EFFECTS OF DIATOMITE AS FILLER ON THE POROUS ASPHALT MIXTURES PROPERTIES

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Abstract: Diatomite is a kind of mineral containing high amorphous silica content which is a very durable substance. Due to its useful characteristics such as lightweight, high porosity, high surface area, low density and high absorptive capacity, diatomite is identified with potential to be used as a filler to improve the performance of asphalt mixture. Porous asphalt is known to have poor strength and durability due to its open structure and high air void contents which exposed the structure to air and water. These factors may influence the adhesive strength of binder-aggregate and lead to cohesive failure within the binder film, which contribute to stripping and moisture damage. The addition of fillers has been identified to improve the adhesion and cohesion properties by stiffening the asphalt binder and enhance the bonding strength between aggregate and binder. Therefore, this study was undertaken to evaluate the potential of diatomite as filler in porous asphalt mixtures and compared with ordinary Portland cement. Field Emission Scanning Electron Microscopy (FESEM) was conducted to investigate the microstructure of the fillers. The compacted samples of porous asphalt mixture with Malaysian aggregate gradation were prepared using Superpave gyratory compactor at the target air voids content of 21%. Each sample was incorporated with 2% of filler and polymer modified binder of PG76 as a binder. The sampleswere then tested for abrasion loss, resilient modulus and indirect tensile strength. The test results show that the samples prepared with diatomite havelower abrasion loss compared to those with cement. Besides, the samples incorporating diatomite show enhanced resilient modulus and indirect tensile strength. Thus, these indicate that the diatomite filler has good potential to improve resistance to stripping and moisture damage compared to cement.

Keywords: *Diatomite, cement, filler, porous asphalt, binder, stripping.*

1.0   Introduction

Diatomite is a kind of non-metallic mineral material mainly composed of the skeletons of microscopic single celled aquatic plants called diatoms. The skeletons are high in natural amorphous silica content (SiO_2), a very durable substance (Ibrahim, 2012). Diatom skeletons are highly porous, light in weight, low density, chemically stable and inert (Degirmenci and Yilmaz, 2009), has high absorptive capacity and insulating ability (Ibrahim and Selim, 2011), and also high viscosity additives. Besides, the use of diatomite as a filtration aid has been identified to be useful as a self-cleaning agent in removing the clogging materials that clogged up the void spaces in porous sphalt such as clay (Abdullah *et al*., 2016). Most importantly, the use of diatomite in asphalt binder has shown the improvement on the physical and rheological properties of modified asphalt. Cong *et al*. (2012) indicated that the diatomite modified asphalt binder improved the viscosity and resistance to deformation at high temperature. In addition, Li *et al.* (2011)investigated the use of diatomite as the filler in porous asphalt mixtures and resulted in better interface adhesion, and low temperature cracking resistance. On this basis, the diatomite is seen to have potential to be used as filler in porous asphalt and the extension of the study is necessary.

Porous asphalt has been used widely due to its ability to allow rainwater to drain quickly from the pavement surface through its pore structure. Due to this ability, porous asphalt is used in wearing courses with approximately 50 mm thick and placed over the existing conventional asphalt surface as a possible solution for road safety improvements in wet conditions and reduction of traffic noise. In terms of safety benefits during rain events, porous asphalt was acknowledged to reduce splash and spray due to rapid dry surfaces, minimize the risk of hydroplaning and wet skidding, thus improves night visibility (Putman and Kline, 2012). Porous asphalt is designed with open-graded aggregate gradations that consists of a large proportion of coarse aggregates with a limited amount of fine aggregates to create larger quantities of interconnected voids of more than 18 percent to allow water to penetrate through the voids (Alvarez *et al*., 2010; Cetin, 2013; Hassan *et al*., 2014). Despite its safety and environmental benefits, the performance and service life of porous asphalt can be affected by the poor structural durability. It can be expected that the life of a porous surface is shorter than a conventional asphalt surface due to deterioration by runoff, air infiltration, subsequent stripping and oxidation, as well as hardening of binder (Scholz and Grabowiecki, 2007). On the other hand, the open gradation and high air void content lead the porous asphalt mixture to poor durability due to less stone-on-stone contact caused by the inappropriate gradation and low density in porous asphalt mixture, which result to a lower performance than normal dense-grade mixture (Putman and Kline, 2012). Moreover, the open structure that facilitates water drainage had exposed the pores of porous asphalt to air, water and clogging materials that eroded the binder film and eventually affect the strength of the binder-aggregate bonding (Aman *et al*., 2014). Specifically, in tropical country like Malaysia which experiences frequent high rainfall intensity will expose the porous

