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Evaluation of Fracture Properties of One and Two-Layer Porous Asphalt Subjected to Clogging

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ABSTRACT

An important requirement for asphalt mixtures is its fracture resistance that would influence the service life, maintenance and management of the pavement networks. Clogging may affect the fracture resistance of porous asphalts. In this paper, One-layer and Two-layer porous asphalt specimens were fabricated using conventional and modified binders. Specimens were conditioned under laboratory-simulative clogging process at different temperatures. The semi-circular bending test was used to characterize the fracture resistance of porous asphalts subjected to these clogging procedures. One-way ANOVA and general linear model were applied to analyse the test results statistically. The analyses indicated that clogging significantly affects fracture toughness, maximum load, and displacement of porous asphalts. In addition, mix type (One and Two-layer porous asphalt) and asphalt binder type have significant effects on the fracture resistance.

1. Introduction

In porous asphalt (PA), the high percentage of air voids allows debris and other materials to penetrate into the open structure. Therefore, clogging is one of the major problems that disrupt its air voids continuity, thus leading to permeability loss and increased sound production. Suresha *et al.,* [1] investigated the effects of clogging materials and aggregate gradations on the clogging permeability of PA. Aggregate gradation was found to affect mixture permeability. Chue *et al.,* [2] evaluated the mix design parameters on the noise properties of PA and found that clogging of pores significantly reduces the sound absorption capacity of the mixtures. Garcia *et al.,* [3] studied the effects of the air void topologies on the clogging ratios of PA. It was reported that tortuosity and macro porosity do not exhibit significant effect on the clogging properties of PA.

Recently, the idea of the Two-layer porous asphalt (TLPA) was conceived to minimize the effect of clogging on the permeability and sound reduction of PA. Hamzah *et al.*, [4] evaluated the clogging

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permeability of one-layer porous asphalt (OLPA) and TLPA in a laboratory simulated condition. The TLPA specimens were found to better resist clogging compared to OLPA specimens. Afonso *et al.*, [5] investigated the hydrological performance of TLPA. Their results showed that the type of clogging cycles and materials significantly affects the infiltration capacity of TLPA. Chu and Fwa [6] evaluated the drainage capacity and sound absorption of single and double layer porous asphalts. It was found that OLPA shows better drainage properties while TLOP exhibits better noise properties.

Fracture resistance of an asphalt mixture significantly influences the service life of the pavement networks. Pavement distress such as longitudinal cracking, thermal cracking, and reflective cracking can be related to the fracture properties of asphalt mixtures. The approach of fracture mechanics has been adopted to explore the properties in asphalt mixtures. It has become increasingly popular amongst the research community since the late 1980s [7]. Fracture testing methods of hot mix asphalt include Single-Edge Notched Beam [8-10], Indirect Tensile fracture parameter [11-12], Disc-Shaped Compact Tension [13-14] and Semi-Circular Bending [15-16] tests. The Semi-Circular Bending (SCB) test is popular among asphalt researchers due to the ease of sample preparation from gyratory compacted cylinders or field cored samples [17-21].

The fracture resistance of OLPA and TLPA is not much investigated. Therefore, the SCB test configuration has been adopted in this study to evaluate the fracture resistance of OLPA and TLPA. The major advantages of the SCB test include the simple geometry of the specimens, little machining operations, ability to conduct the fracture toughness tests in full range, application of compressive loads as opposed to tensile loads, easy set-up procedure, and the ability to prepare specimens from typical pavement cores. Figure 1 shows a flow chart depicting the evaluation of fracture resistance of one and two-layer porous asphalts under clogging condition using the SCB test.

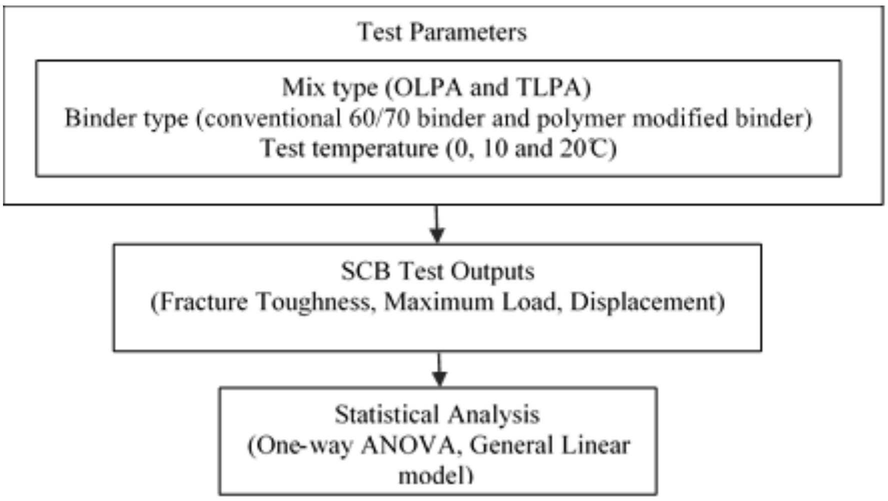


Fig. 1. Research plan

2. Methodology

2.1 Materials and Mixtures Type

Two binder types were used in this study namely; conventional 60/70 penetration grade and a polymer modified binder with high temperature performance grade of 76°C. These binders are designated as 70 and 76, respectively. Both binders were supplied by Shell Ltd. The binder properties are shown in Table 1.

