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Mechanical Properties of Open Graded Asphalt Mixtures with Pumice Aggregate

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ABSTRACT: Open graded asphalt is used as a wearing course to provide both increased safety in wet weather (through reduced surface water and spray during rain) and reduced noise levels. In this study, Pumice aggregates were applied as a portion of fine aggregate for the improvement of dynamical specification of porous asphalt and the Cantabro, Los Angeles abrasion, and the bitumen precipitation tests were conducted. First, the amount of optimized bitumen related to each of the three types of aggregates and fine Pumice has been estimated, then the properties of the Marshall Resistance and indirect tensile strength have been assigned. Mixtures with 5 percent of fine Pumice has shown better characteristics in Marshall test as well as indirect tensile strength. Also, the results of dynamic creep test showed that the rutting potential decreased by using Pumice aggregate. There is the best amount of permanent deformation for mixtures containing 5% Pumice.

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1- Introduction

Porous asphalt (PA) in Europe or open-graded friction course (OGFC) mixtures in the US is a special type of asphalt concrete with a porosity of up to 20%. In the rain, the water does not stay on the road surface as it flows through the pores into the drainage system. Thereby, important safety problems such as aquaplaning as well as low visibility due to splash and spray are eliminated [1]. In addition, due to its high porosity and surface texture, PA concrete is a low noise pavement reducing the initial noise emissions due to traffic in comparison to the dense surfaces by as much as 4dBA [2]. The rapid and extensive development has recently led to the construction of industrial cities and the associated network of roads [3-6]. Site planners, as well as public-works departments, are engrossed by PA pavements a lot. If we design and install PA appropriately, it can offer us beautiful and cost-effective pavements that can survive even over twenty years [7]. Compared to the conventional constructions, underlying stone beds are more expensive. However, since many elements of standard storm-water management systems are eliminated, the cost seems quite logical. Moreover, in occasions that unit costs count, PA pavement is comparably cheaper [8]. Porous pavements endure heavy traffic even after two decades and little cracking or pothole problem arises. Even the surface looks well and the rainwater is drained well after many years. Furthermore, PA helps reduce the need for storm sewer systems since it refills water tables and aquifers instead of forcing rainfall into storm sewers. In areas where storm-water impact fees are imposed by local governments, such fees may be reduced by using PA [7].

A number of studies have been found in the literature on studying the effect of using lightweight aggregate on the properties of the asphalt mixtures. Mallick et al. (2004) evaluated the use of synthetic lightweight aggregate made from waste fly ash and plastics in hot mix asphalt. The scope of this laboratory study included the preparation of aggregate blends and mixing with different percentages of synthetic lightweight aggregates, compaction of samples, testing of samples and finally analysis of results. The results indicated that the inclusion of synthetic lightweight aggregates enhances stiffness and resistance against rutting and moisture-induced damage of hot mix asphalt [10]. Awwad (2007) is directed to study the effect of replacing the conventional aggregate by the recycled lightweight aggregate concrete on the properties of hot mix asphalt [11]. Shen et al. (2008) presented the results of a laboratory study evaluating the mixture characteristics and durability of porous asphalt made with granulated synthetic lightweight aggregate (GSLA). Porous asphalt specimens incorporating 0%, 5%, 10%, 15% and 20% GLSA by volume as a coarse aggregate (retained on a No. 4 sieve) replacement were prepared. The findings showed that the samples with 15% GSLA have the best results [12]. Khan et al. (2009) in a study, investigated the use of lightweight aggregate (LWA) in hot mix asphalt and aggregate-base and sub-base layers as a strategy of reducing frost damage in pavements. The paper compares thermal conductivity, thermal diffusivity and specific heat capacity of LWA–asphalt mix with those of a conventional asphalt mix. The findings showed that the use of LWA–

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asphalt surface course and an LWA base or sub base course in a pavement will completely eliminate frost penetration into the subgrade [13]. Khan and Mrawira (2010) in another paper discussed (in the context of the larger research program) the development of an optimized design of lightweight aggregate (LWA) asphalt mix. It is has been demonstrated that because of superior insulating behavior, LWA-asphalt mix can reduce frost penetration into the underlying pavement layers. Thus, the maintenance cost associated with frost damage can be reduced. This paper presents the physical properties of LWA, the lessons learned from the mix design process, as well as the preliminary thermal and mechanical properties of the optimized LWA-asphalt mix [14].