structures to water induced problems. Also, the issues of high traffic impact stress due to the rapid development in the infrastructure and road construction give a profound effect on the durability of porous asphalt layer which enhance the deterioration of the asphalt pavement.

These factors cause loss of bonding in binder-aggregate system as a result of adhesive and cohesive failures in porous asphalt, thus leading to stripping which contribute to deterioration in the performance and service life of pavement. Stripping failure is defined as the separation or detachment of the aggregate and asphalt binder due to the loss of adhesion between these two materials usually in the presence of moisture, typically accompanied by gradual loss of strength over the years, which causes distress manifestations like raveling, rutting, shoving, corrugation and cracking (Haghshenas *et al*., 2015; Xiao and Amirkhanian, 2010). Recently, many types of additive have been used as mineral filler in improving the performance of hot mix asphalt pavements to various distresses. The addition of filler can positively affect the overall mixture performance by improving the aggregate-binder bonding and minimizing moisture-related problem (Chuanfeng *et al*., 2013). Hydrated lime is the most commonly used additive in asphalt pavements and it has been proved by Jahromi (2009) that the use of hydrated lime improves adhesive effects and reduces the water-induced problem of the asphalt mixture. Ordinary Portland cement also has the potential to be used as additive but there is limited research regarding the use of cement as filler in asphalt mixtures (Huang *et al*., 2010). Therefore, this study evaluates the effect of using diatomite as filler on the properties of porous asphalt through abrasion loss, resilient modulus and indirect tensile strength and compared with ordinary Portland cement.

2.0   Experimental Program

2.1   Materials

The crushed granite aggregate used in this experiment was supplied by Hanson Quarry Products in Kulai, Johor. The gradation limit of the combined aggregate for porous asphalt was selected according to the Standard Specification for Porous Asphalt, Public Works Department, Malaysia (PWD, 2008), as presented in Figure 1. In this study, the aggregate gradation employed for porous asphalt mixture was Grading B with nominal maximum aggregate size of 14 mm.
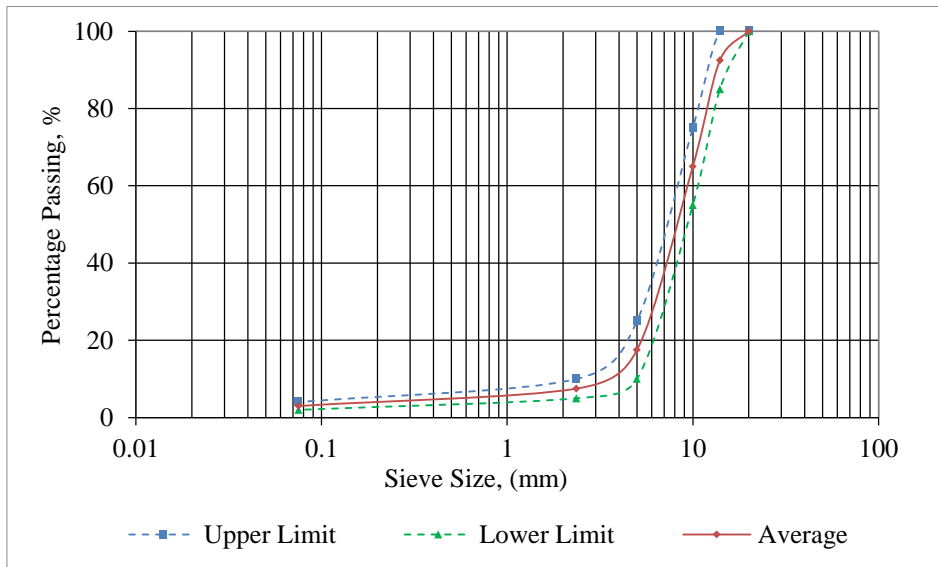
Figure 1:Plotted Malaysian gradation limits for porous asphalt