Table 1
Properties of binders used

Properties	Binder	
	Conventional binder (70)	Modified binder (76)
Viscosity at 135°C (Pa.s)	0.594	2.65
Softening Point (°C)	52	66
Penetration (0.1 mm)	63	48
Ductility (cm)	>100	83
Specific gravity (gr/cm^3)	1.03	1.055

The crushed granite aggregate used was supplied by a local quarry. Table 2 presents its physical properties. The aggregate gradations for top and bottom layers of TLPA are shown in Figure 2. The aggregate gradation for top layer was used as the gradation of OLPA. A 20 mm top layer thickness was selected for TLPA specimens, while the total height for OLPA and TLPA mixtures were fixed at 70 mm. Hydrated lime was used as filler. Four binder contents ranging from 4.3% to 7.3% were incorporated.

Table 2
Physical properties of aggregate used

Properties	Value
Flakiness Index %	18.1
Elongation Index %	18.4
Aggregate Crushing Value (ACV) %	17.9
Los Angeles Abrasion Value (LAAV) %	20.1

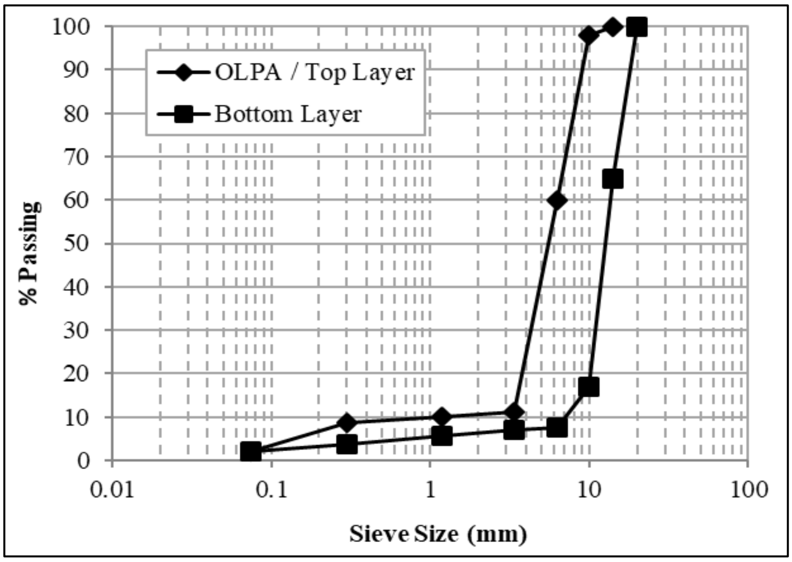


Fig. 2. OLPA and TLPA gradations

2.2 Sample Preparation

The preparation method for OLPA and TLPA specimens followed the procedure described by Hamzah and Hardiman [22]. The TLPA specimens have a top layer thickness of 20 mm. The required quantity for the bottom layer mixture was placed first inside the Marshall mould, followed by the top layer mixture. The mixture was then compacted at 50 blows per face in the normal way. The compaction method attempted to simulate the hot-on-hot method used to compact the TLPA on

Dutch highways. The average air voids of OLPA and bottom layer of TLPA are 19% and 24%, respectively. Cylindrical specimens, OLPA and TLPA, were prepared by incorporating two binder types. To evaluate the effects of temperature, selected fresh specimens were conditioned at 0, 10, and 20°C in an incubator to maintain the specimens' temperature at the test temperature of the SCB test. Some specimens were then clogged in the laboratory according to the method described by Hamzah *et al.,* [4]. Clogging was conducted using a falling-head water permeameter. Selected clogged specimens were tested using the SCB test at 0°C. The test parameters and the designations of the specimens are summarised in Table 3. The parameters evaluated include mixture type, binder type, and test temperature.

Standard Marshall specimens were used for the SCB. The thickness of both fresh and clogged specimen was cut to (50±3) mm and the top and bottom surfaces was ensured flat and parallel before cutting it into two equal halves. A vertical notch was cut at the centre of the halved specimens. The notch dimensions are 3.5±0.1 mm wide and 10±1 mm in height. Metal bearing strips were glued to the bottom of the specimen where it rested on the rollers. Figure 3 shows the specimens prepared for the SCB test.

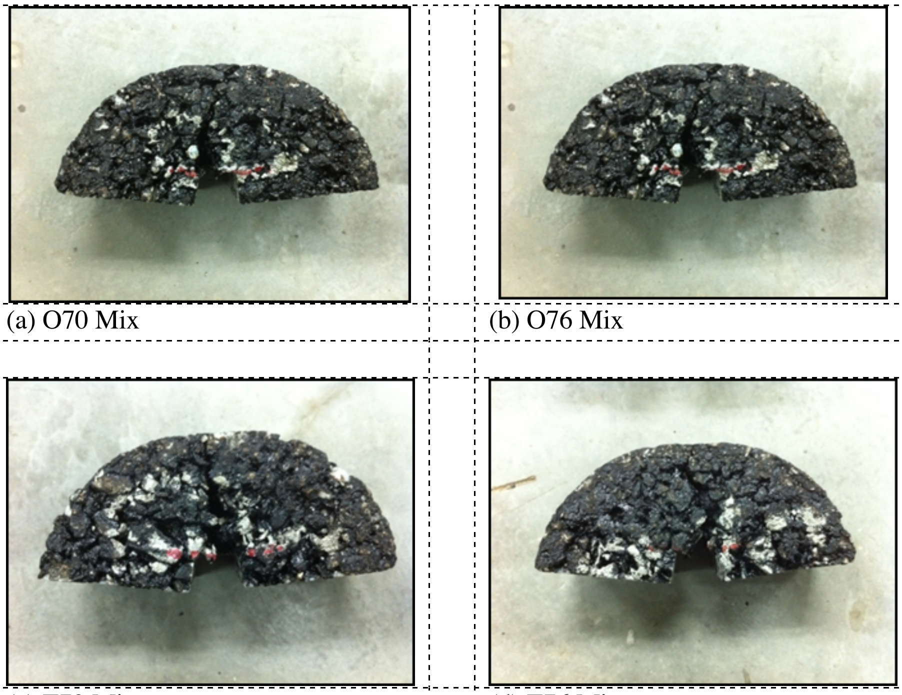
Table 3
Test parameters and specimen designation

