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Used Cylinder Oil Modified Cold-Mix Asphalt Concrete

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Abstract: The purpose of this study is to evaluate mechanical properties of control and modified asphalt mixtures. The modified asphalt mixtures were studied on cold-mix asphalt. Used Cylinder Oil (UCO) was used as a modifier in this study. The modification efficiency was evaluated by the improvement in the performance of prepared asphalt concrete mixes. Physical analysis of the UCO was then performed. Asphalt concrete mixes having different percentages of UCO (0, 20, 25 and 30%) as a modifier were prepared. These samples were characterized using the Marshall Stability, indirect tension test, static creep and dynamic creep test. As a result, the addition of oil to the asphalt has reduced the solvency of maltenes. The higher the added percentages of oil are seen, the softer the asphalt-UCO binders happen. It is believed that the higher the percentages of the UCO were existed, the lower the ability of the mixes to resist deformation occurred.

Key words: Cold-mix asphalt, modified asphalt, used cylinder oil

INTRODUCTION

Over 96% of the world's pavement network is surfaced with asphalt (NCAT, 1999). In fact, billions of dollars are being spent annually for reconstructing, rehabilitating and/or maintaining these roads. Minor improvement in the performance of the pavement would result in substantial savings of public funds. Road agencies have recognized the need to produce better asphalt mixture and to improve pavement design procedures and construction practices. Agencies have continually modified their specifications regarding bituminous mixtures and/or have established/adopted new asphalt mixtures such as Superpave and polymer modified asphalt mixture. The design of some asphalt mixtures is based on the analysis of their volumetric parameters (Epps *et al*., 1997; FHWA, 1996; Anonymous, 1996) whereas the design of others is based on their engineering properties. Such properties impact the durability and performance of the pavement structure and are used as inputs to many pavement structural design procedures. Typically, fillers and modifiers are used to improve the bond between asphalt cement and aggregate, lower the optimum asphalt content, increase the density and increase the stability (Brown, 1989). The main reason for using these fillers and some other types of modifiers is to improve the performance of paving mixture to meet requirements under prevailing conditions. Another early method of asphalt modification consisted of mixing two or more asphalt binders of different paving grades or sources. This technique has been continuously used for years and often delivers a satisfactory end product. One major problem with this technique is that sometimes asphalt is not chemically compatible. Compatibility cannot be predicted effectively and leads to premature pavement distresses (Anderton, 1991).

In the recent past, modified asphalt concrete has been introduced in the construction of pavements to withstand the effects of high ambient temperatures. Schoenberger *et al*. (1999) examined the affect of diesel-contaminated soil to produce an asphalt paving material. The results showed the roadway has performed well for almost four years and remained in excellent condition. No maintenance has been performed on the road during that time. Katamine (2000) carried out research on performance of asphalt concrete mixtures containing oil shale. He concluded that the oil shale fillers have provided mixes with higher ability to resist deformation than the standard mix, as measured by the Marshall quotients and the wheel tracking machine. Asi and Assa'ad (2005) studied the affect of Jordanian oil shale fly ash on asphalt mixes. It has indicated that oil shale fly ash modification has improved the diametral resilient modulus and the dynamic creep test of the modified mixes as compared to the control mix. Edwards *et al*. (2006), were studied the effects of commercial waxes on asphalt concrete mixtures. The result has shown in dynamic creep testing that the smallest strain was recorded for the asphalt mixture with bitumen containing commercial waxes, indicating better resistance to rutting.

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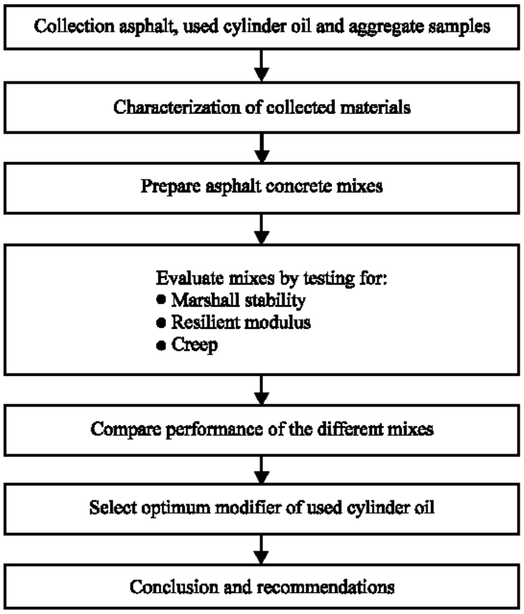

Fig. 1: Flow chart of the experimental program

In Malaysia, small-scale road maintenance always becomes a problem since the existing premixed asphalt plants produce hot-mixed asphalt concrete in a large quantity. Another problem occurs when the maintenance sites are far from the premixed plant. The premixed asphalt may harden by the time it reaches the maintenance sites. As a result, significant quantities of asphalt were wasted. Cold-mixed asphalt was introduced to solve this problem. However, road authorities in Malaysia are still not using the cold-mixed asphalt due to its highly priced raw material.