The aggregate was tested for specific gravity and water absorption. Polymer modified binder, PG76 was used as a binder for the mix design and sample preparation as recommended by PWD (2008). PG76 is very suitable to be used for efficient performance of porous asphalt mix as it is modified with polymer and exhibits outstanding high viscosity property. The properties for aggregates and binder used in this study are presented in Table 1.

Table 1: Materials Properties

Materials	Properties	Value
Coarse aggregate	Specific Gravity Bulk	2.695
	Specific Gravity Saturated Surface Dry (SSD)	2.709
	Specific Gravity Apparent	2.733
	Water Absorption (%)	0.520
Fine aggregate	Specific Gravity Bulk	2.427
	Specific Gravity Saturated Surface Dry (SSD)	2.477
	Specific Gravity Apparent	2.554
	Water Absorption (%)	2.048
Asphalt binder PG76	Viscosity at 135°C	2.8 Pa.s
	Penetration at 25°C	38.6 dmm
	Softening Point	60°C
	Specific Gravity at 25°C	1.030

Two types of filler were selected for comparison i.e. diatomite and ordinary Portland cement, which passing 75 µm sieve size. The diatomite was supplied from I-Chem Solution Sdn Bhd, Selangor, Malaysia. The physical and chemical properties of diatomite are shown in Table 2 as reported by the supplier. The result shows that the diatomite contains a high content of silica (SiO_2) and other components such as aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) are mainly little. Besides, it can be seen from the table that the specific gravity of diatomite is about 2.20 in average, whilst the specific gravity of ordinary Portland cement is known to be higher which is 3.20.

Table 2: Properties of diatomite

Chemical composition (%)		Physical properties	
SiO_2	90.3	Color	White
Al_2O_3	3.8	PH	9-10
Fe_2O_3	1.3	Specific gravity	2.1-2.3
CaO	0.3	Bulk density	0.35
MgO	0.3		
Na_2O	3.1		
LOI	0.5		