Tests Parameters	Details			
Mix Type	OLPA		TLPA	
Binder Type	Conventional binder (70)		Modified binder (76)	
Test Temperature for Fresh Specimens	0, 10, 20 (°C)			
Test Temperature for Clogged Specimens	0 (°C)			
Designations for Specimens	O70	O76	T70	T76

Fig. 3. Specimen prepared for SCB test

2.2 Semi-Circular Bending Test

The test specimens were placed in an environmental chamber corresponding to the test temperatures for at least 4 hours prior to testing. The specimen was then placed on the testing rig and a vertical load was applied on top of the specimen at 5.0±0.2 mm/min. The vertical force and displacement obtained from the test were recorded. A valid test is obtained if the crack path took place within ±10 mm from the centre of the loading strip which is equal to 10% of the diameter of the specimen. A valid zone is necessary to eliminate the possibility of having a large variation of test results. The procedure was repeated if the crack ended outside the valid crack zone. This test was carried out on at least 4 samples at 0, 10, and 20°C. Figure 4 illustrates the condition of the specimens after testing at 0°C. Specimens tested at 0°C produces a clearer view of the crack propagation compared to specimens tested at higher temperature. Therefore, clearer crack propagation can be better viewed when specimens are tested at 0°C and below.



(a) O70 Mix (b) O76 Mix

(c) T70 Mix (d) T76 Mix

Fig. 4. Fresh specimens tested at 0°C

Based on the maximum load, $F_{max,i}$, and vertical deformation, ΔW_i, obtained from the plot, the strain at the maximum force $\varepsilon_{max,i}$, can be calculated using Eq. (1).

$$\varepsilon_{\mathrm{max,i}} = \frac{\Delta \mathrm{W}_i}{W_i} \times 100\% \quad (1)$$

where, W is the height of specimen (mm) and ΔW_i is the vertical displacement (or displacement) at maximum force of specimen (mm).

The maximum stress at failure, $\sigma_{max,i}$, is calculated using Eq. (2).

$$\sigma_{\mathrm{max,i}} = \frac{4.263 \times \mathrm{F}_{max,i}}{D_i \times t_i} N/mm^2 \quad (2)$$

where D is the diameter of specimen (mm), t is the thickness of specimen (mm) and $F_{max,i}$ is the maximum force of specimen (N).

The fracture toughness, $K_{lc,i}$ of the specimen is then calculated using Eq. (3).

$$K_{\mathrm{lc,i}} = \sigma_{\mathrm{max,i}} \times f\left(\frac{a_i}{W_i}\right) \mathrm{N/mm}^{3/2} \quad (3)$$

where W_i is the height of specimen (mm), ai is the notch depth of specimen (mm), $\sigma_{max,i}$ is the stress at failure of specimen (N/mm^2) and $f(a_i/W_i)$ is the geometric factor of specimen. Rounded to three digits.

Eq. (4) was used to calculate the geometric factor $f(a_i/W_i)$:

$$f\left(\frac{a_i}{W_i}\right) = -4.9965 + 155.58\left(\frac{a_i}{W_i}\right) - 799.94\left(\frac{a_i}{W_i}\right)^2 + 2141.9\left(\frac{a_i}{W_i}\right)^3 - 2709.1\left(\frac{a_i}{W_i}\right)^4 + 1398.6\left(\frac{a_i}{W_i}\right)^5 \qquad (4)$$

Finally, the fracture toughness, K_{Ic}, of the mixture was calculated as an average of the $K_{Ic,i}$ values using Eq. (5).

$$K_{\mathrm{Ic}} = \frac{\sum_{i=1}^{4} K_{\mathrm{Ic,i}}}{4} \mathrm{N/mm}^{3/2} \qquad (5)$$

3. Results

Typical plots showing the relationship between load and load line displacement for specimens tested at three temperatures are shown in Figure 5. All mixtures showed similar change in behaviour with temperature and loading. At high temperature, PA mixtures are more ductile and have lower peak loads and larger displacements. At low temperature, mixtures are brittle and have high peak loads, and small deformation ability. At intermediate temperature, mixtures exhibit an intermediate behaviour. Fracture toughness is calculated for all mixtures and all temperatures using Equation 5 displayed in Section 2.3. Analyses were performed to evaluate the effects of different mixture types and testing conditions on mixtures' cracking resistance.