This research will offer low cost cold-mixed asphalt which can be packed in a small container for transportation to the maintenance sites. The main ingredients are asphalts and UCO. In this program, Marshall testing data were used to select the optimum combination of modified asphalt. Specimens prepared at these optimum combinations were subjected to conventional and Superpave method.

This investigation was undertaken to evaluate the performance of UCO modified asphalt mixes through laboratory evaluation. A schematic representation of the experimental program conducted in this investigation (Fig. 1).

MATERIALS AND METHODS

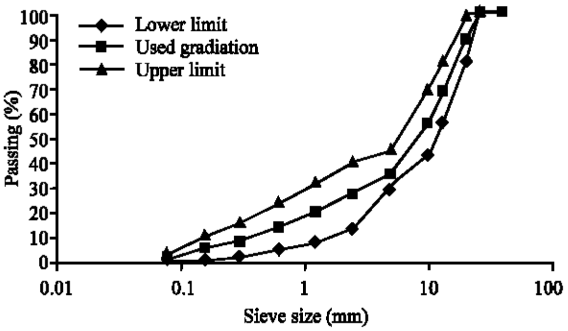

Fig. 2: Malaysia Ministry of Public Works (PWD) specified gradation limits and used gradation

Table 1: Result analysis of UCO

Properties	Values
Viscosity (40°C), (cSt)	29.60
Viscosity (100°C), (cSt)	4.20
Unit weight (kg m^{-3})	756.00
Specific gravity	0.85
Color	Dark grey

Table 2: Physical properties of the asphalt cement

		UCO (%)		
Properties[a]	Control sample	20	25	30
Ductility (cm)	100+	81.00	66.00	49.00
Penetration	73.00	212.00	294.00	382.00
Softening point (°C)	49.40	34.10	31.20	28.30
Viscosity (cSt)	416.00	132.00	116.00	99.00
Specific gravity	1.022	0.995	0.989	0.974

[a]: All values are average of three readings

The aggregate selected for the laboratory work is granite stone which was obtained from Selangor, Malaysia. The selected aggregate gradation was in accordance with the Malaysia Ministry of Public Works (PWD) recommended gradation for heavy traffic wearing course (Fig. 2). The UCO in this research was obtained from a car service centre at Selangor, Malaysia known as Bengkel Raya. The analysis of the UCO is presented in Table 1. Asphalt samples were collected from the asphalt cement producing refinery in Malaysia. 80/100 penetration asphalt cement was used in this study. Standard laboratory test results for asphalt cement are incorporated in Table 2, 3.

Marshall stability and flow tests (ASTM D1559): The Marshall stability test was performed in this study to evaluate the stability of cold mix asphalt made with UCO. The Marshall test method uses standard cylindrical test specimens of 64 mm height and 102 mm diameter. Marshall method (ASTM D1559) was used for determining the optimal bitumen content for the control sample and modified asphalt mixtures. Three identical samples were produced for all alternatives Sixty specimens weighing 1,200 g were prepared. Compacting energy was applied as 75 blows. The specific gravity values of aggregates and the asphalt cement were measured. The average specific

Table 3: Thin film oven test result of control binder and asphalt-oil binders

Binder types[a]	Penetration Before TFOT	Penetration After TFOT	Retained penetration (%)	Softening Point Before TFOT	Softening Point After TFOT	Increase in SP (°C)
Control binder	64.2	56.2	87.5	43.8	47.0	3.2
UCO (%)						
20	212.0	120.0	56.6	34.1	42.3	8.2
25	294.0	126.5	43.0	31.2	39.1	7.9
30	382.0	135.4	35.4	28.3	38.5	10.2

[a]: All values are average of three readings

gravity for each mix for each percentage of modifier type was calculated. The aggregate specimens were blended and mixed with various percentages of asphalt cement. Three specimens from each modifier were mixed with 4% asphalt cement. For the other twelve specimens, the asphalt contents were increased in steps of 0.5% from 4% up to 6%. From each UCO percentages, samples were placed in the water bath at 60°C. After 30 min immersion in the water bath, samples from each set were tested for Marshall stability and flow.

Resilient modulus test, MR (ASTM D4123): The resilient modulus (MR) was determined from tests on diametral in the indirect tension mode. Five samples from each UCO content and control sample were tested under the diametral MR test at test temperatures (40°C). Pulse time was chosen 1000 m sec for high trafficked roads volume roads and 3000 m sec for low trafficked volume roads. The testing procedure followed ASTM D4123 (ASTM Standards, 1992).