1- 2- Problem Statement and Goals

This study examines the possibility of using Pumice in different amounts for PA. Therefore, the resilient modulus, indirect tensile fatigue, dynamic creep and indirect tensile strength ratio tests were performed on samples containing different percentages of Pumice at optimum asphalt binder.

2- Materials

Two types of aggregates are used in this research. Table 1 shows the results of chemical compositions of the Pumice aggregates. The Pumice aggregates were finer than sieve No. 4. Bitumen with 70-60 penetration grade modified with Styrene butadiene styrene (SBS) used in this study.

Table 1. Chemical composition of Pumice used in this research

Chemical	Percent	Chemical	Percent	Chemical	Percent
SiO_2	46.06	MgO	1.99	SO_3	0.03
AL_2O_3	16.57	TiO_2	0.78	Na_2O	0.69
Fe_2O_3	16.10	P_2O_5	0.21	K_2O	2.69
CaO	12.46	MnO	0.09	Total	97.66

3- Experimental Design

For making PA samples, grading for making PA was chosen according to the first mix of this study that was a PA mix (with 100% granite aggregate). The 2% and 5% of the fine Pumice are superseded for the control mix in the second and third mixes, respectively.

3- 1- Optimum Bitumen of PA

36 samples were made by bitumen between 5.5 and 7 percent for each type of PA mixture. Optimum content of bitumen was designated using the criteria of PA mixtures in these tests:

1. Drain down
2. Air void
3. Cantabro loss tests

In bitumen drain down test, the value of binder down was designated in un-compacted PA according to ASTM D6390 standard based on the following equation.

$$D = \frac{A - B}{C} \quad (1)$$

Where A is the original weight of waiter, B is the final weight of waiter, and C is the weight of asphalt mixture.

With Equation 2, the values of air void of PA mixture were calculated to determine bulk specific gravity and maximum specific gravity of asphalt samples according to ASTM D3203.

$$AirVoid = 1 - \frac{G_{mb}}{G_{mm}} \quad (2)$$

Where, G_{mb} is the bulk specific gravity and Gmm is the maximum appearance specific gravity.

To investigate the strength of aggregates against the abrasion, Cantabro Loss test was done. Los Angeles Abrasion test without using metal balls is used for this test according to ASTM C131 standard. The following equation is used to calculate the Cantabro test.

$$L = 100(\frac{A - B}{A}) \quad (3)$$

Where A is the weight of aggregate before the test, and B is the weight of the sample after the test.

3- 2- Mechanical Tests

3- 2- 1- Indirect Tensile Stiffness Modulus (ITSM) Test

Stiffness modulus test was performed by applying a linear force along the diameter axis of the specimen. Each loading cycle was 0.1 s long. Thus, the given total duration of loading and unloading is 1 s, the rest time period of each cycle is 0.9 s. In the stiffness modulus test using ITSM, the value of the stiffness modulus can be determined by applying Equation 4:

$$E_R = \frac{p(\vartheta + 0.27)}{t \times \Delta H} \quad (4)$$

Where, E_R is the stiffness modulus (MPa); p the repeated load (N); ϑ the Poisson ratio, which is assumed to be 0.35 in asphalt mixture; t the thickness of PA sample (mm); and ΔH is the recoverable horizontal deformation (mm).

3- 2- 2- Dynamic Creep Test

The dynamic creep test applies a repeated pulsed uniaxial stress on an asphalt specimen and measures the resulting deformations in the same direction using linear variable differential transducers (LVDTs). The dynamic creep test was conducted by applying a dynamic stress of 100 kPa for 1 h at 40 ºC.

3- 2- 3- Moisture Susceptibility Test (AASHTO T283)

In AASHTO T283 test, a load was applied to the specimen by forcing the bearing plates together at a constant rate of 2 in (50.8 mm) per minute, based on Equation 5:

$$S = \frac{2P}{\pi D t} \quad (5)$$

Where, P is the peak value of the applied vertical load (repeated load) (kN); t is the mean thickness of the test specimen (m); and D is the specimen diameter (m). The indirect tensile strength ratio (TSR) was determined using Equation 6:

$$TSR = 100(\frac{S_{cond}}{S_{uncond}}) \quad (6)$$

Where, S_{cond} is the average indirect tensile strength of the wet specimens, and S_{uncond} is the average indirect tensile strength of the dry specimens.