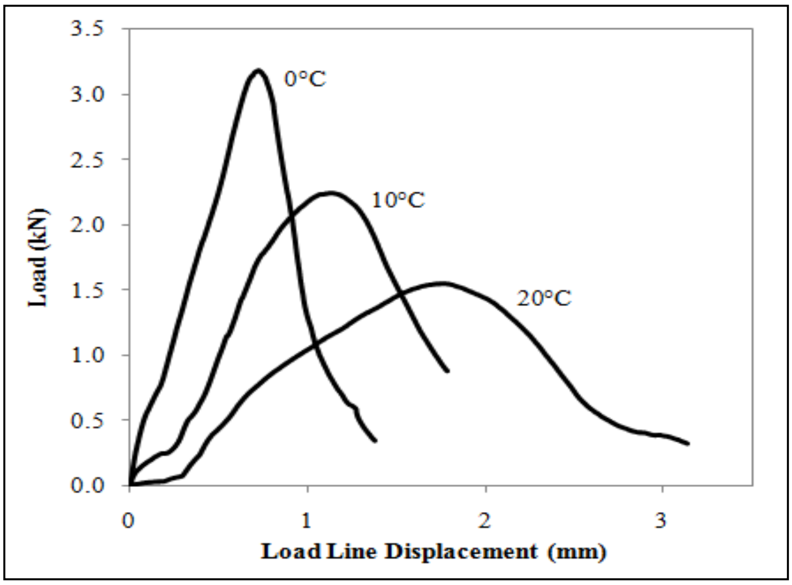


Fig. 5. Typical plot of loading versus displacement

3.1 Effects of Temperature

The results for fracture toughness, maximum load and displacement at three temperature levels are shown in Figure 6. It is shown that lower temperature registers higher fracture toughness and maximum load. For instance, at 0°C, T76 registers 24 N/mm3/2 and 3.7 kN for fracture toughness and maximum load, respectively. Meanwhile, similar sample registers 12.5 N/mm3/2 and 1.9 kN, respectively at 20°C. As the testing temperature increases, the fracture toughness and maximum load decreases significantly. At 10°C, the highest fracture toughness is shown by O76 (21.8 N/mm3/2) mix while T70 (14.4 kN) exhibits the lowest fracture toughness. The graph slopes downwards as the testing temperature increases. This trend is also similar for maximum load. As for displacement, the displacement is smaller at the lowest testing temperature. The displacement increases as the temperature increases. This is due to the rheological behaviour of the binder at different temperatures.

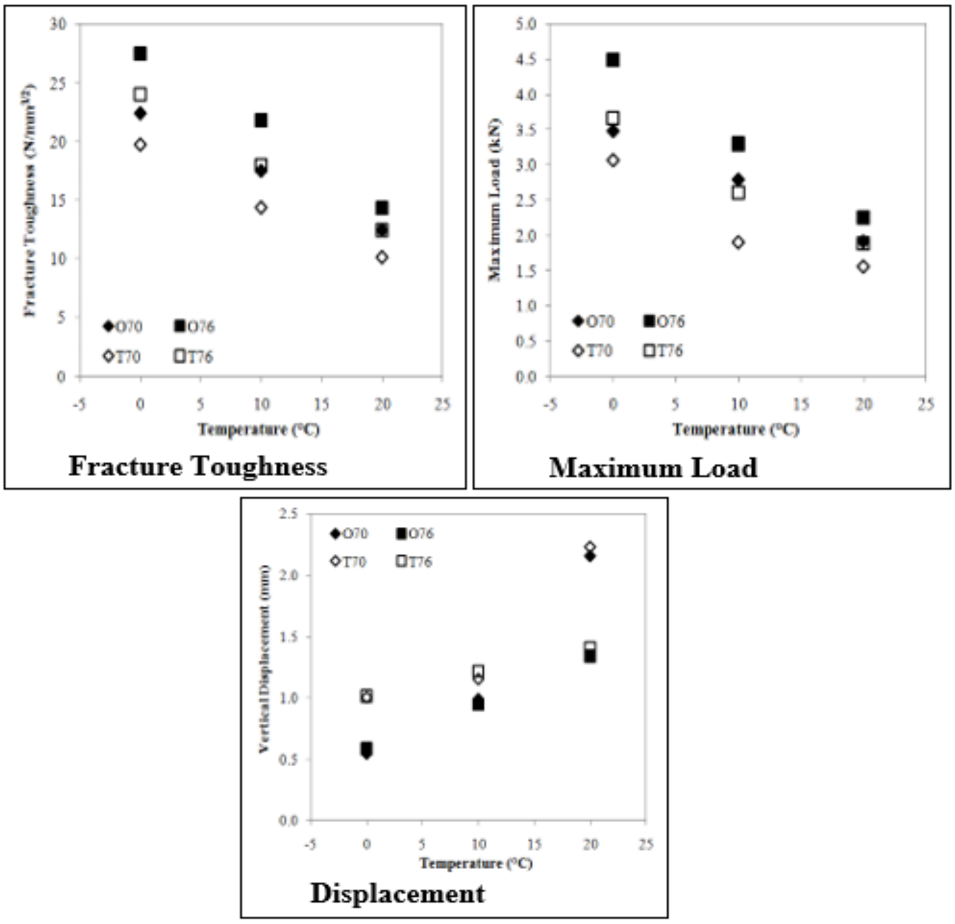


Fig. 6. Effects of temperature on fracture toughness, Maximum load and displacement

The results were statistically analysed to ascertain the effects of temperature on fracture toughness, maximum load, and displacement of PA. One-way Analysis of Variance (ANOVA) was used to analyse the results and shown in Table 4. The analyses indicate that temperature significantly affect the fracture toughness, maximum load, and displacement of PA with p-values less than 0.05.