2.2   Mixture Design and Sample Preparation

The design binder content of the porous asphalt mix was determined by the average of the upper limit from the binder draindown test and lower limit from the Cantabro test results as well as the target air void content of 21%. The 21% air void content was selected to prevent over-compaction on the samples particularly for samples with diatomite filler so that the number of gyrations obtained would not exceed the maximum compaction of 75 gyrations as recommended in the Superpave system. The binder draindown test is used to quantify the sufficient quantity of bitumen film thickness to coat the aggregate particles. While Cantabro test is used to evaluate the mixture's resistivity against stripping or aggregate loss. Therefore, the binder contents used for mixture with diatomite and cement were 5.25% and 5% respectively. The Superpave gyratory compactor was used to produce compacted cylindrical samples of 100 mm diameter and thickness of approximately 50 mm, with 725 g of blended aggregate.The samples were mixed at the temperature of 180°C and the loose mixtures were then conditioned in an oven for 2 hours at the compaction temperature of 170°C to allow the asphalt binder absorption into the aggregate. The machine was set at a loading pressure of 600 kPa and an external angle of gyration of 1.25°. A few compaction trials were conducted at various numbers of gyrations i.e. 20, 40, 60 and 80 to determine the desired number of gyrations. As shown in the Figure 2, the number of gyration to achieve the target of 21% air voids content is 58 and 45 gyrations for diatomite and cement accordingly. Both materials were added for 2% by mass of total aggregates as a part of mineral filler.
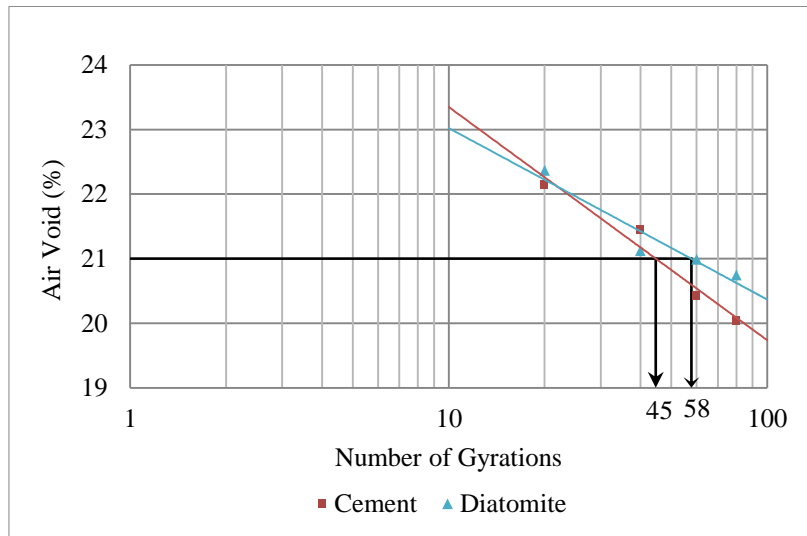
Figure 2: Determination of gyration number

2.3   Laboratory Tests

2.3.1   Field Emission Scanning Electron Microscope (FESEM)

The investigation on the surface texture for both types of filler was conducted using the Field Emission Scanning Electron Microscope (FESEM). The test gives the images of the sample surface by scanning it with a high energy beam of electrons in a raster scan pattern. In addition, the test generates an image of the sample at the micro-scale in order to study their microstructural properties. The samples of filler powder were prepared in a small quantity and sputtered with a thin layer of carbon or metallic coating to make the surfaces conductive.

2.3.2   Cantabro Test

Cantabro test was conducted to determine the resistance of compacted specimens to stone loss. This test was carried out using Loss Angeles abrasion machine without the steel balls and rotated 300 times at 25°C.   The abrasion loss was calculated by the percentage of weight loss using the following equation (Eq. 1):

$$L = (M_1 - M_2 / M_1) \times 100 \tag{1}$$

where M_1 and M_2 are the initial and final weight of test specimen respectively, and L is the percentage of abrasion loss.

2.3.3   Resilient Modulus Test

In this study, the Resilient Modulus Test of bituminous mixtures was performed in accordance with ASTM D4123 (ASTM, 2005). Resilient modulus is a non-destructive test which measures the material stiffness under different conditions such as temperature or moisture, density and load level. It is also can be defined as the ratio of the applied cyclic stress to the recoverable (elastic) strain after many cycles of repeated loading. The test was conducted at temperature of 25°C (± 1°C), at a loading frequency of 0.5 and 1 Hz for each test temperature as well as the load duration of 0.1second. It applies compressive loads with a haversine waveform. The load was applied vertically in the vertical diametric plane of a cylindrical specimen. The resulting horizontal deformation of the specimen was measured and, with assumed Poisson's ratio was used to calculate the resilient modulus. The total resilient modulus was automatically computed from the machine using the total recoverable deformation, which includes both the instantaneous recoverable and the time dependent continuing recoverable deformation during the unloading and rest-period portion of one cycle.