4- Results and Discussion

4- 1- Results of Optimum Bitumen

Optimum bitumen test results for PA mixtures are presented in Tables 2 to 4, including sample air void, binder drain down and Cantabro loss. For PA, the mixture, including 0, 5 and 10 percent of Pumice in order of mixture air void in the samples with of 6, 6.5 and 7 percent bitumen was in the value of 18% of the standard.

Table 2. Air void values of PA samples

Sample type		G_{mm}	G_{mb}	Bitumen content	Average of air void
Type 1	0% Pumice	2.48	1.96	5.5	21.3
Type 1	0% Pumice	2.48	2.02	6	18.2
Type 1	0% Pumice	2.425	2.05	6.5	15.7
Type 1	0% Pumice	2.39	2.08	7	12.1
Type 2	2% Pumice	2.32	1.86	5.5	20.5
Type 2	2% Pumice	2.30	1.87	6	18.8
Type 2	2% Pumice	2.29	1.87	6.5	18.30
Type 2	2% Pumice	2.27	1.85	7	17.1
Type 3	5% Pumice	2.18	1.74	5.5	20.1
Type 3	5% Pumice	2.17	1.75	6	19.5
Type 3	5% Pumice	2.156	1.76	6.5	18.3
Type 3	5% Pumice	2.14	1.76	7	16.7

The results of Table 3 show that this amount for PA with 5% Pumice in the test varies from 22.7 to 9.1% in the mixtures with 5.5 and 7% bitumen, respectively and this trend will be increased by decreasing bitumen percent. The maximum value of Cantabro loss is 18% according to the European standard. Here, samples with this criterion have 5.5 % bitumen. According to this, the amount of combined bitumen of ordinary PA should be more than 5.5%. According to the fact that the standard of Cantabro loss is 18%, the minimum amount for mixture with 5% Pumice should be more than 6%. For the mixture with 10% Pumice, the Cantabro loss varies from 28.4% to 9.1% in the samples with 5.5 and 7% bitumen, respectively. The combined bitumen should be at least 6.5% for achieving the standard of 18%.

The value of 0.3% is the acceptable amount of bitumen drain down specified by the European standard criterion. The data of Table 4 show that the minimum values of drain down test for PA are 5% bitumen and the maximum acceptable amount is 6.5% bitumen. The amount of bitumen drain down for PA of the mixture with 5% Pumice varied from 0.17 to 0.35 in the samples with 5.5 and 7% bitumen, respectively. Of course, the allowable value of bitumen percent for the standard criterion (0.3%) occurred in 6.7% bitumen. The bitumen percent for mixture with 5% Pumice varied from 0.23% to 0.45% in the sample with 5.5 and 7% bitumen, respectively. The Results show that the achieved optimum bitumen for the mixtures with 0, 5 and 10 percent Pumice were 6.5%, 7%, and 6.5%, respectively.

4- 2- Analysis of Results of Mechanical Tests

Stiffness modulus for different PA mixtures are presented in Figure 1. The values of stiffness modulus at a constant temperature for control samples (0% Pumice) were higher than the mixtures with 5 and 10 % Pumice. The data of Figure 1 show that the main reason for increasing mixture stiffness modulus is the greater adhesion between fine aggregate Pumice and bitumen in PA mixture with 5 and 10% Pumice. Also, the higher internal friction, which is due to the increased angularity of aggregate, leads to increasing the resilient modulus of PA mixtures containing different percentages of light weight aggregates. Whenever the temperature decreases, it causes a significant increase in the amount of sample stiffness modulus. At the lowest test temperature of 5 oC, the resilience is the highest, which shows the stiffest material condition under recoverable deformation behavior conditions. This causes an increasing slip in the aggregate and softening of the asphalt mixtures, whereby the resilient modulus of samples with and without Pumice declines. Also, it will be noted that the increase in the stiffness modulus would be less by decreasing temperature. Because of the high susceptibility of the bitumen to the changing of temperature, the stiffness modulus of the mixtures with and without pumice decreased at higher temperatures. This phenomenon could be explained by the viscosity of the bitumen, which increased at lower temperatures.

The results of the repeated load axial test on PA samples for determining rutting susceptibility are shown in Figures 2 to 3.