3.2 Effects of Mix Types

Figure 6 also shows the effects of mix type on the fracture toughness, maximum load, and displacement. OLPA specimens generally exhibit higher fracture toughness than TLPA mixes. For instance, at 0°C, 070 registers 22.4 N/mm3/2 compared to T70 with 19.8 N/mm3/2 which is a 12.3% difference between the two mixes. This indicate that OLPA are more resistant to cracking than TLPA. This is related to the air voids of each mixes. The air voids in OLPA are significantly lower than TLPA specimens. Therefore, more strain energy or driving force is required to break a more compacted asphalt mixture. According to Harvey and Tsai (1996), lower air voids creates a more homogenous aggregate asphalt structure with fewer, smaller, and better-distributed voids, resulting in less stress concentration at large voids. In addition, the displacement is higher at low temperature and decreases as the test temperature increases.

One-way ANOVA was carried out to determine the significance of mix type effects. The results shown in Table 5 indicate that mix type significantly affect all PA properties with p-values less than 0.05.

Table 4
One-Way ANOVA on effect of temperature

Source	DF	SS	MS	F	p-value
Effect of Temperature on Fracture Toughness					
Temperature	2	147.60	73.80	28.32	0.001
Error	6	15.64	2.61		
Total	8	163.23			
Effect of Temperature on Maximum Load					
Temperature	2	3.7119	1.8559	23.62	0.001
Error	6	0.4714	0.0786		
Total	8	4.1832			
Effect of Temperature on Displacement					
Temperature	2	4.1666	2.0833	27.36	0.001
Error	6	0.4569	0.0762		
Total	8	4.6235			

Table 5
One-Way ANOVA on effect of mix types

Source	DF	SS	MS	F	p-value
Effect of Mix Type on Fracture Toughness					
Mix Type	1	10.414	10.414	14.90	0.018
Error	4	2.795	0.699		
Total	5	13.209			
Effect of Mix Type on Maximum Load					
Mix Type	1	0.2415	0.2415	10.01	0.034
Error	4	0.0965	0.0241		
Total	5	0.3380			
Effect of Mix Type on Displacement					
Mix Type	1	0.3209	0.3209	19.37	0.012
Error	4	0.0663	0.0166		
Total	5	0.3871			

3.3 Effects of Binder Types

There is an increasing trend to adopt modified binder to improve the properties of asphalt mixes [23]. The properties comparison between OLPA and TLPA mixes incorporating modified and base binders are also shown in Figure 6. At the 0°C, OLPA mixes made with modified binder exhibit higher fracture toughness (27.5 N/mm3/2) than OLPA mixes with base binder (22.4 N/mm3/2). The maximum load graphs illustrate a similar trend to the fracture toughness plot where O70 and O76 registers 3.5 kN and 4.5 kN, respectively at 0°C. Modified binder improves the maximum load attained by the specimens. As for displacement, an obvious difference is seen at the highest temperature (51% difference) while there is no significant difference at the lowest (6.8% difference) and intermediate (5% difference) temperatures. According to Li and Marasteanu, mixtures with modified binder were found to have significant higher fracture toughness than mixtures with base binder, especially at lower temperatures. Polymer modified binders have higher flexibility at lower temperatures [23].

Table 6
One-Way ANOVA on effect of binder type

Source	DF	SS	MS	F	p-value
Effect of Binder Type on Fracture Toughness					
Binder Type	1	39.43	39.43	29.49	0.006
Error	4	5.35	1.34		
Total	5	44.78			
Effect of Binder Type on Maximum Load					
Binder Type	1	1.5586	1.5586	129.60	0.001
Error	4	0.0481	0.0120		
Total	5	1.6067			
Effect of Binder Type on Displacement					
Binder Type	1	1.009	1.009	8.19	0.046
Error	4	0.493	0.123		
Total	5	1.502			

Table 7
GLM on the effects of mix type (MT), binder type (BT), and temperature (T)

Source	DF	SS	MS	F	p-value
Effect of MT, BT and Temp on Fracture Toughness					
MT	1	91.713	91.713	41.28	<0.001
BT	1	136.345	136.345	61.37	<0.001
T	2	738.132	369.066	166.13	<0.001
MT * BT	1	2.321	2.321	1.04	0.317
MT * T	2	8.687	4.343	1.96	0.163
BT * T	2	15.186	7.593	3.42	0.049
MT * BT *T	2	3.849	1.924	0.87	0.433
Error	24	53.319	2.222		
Total	35	1049.550			
Effect of MT, BT and T on Maximum Force					
MT	1	2.0880	2.0880	29.50	<0.001
BT	1	2.1073	2.1073	29.78	<0.001
T	2	19.6198	9.8099	138.61	<0.001
MT * BT	1	0.0342	0.0342	0.48	0.493
MT * T	2	0.1016	0.0508	0.72	0.498
BT * T	2	0.4754	0.2377	3.36	0.052
MT * BT * T	2	0.5925	0.2962	4.19	0.028
Error	24	1.6986	0.0708		
Total	35	26.7174			
Effect of MT, BT and T on Displacement					
MT	1	0.53778	0.53778	9.02	0.006
BT	1	0.61884	0.61884	10.38	0.004
T	2	6.29857	3.14929	52.83	<0.001
MT * BT	1	0.00160	0.00160	0.03	0.870
MT * T	2	0.21254	0.10627	1.78	0.190
BT * T	2	1.39217	0.69609	11.68	<0.001
MT * BT * T	2	0.00905	0.00452	0.08	0.927
Error	24	1.43067	0.05961		
Total	35	10.50122			

One-way ANOVA was carried out to ascertain the effects of binder type on PA mix's performance. In Table 6, the analyses indicate that binder types significantly affect the fracture toughness, maximum load, and displacement of PA with p-values less than 0.05.