2.3.4   Moisture Susceptibility Test

The evaluation of compacted bituminous mixture to moisture susceptibility was done using the modified Lottman method according to AASHTO T283 (AASHTO, 2007). Two subsets of samples were fabricated with each subset consists of three samples and divided into dry subset and moisture conditioned subset. The dry or control subsets (unconditioned) were left at 25°C in an incubator for two hours before testing. The wet subsets (conditioned) were preconditioned by vacuum saturation for approximately 15 minutes to achieve a saturation level between 55% and 80%. After saturation, the samples were wrapped in leak proof plastic bags containing 10 ml of water. Consequently, the samples were placed in a freezer at a temperature of -18°C for 16 hours, followed by immersion of the samples in a water bath at 60°C for 24 hours. Prior to indirect tensile testing, the conditioned samples were placed in water bath at 25°C for another 2 hours. The indirect tensile strength (ITS) test was performed according to the ASTM D6931 (ASTM, 2012). In this test, a loading rate of 50 mm/min was applied using a Marshall loading machine with steel loading strips. The maximum load was recorded and the tensile strength of asphalt mixture was calculated using Eq. 2:

$$ITS = 2000F \, / \, \pi hD \qquad\qquad (2)$$

where ITS is the indirect tensile strength (kPa), F is the maximum load (N), h is the height of the specimen (mm) and D is the diameter of the specimen (mm).

The ITS values for unconditioned and conditioned samples were then used to calculate the Tensile Strength Ratio (TSR) values which indicate the resistance of an asphalt

mixture to moisture damage (Ahmad *et al*., 2014). The TSR value is calculated using Eq. 3:

$$TSR = (ITS_{wet} / ITS_{dry}) \times 100 \tag{3}$$

where TSR is the tensile strength ratio (%), ITS_{wet} is the average of ITS of moisture-conditioned subset (kPa) and ITS_{dry} is the average ITS of dry subset (kPa).

3.0   Results and Discussion

3.1   FESEM Analysis

The comparison of the macro texture between ordinary Portland cement and diatomite is shown in Figure 3. From the figure, it can be seen that these fillers are very different to each other. The figure shows that the texture of cement appears to be more dense and compact with its minerals attached to each other. In contrast, the particles of diatomite present the microscopic porous structure which can be seen clearly as a single grain structure. The microscopic porous structure of diatomite shows that it has high surface area which led to the increase in binder content due to its high absorptive capacity (Shukry *et al*., 2016).
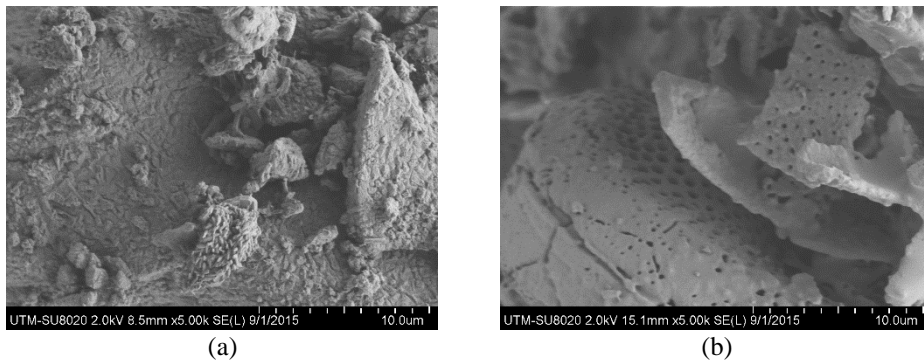

(a)   (b)

Figure 3: FESEM images at 5000× magnification of(a) Cement and (b) Diatomite

3.2   Abrasion Loss

The resistance to particle losses was analyzed using Cantabro test. This test was carried out to assess the bonding properties between aggregate and bitumen. The result for abrasion loss is shown in Figure 4. From the figure, it can be observed that the abrasion loss of samples prepared with diatomite is 27.9% which is lower than the samples incorporating cement with the abrasion loss of 33.2%. This might be due to the higher binder content of mixture with diatomite compared to the mixture with cement. According to Suresha *et al*. (2010), the mixtures with higher binder content will result in