Table 3. Results of Cantabro loss test

Sample type		Bitumen content	Loss percent
Type 1	0% Pumice	5.5	22.7
Type 1	0% Pumice	6	15.6
Type 1	0% Pumice	6.5	13.4
Type 1	0% Pumice	7	9.1
Type 2	2% Pumice	5.5	31.5
Type 2	2% Pumice	6	22.1
Type 2	2% Pumice	6.5	17.7
Type 2	2% Pumice	7	11.2
Type 3	5% Pumice	5.5	28.4
Type 3	5% Pumice	6	21.7
Type 3	5% Pumice	6.5	14.7
Type 3	5% Pumice	7	9.1

Table 4. Results of binder drain down test

Sample type		Bitumen content	Drain down percent
Type 1	0% Pumice	5.5	0.26
Type 1	0% Pumice	6	0.29
Type 1	0% Pumice	6.5	0.35
Type 1	0% Pumice	7	0.43
Type 2	2% Pumice	5.5	0.17
Type 2	2% Pumice	6	0.24
Type 2	2% Pumice	6.5	0.27
Type 2	2% Pumice	7	0.37
Type 3	5% Pumice	5.5	0.23
Type 3	5% Pumice	6	0.28
Type 3	5% Pumice	6.5	0.34
Type 3	5% Pumice	7	0.37

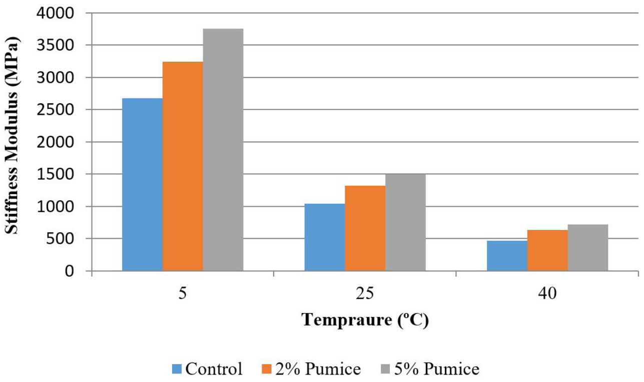

Fig. 1. Stiffness modulus with temperatures in 3 types of PA mixture

The data of Figures 2 to 3 show that the values of permanent deformation have been decreased by using Pumice. There was the lowest value of rutting susceptibility for mixtures type 2. In the mixtures, including Pumice, besides the noted reason, there was more adhesion and wettability between Pumice, which was suitable for fine aggregate with bitumen in PA mixture. Also, because PA sample with Pumice has a lower abrasion, this sample is more angular than virgin aggregate, therefore the resistance to friction in mixtures with Pumice is higher and this property decreases rutting in the pavement.
As shown in Figures 2 and 3, the mentioned factors decreased rutting susceptibility and deformation value compared with type 1 mixture.

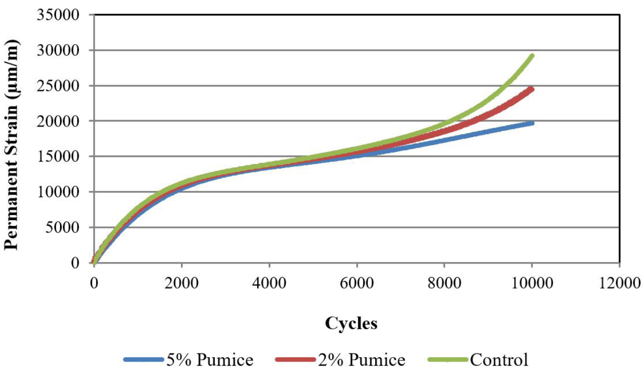

Fig. 2. The comparison of axial strain percent in PA samples (50 kPa)

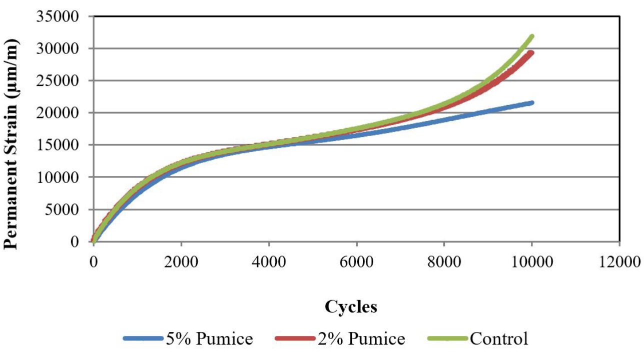

Fig. 3. The values of permanent deformation in PA samples (100 kPa)