A general linear model (GLM) analysis was performed on the mixes to evaluate the effects of each factor and the interaction effects of these factors on fresh PA mixes properties. A p-value less than 0.05 indicates significant factor. Table 7 shows that mix type, binder type, temperature and the interaction between binder type and temperature have significant effects on the fracture toughness of fresh specimens. The interaction factor between mix type and binder type, mix type and temperature, and the interaction of all three factors show no significant effect on fracture toughness. The most significant factor found to affect fracture toughness, maximum load and displacement of fresh specimens is temperature. This is shown by the highest F value obtained. The next significant factor is binder type, followed by mix type which has the least effect on fracture toughness, maximum load and displacement. This is because viscosity of binder changes with temperature.

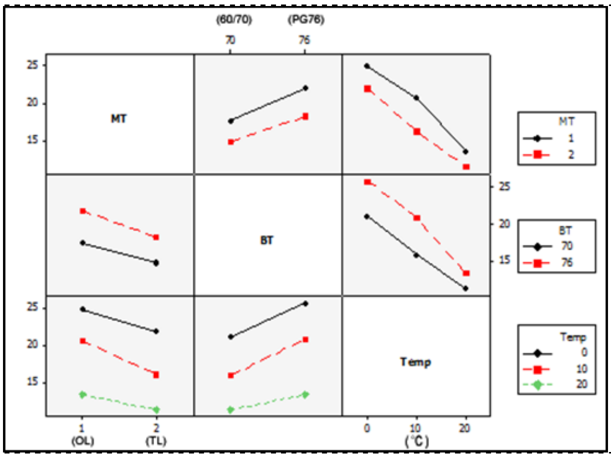


Fig. 7. Interaction plot for fracture toughness

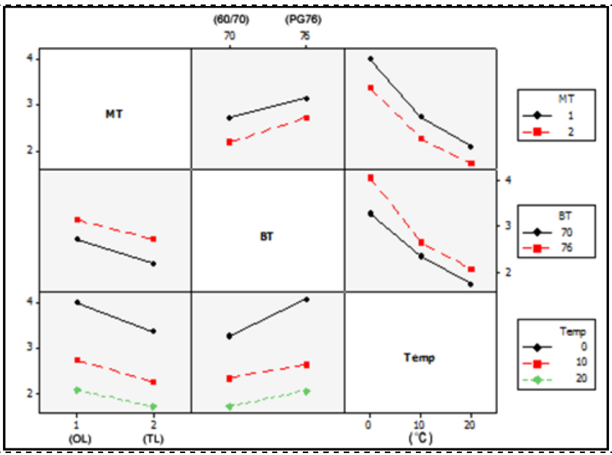


Fig. 8. Interaction plot for maximum load

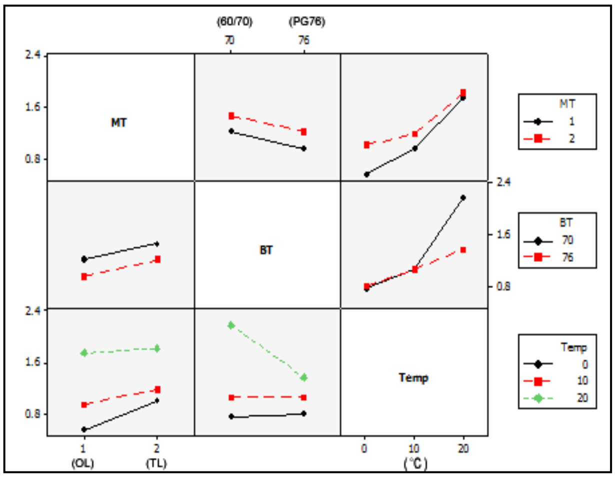


Fig. 9. Interaction plot for displacement

The interaction between mix type and binder type, mix type and temperature, and binder type and temperature show no significant effect on the maximum load of fresh specimens. Meanwhile, mix type, binder type, temperature, and the interaction between the three prove to have significant effect on the maximum load. In addition, the three single factors and the interaction between binder type and temperature are found to have significant effects on the displacement of fresh specimens while interactions between mix type and binder type, mix type and temperature, and interactions between the three have no significant effects. Figures 7 to 9 graphically show the interaction plots between mix type (MT), binder type (BT), and temperature (Temp) for fracture toughness, maximum load, and displacement, respectively.

3.4 Effects of Clogging

SCB test was carried out on fresh specimens (FS) and clogged specimens (CS) subjected to 10°C, 30°C, and 50°C clogging test. The entire specimens were tested at 0°C. The results are compared and shown in Figures 10 to 12. In Figure 10, CS subjected to low and high clogging temperatures exhibit lower fracture toughness compared to FS. For instance, O70 registers 19.3 N/mm3/2 at 10°C clogging temperature whereas FS specimens registers 22.4 N/mm3/2. On the other hand, CS at ambient clogging temperature generally register higher fracture toughness (31.91 N/mm3/2 for O76) compared to FS (27.53 N/mm3/2). CS clogged at higher temperature were expected to have the highest fracture toughness and maximum load due to higher aging rate but the results shows otherwise. This may be due to the clogged material that interrupts the original structure of the mix and had altered the gradation during conditioning at higher clogging temperature.