lower abrasion loss because of thicker binder films which provide the greater adhesion between the coated aggregate particles and enhance the chemical bonding between aggregate and binder in asphalt mixture.In addition, the lower abrasion loss indicates that the samples possess better cohesion and resistance to raveling which contribute to the higher durability of the mixture (Rodriguez-Hernandez *et al.*, 2015).
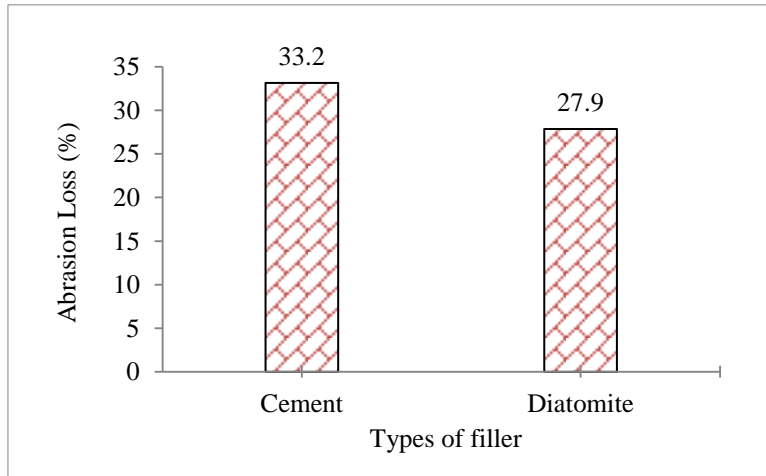

Figure 4: Abrasion Loss

3.3   *Resilient Modulus*

Figure 5 shows the result obtained from the resilient modulus test. In this study, the resilient modulus was measured at 25°C, 30°C and 35°C. It can be seen that the resilient modulus value for all types of filler decrease as the temperature increase from 25°C to 35°C. As the temperature increases, the resilient modulus values drop from 1483 MPa to 539 MPa for mixtures with cement and 2079 MPa to 854 MPa for mixtures with diatomite.The results show that the mixture with diatomite has the highest resilient modulus compared to the mixture with cement at all temperatures. Therefore, it can be concluded that the diatomite enhances the stiffness of the porous asphalt mixture and least susceptible to the temperature changes compared with the mixture containing cement.This might be caused by the different binder content of diatomite mixtures where the binder adhesion also has a significant effect on the resilient modulus. As the optimum binder content of diatomite mixture is slightly higher, the mixture has enough binder content that can improve the inter-aggregate adhesion and causes smaller recoverable strain (Hamzah and Yi, 2008).
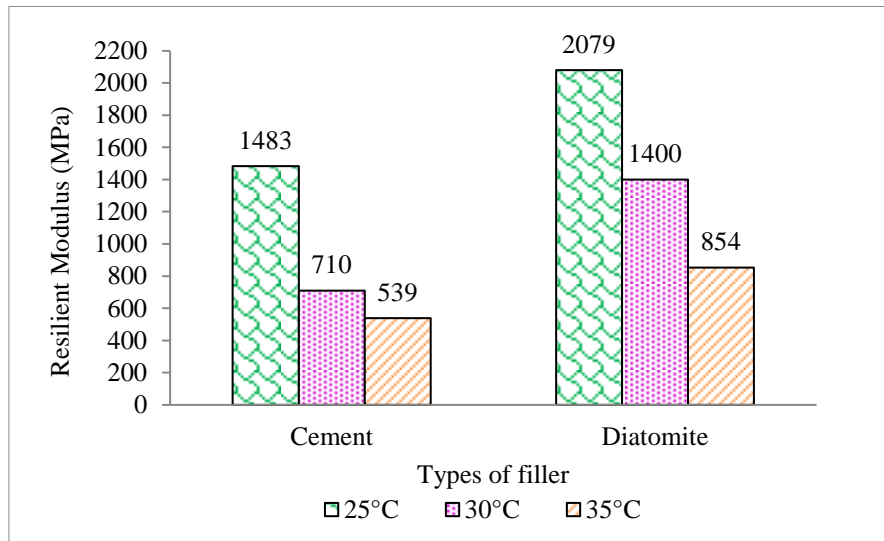
Figure 5: Resilient Modulus result

