses in Pakistan. Journal of Himalayan Earth Science, 46(1), 430–438.

- Shirgir, B., Mamdoohi, A., Hassani, A. (2015). Prediction of Pervious Concrete Permeability and Compressive Strength Using Artificial Neural Networks. International Journal of Transportation Engineering, 2(4), 307-316.
doi: 10.22119/ijte.2015.10444

- Singh, P., & Walia, G. (2014). Application of fractal analysis in pavement materials. Journal of Basic and Applied Engineering Research, 1, 38–42.

- Starke, P., Göbel, P., & Coldewey, W. G. (2010). Urban evaporation rates for water-permeable pavements. Water Science and Technology, 62(5), 1161–1169.

- Stoyan, D. (1979). Mandelbrot, BB, Fractals: Form, Chance, and Dimension. San Francisco. WH Freeman and Company. Zeitschrift Angewandte Mathematik Und Mechanik, 59(8), 402–403.

- Suman, S. K., & Kumar, R. (2022). Hydraulic Design of Reservoir in Permeable Pavement for Mitigating Urban Stormwater. In River Hydraulics, pp. 1–11.

- Tang, Z., Huang, F., & Peng, H. (2021). Effect of 3D roughness characteristics on bonding behaviors between concrete substrate and asphalt overlay. Construction and Building Materials, 270, 121386.
doi: org/10.1016/j.conbuildmat.2020.121386

- Tziampou, N., Coupe, S. J., Sañudo-Fontaneda, L. A., Newman, A. P., & Castro-Fresno, D. (2020). Fluid transport within permeable pavement systems: moisture loss measurement and the current state of knowledge. Construction and Building Materials, 243, 118179.
doi: org/10.1016/j.conbuildmat.2022.128342

- World Tourism Organization. (2017). 2017 Edition UNWTO. A review of evaporation processes, UNWTO Tourism Highlights, p.10.
doi:.org/10.1051/e3sconf/20199705044

- Yu, T., Zhang, H., & Wang, Y. (2020). Interaction of asphalt and water between porous asphalt pavement voids with different aging stage and its significance to drainage. Construction and Building Materials, 252, 119085.
doi:org/10.1016/j.conbuildmat.2020.119085

- Zhu, J., Ma, T., Lin, Z., Xu, J., & Qiu, X. (2021). Evaluation of internal pore structure of porous asphalt concrete based on laboratory testing and discrete-element modeling. Construction and Building Materials, 273, 121754.
doi:10.doi.org/10.1016/j.conbdmat.2021. 1.54