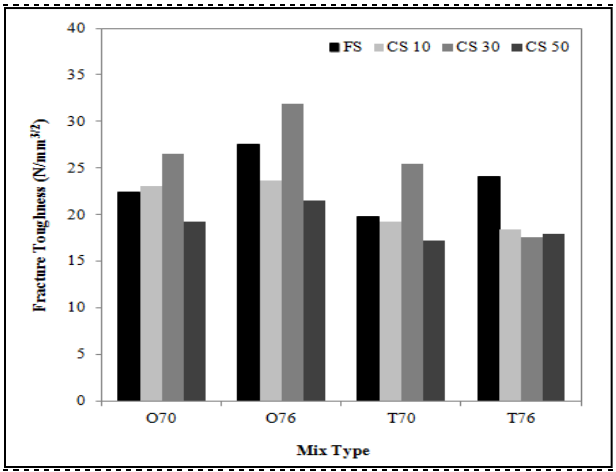


Fig. 10. Effects of clogging on fracture toughness

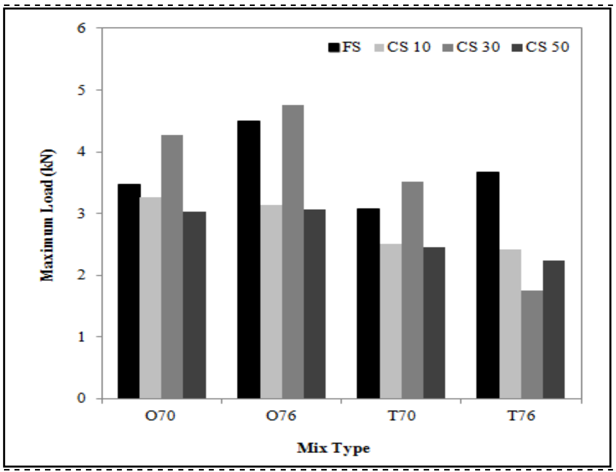


Fig. 11. Effects of clogging on maximum load

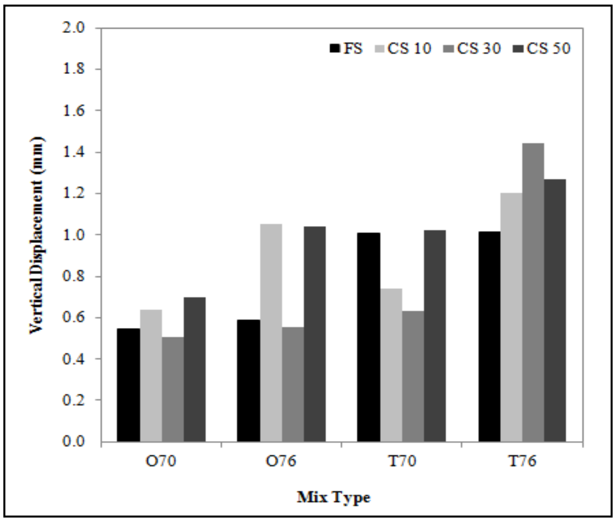


Fig. 12. Effects of clogging on displacement

In Figure 11, the trend for maximum load is similar to the trend obtained for fracture toughness. Generally, CS clogged at ambient temperature registers higher maximum load while CS clogged at the highest temperature exhibit the lowest maximum load. Meanwhile, the displacement shown in Figure 12 is higher for CS clogged at 10°C (1.05 mm for O76) and 50°C (1.04 mm for O76) compared to FS. CS clogged at ambient temperature (0.56 mm for O76) recorded a lower value compared to FS (0.59 mm for O76).

The data was further analysed using ANOVA to determine the effects of clogging on PA mix's performance. The results in Table 8 indicate that clogging significantly affects the fracture toughness, maximum load, and displacement of PA with p-values less than 0.05.

Table 8
One-Way ANOVA on effects of clogging

Source	DF	SS	MS	F	p-value
Effect of Clogging on Fracture Toughness					
Clogging	3	84.378	28.126	72.34	<0.001
Error	8	3.110	0.389		
Total	11	87.489			
Effect of Clogging on Maximum Load					
Clogging	3	4.8105	1.6035	71.91	<0.001
Error	8	0.1784	0.0223		
Total	11	4.9889			
Effect of Clogging on Displacement					
Clogging	3	3.5236	1.1745	35.10	<0.001
Error	8	0.2677	0.0335		
Total	11	3.7913			

A GLM analysis was performed to determine the effects of mix type, binder type, clogging temperature, and the interactions between mix type and binder type, mix type and clogging temperature, binder type and clogging temperature, and the interactions between the three factors. The results summarized in Table 9 shows that the p-value indicates significant effects of all three single factors and the interactions between two and all three factors on the fracture toughness of CS. Similar trend is shown by the three factors and their interactions on the maximum load of CS. Only binder type has no significant effects on the maximum load of CS. Clogging and cleansing cycles had exposed the binders to air and water that oxidizes and made the binders stiff. Therefore, different binder type shows no significant effects on maximum load. The analyses on displacement also carry a similar trend to fracture toughness and maximum load but only the interaction between mix type and clogging temperature exhibit no significant effects on displacement. The GLM analyses shows that mix type, binder type, clogging temperature, and the interactions between most of the factors have significant effects on the fracture toughness, maximum load, and displacement of CS compared to FS. The most significant factor affecting fracture toughness, maximum load and displacement is mix type. This is shown by the highest F value, followed by clogging temperature and binder type. Figures 13 to 15 graphically illustrate the interaction plots of the three factors on CS's properties.