3.4   *Indirect Tensile Strength*

Table 3 summarises the result of indirect tensile strength for both unconditioned (dry) and conditioned samples as well as the values of tensile strength ratio. As shown in Figure 6, it can be observed that the indirect tensile strength for conditioned samples is lower than those for unconditioned samples. This indicates that deterioration has occurred in the mixtures and it proves that moisture conditioning has a significant effect on reducing the tensile strength of the mixtures. In addition, the result also shows that the mixture containing diatomite exhibits significantly higher indirect tensile strength value for both conditions than the mixture containing cement. Therefore, it can be concluded that the usage of diatomite shows better resistance to stripping and less susceptible to moisture damage compared with those with cement.

The tensile strength ratio (TSR) result shows that the mixture prepared with diatomite has slightly higher TSR value of 91.9% compared to the mixture prepared with cement which is 90.6%. This difference may be attributed by the fact that the amount of design asphalt binder used in preparing mixture with diatomite was higher than those prepared using cement. Diatomite has a porous structure and high surface area which provides such a huge amount of pore to adsorb the asphalt binder and results in an asphalt binder with a stiffer consistency (Chen *et al*. 2010). Consequently, it improves the cohesive strength and the adhesive bonding between asphalt and aggregate, and hence increases the resistance to moisture damage due to stripping. However, it should be noted that the minimum requirement of 80% for TSR value has been specified for Superpave mix design in AASHTO T283. The results show that all mixtures demonstrate higher TSR

values which are greater than 80%. This proves that cement also has a good potential to provide resistance against moisture susceptibility within asphalt mixture (Behiry, 2013).

Table 3: ITS and TSR results for each types of mix with different filler types

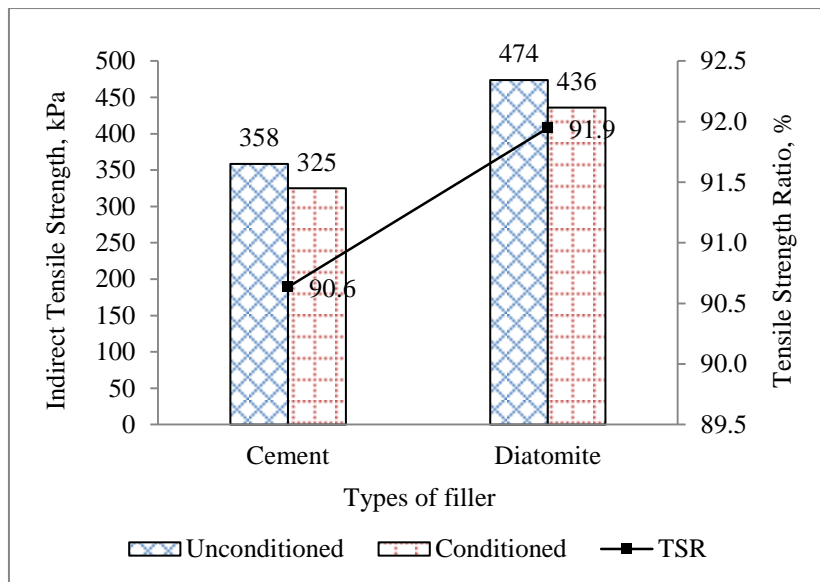| *Types of filler*	*Indirect Tensile Strength (kPa)*		*Tensile Strength Ratio (%)*
	Unconditioned	*Conditioned*	
Cement	358	325	90.6
Diatomite	474	436	91.9

Figure 6: Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) results

4.0   Conclusions

From the study, it can be concluded that, the porous structure of diatomite has contributed to the increase in the design binder content. Furthermore, samples with diatomite have better tensile strength, resilient modulus and resistance against abrasion compared to samples with cement. This finding also implies that mixtures with diatomite exhibit better resistance to moisture damage than mixture with cement. Therefore, diatomite is seen to have potential to be used as filler in porous asphalt.

5.0 Acknowledgements

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