The results of determining the moisture-induced damage of asphalt mixtures are provided in Figure 4 based on moisture sensitivity. The data presented in Figure 4 indicate that the effect of using aggregates, binders and different additives on the moisture-induced damage is sensible. Each of these components with mixture features can improve or weaken the asphalt mixture against moisture-induced damage. Although based on previous studies, the AASHTO T283 experimental procedure and indirect tensile strength ratio indicate better field results, it is clear that this test only determines the degree of asphalt mixture strength against moisture induced damage. The results cannot be used without previous and similar studies about the role of asphalt binder, aggregates, additives and percentage of additive or important properties such as permeability in the determination of failure mechanisms and causes of high strength or weakness of asphalt mixtures on moisture sensitivity or it would be possible to provide solutions to improve moisture resistance of asphalt mixtures. Also, other factors such as differences in the degree of water acidity in various projects even with the same materials may change the type of required additive. Since this index is the indirect tensile strength in wet to dry conditions, it is expected that the measure is less than 100 kPa due to the degradation of adhesion properties of asphalt binder and asphalt binder-aggregate.
The data of Figure 4 show that mixture with 10% Pumice had the best values of tensile strength ratio after 1 freeze-thaw cycle. In mixtures with 5 and 10% light weight aggregate, the suitable compatibility of bitumen and Pumice caused a great thickness of bitumen film over the aggregate surface. The higher film of bitumen in the mixtures containing light weigh aggregate itself is an important reason against moisture sensitivity. Also, light weight aggregate is a basic aggregate; thus stripping of bitumen from the aggregate surface does not occur easily in the presence of moisture. TSR of the control mixtures (without Pumice) containing granite is greater than mixtures containing Pumice, which leads to a better resistance against moisture damage. Considering that Pumice has less SiO_2 compared to granite, this causes a reduction in the bond between asphalt and aggregate. Thus, using Pumice is more effective in mixtures containing an acidic aggregate.

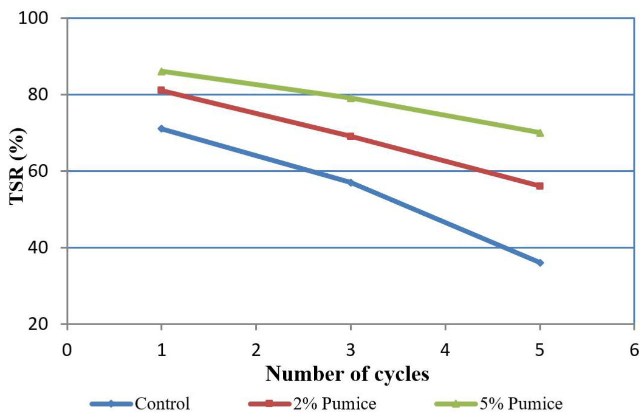

Fig. 4. The results of moisture susceptibility test

5- Conclusion

In this study, the effect of adding light weigh aggregate as a part of aggregate was investigated for increasing stiffness modulus, resistance against permanent deformation and moisture damage of PA mixture. The specific results of this study are:

- The porous surface of light weight aggregate leads to absorbing more bitumen than granite aggregate and this event causes a the higher value of optimum bitumen content for the PA mixture containing Pumice aggregates.
- The mixtures containing Pumice aggregate has a higher stiffness modulus than control mixtures. Porous asphalt mixture type 2 had the best values of stiffness modulus. Permanente deformation as an index to evaluate rutting sensitivity of PA showed that mixtures with 5% Pumice had the best performance against the permanent strain.
- The Results of modified Lottman tests showed that mixtures with 10% Pumice had the higher strength against the moisture damage test.
- According to the results of this research, it can be seen that the use of Pumice has been able to improve the characteristics of asphalt mixture such as resilient modulus, rutting and moisture damage. Accordingly, the investigation of the effect of this material on other performance properties of the asphalt mixture such as fatigue cracking and thermal cracking is suggested. The field performance of this material can be tested in the pilot form in small projects. In the case of confirmation of laboratory results, it can be used as an alternative to a part of the aggregate in asphalt mixture plants.

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