Table 9
GLM on effects of mix type (MT), binder type (BT), and clogging temperature (CT) on CS

Source	DF	SS	MS	F	p-value
Effect of MT, BT and Temp on Fracture Toughness					
MT	1	244.126	244.126	189.52	<0.001
BT	1	16.415	16.415	12.74	0.001
CT	3	276.504	92.168	71.55	<0.001
MT * BT	1	56.355	56.355	43.75	<0.001
MT * CT	3	45.460	15.153	11.76	<0.001
BT * CT	3	60.841	20.280	15.74	<0.001
MT * BT * CT	3	81.768	27.256	21.16	<0.001
Error	32	41.219	1.288		
Total	47				
Effect of MT, BT and Temp on Maximum Force					
MT	1	10.4160	10.4160	207.96	<0.001
BT	1	0.0037	0.0037	0.07	0.788
CT	3	9.6625	3.2208	64.30	<0.001
MT * BT	1	1.3002	1.3002	25.96	<0.001
MT * CT	3	2.5719	0.8570	17.11	<0.001
BT * CT	3	2.7449	0.9150	18.27	<0.001
MT * BT * CT	3	1.7419	0.5806	11.59	<0.001
Error	32	1.6028	0.0501		
Total	47	30.0430			
Effect of MT, BT and Temp on Displacement					
MT	1	5.6719	5.6719	195.25	<0.001
BT	1	4.9794	4.9794	171.41	<0.001
CT	3	1.7270	0.5757	19.82	<0.001
MT * BT	1	2.2620	2.2620	77.87	<0.001
MT * CT	3	0.2489	0.0830	2.86	0.052
BT * CT	3	1.7047	0.5682	19.56	<0.001
MT * BT * CT	3	0.9097	0.3032	10.44	<0.001
Error	32	0.9296	0.0291		
Total	47	18.4332			

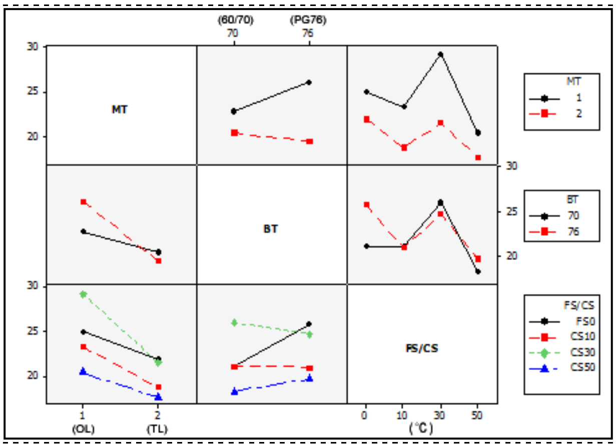


Fig. 13. Interaction plot for the effects of clogging on fracture toughness

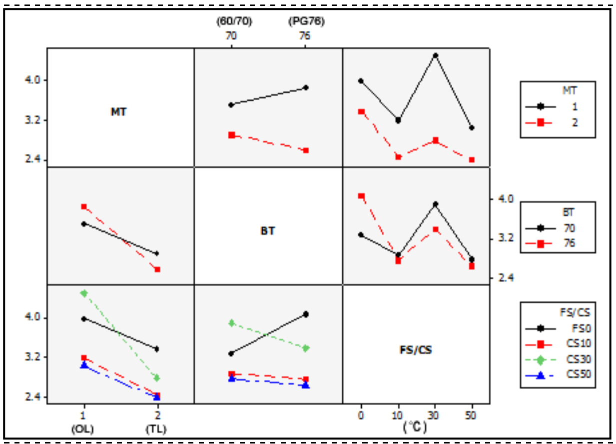


Fig. 14. Interaction plot for the effects of clogging on maximum load

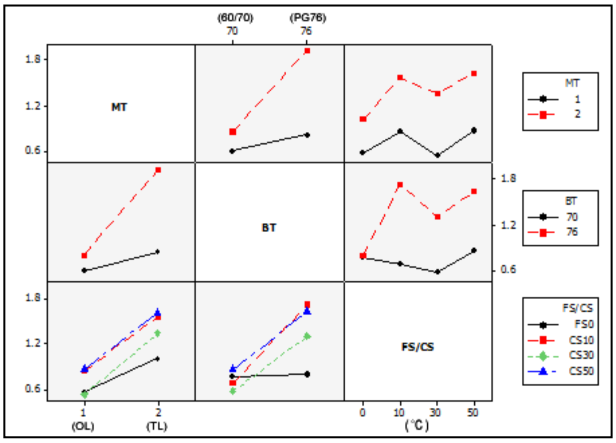


Fig. 15. Interaction plot for effects of clogging on Displacement

4. Conclusions

In general, temperature, binder type, mix type and clogging have significant effects on the fracture toughness, maximum load and displacement of PA. These results are supported by statistical analysis. PA mixes exhibit higher fracture toughness and maximum load at lower temperature, while the displacement results show otherwise. OLPA exhibits better performance in fracture toughness compared to TLPA. Mixes incorporating modified binder show better fracture performance compared to mixes with base binders. GLM analysis shows that the single factors (mix type, binder type and temperature) and interaction between binder type and temperature have significant effects on fracture properties of PA mixes. Temperature is found to be the most significant factor to affect fracture properties of fresh PA followed by binder type and mix type. Clogged specimens exhibit lower fracture toughness compared to fresh PA specimens. The GLM analysis generally shows significant effects of all three single factors and the interactions between two and all three factors on the fracture toughness of clogged specimens.

Aging affect the properties of asphalt binders and mixtures, whether in the fields or in the asphalt plants [24-25]. It is recommended by the authors to evaluate the effect of the aging on the clogging properties of PA specimens. Recently, artificial neural network is used for analysis of data [26-27]. It is also recommended to use of this method for analysis of laboratory PA data.

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