Static creep test: Applying a static load to specimen and then measuring the specimen's permanent deformation after unloading conduct a static creep test. Creep deformation of a cylindrical specimen under a uniaxial, static load is measured as a function of time, the sample dimensions and test conditions were standardized using Universal Testing machine (UTM)-25. Deformation values were measured with time by a linear variable transformer (LVDT). Test was carried out for all mixtures at the dosage of optimal bitumen. Because the permanent deformation risk was more under the heavy load and high temperature test parameters were selected: uniaxial load was 425 kPa (0.4 MPa), temperatures 40°C, load duration was 3600 sec.

Dynamic creep test: The dynamic creep test is a test that 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 test was performed in accordance with the protocol developed by NCHRP 9-19 SUPERPAVE Models, Draft Test Method W2 (Witczak *et al*., 2001). Experiments were realized at 40°C test temperatures. Samples were exposed to 780 N (100 kPa) starting load. Average 1100 N (138 kPa) load was put into practice during the duration of test. The testing was continued until the maximum axial strain limit reached 10,000 microstrains, or until 10,000 cycles, whichever occurred first.

RESULTS AND DISCUSSION

Physical tests on asphalt-UCO binders and the control binder: To evaluate the physical properties of the asphalt-UCO binders (a conventional binder with various added percentages of oil), four percentages of oil were added to the conventional binder. The added percentages were 0, 20, 25 and 30% of the binder content by weight. The conventional binder (80/100) a typically used binder for wearing courses in Malaysia. The following physical tests were then carried out on the asphalt-oil binders and on the control binder. The results are reported in Table 2. The ductility test has been used in the past by Heukelom (1966) to observe the ability of asphalt to withstand continuous deformation until fracture. Asphalt is built up from hydrocarbon molecules and when subjected to continuous deformation, these molecules will show instantaneous deformation leading to the separation of these molecules. Ductility testing was criticized by Saal (1955), who nevertheless claimed that the ductility of bitumen appeared to depend upon the hardness (ring and ball) and the penetration index of the bitumen. Heukelom (1966) claimed that elongation at break, observed in ductility tests, is a simple function of the stiffness modulus.

The higher the added percentages of oil, the softer the asphalt-UCO binders. This can be attributed to the fact that the bitumen consists of asphaltenes and maltenes. The high-molecular-weight asphaltenes are of a complex nature and are dispersed in low molecular weight hydrocarbons, known as maltenes. These maltenes and the resinous components of the bitumen maintain the stability of the asphaltenes dispersion and are also required to act as solvent for any additives introduced into the bitumen. Therefore, either insufficient solvent (i.e., maltenes) or a high percentage of asphaltenes results in a segregation of the asphaltenes (Katamine, 2000).

Consequently, the addition of the oil to the asphalt has reduced the solvency of the maltenes and accordingly, softened the domains that are required to be strong, to ensure a stiff binder at normal temperatures. The higher the percentages of the oil in the asphalt-UCO binders, the lower the ability of such asphalt-UCO binders to withstand elongation.

The addition of UCO to the conventional binder had increased the solvency of the binder and reduced the stability provided by the maltenes. Accordingly, the asphalt-UCO binders possessed decreased softening points, increased penetration and provided less ductility. The asphalt-UCO binders were greatly influenced by the TFOT, in comparison with the control binder. The higher the percentages of the oil added to the binder, the clearer the above-mentioned effects. Such serious changes in the rheological properties indicate the need for the UCO to be further treated to prevent such changes from taking place before being recommended, to be mixed with conventional binders and accordingly to be used in bituminous mixes to improve their characteristics

Thin Film Oven Test (TFOT): The standard test method ASTM D5, the thin-film oven (TFO) test simulates short-term aging by heating a film of asphalt binder in an oven for 5 h at 163°C (325°F). The effects of heat and air are determined from changes incurred in physical properties measured before and after the oven treatment by other test procedures. Table 3 indicates the changes that have taken place in the asphalt-UCO binders as a result of the above test.

Marshall stability test result: The Marshall stability test was performed in this study to evaluate the stability of cold mix asphalt made with UCO. The results of Marshall test are presented in Table 4. From Table 4, it can be seen that the samples with 0% UCO, after 30 min immersion in water bath, have the highest Marshall Stability values, followed by the 25, 20 and 30% UCO, respectively. Although, there is inconsistency in these results with the UCO content, the difference between the Marshall Stability values was not notably high. In general, Marshall Stability may not be a good discriminator test.

Previous research by Katamine (2000) has been used Jordanian oil shale as additive in asphalt concrete preparation. Performance of asphalt concrete mixtures containing 7.9, 9.1 and 12.9% oil shale has shows the Marshall stability's result was increasing when compare with control mix. But it is different in this study where control mixture has shown highest value in Marshall stability compare with asphalt-UCO mixtures. It could be concluded the influence of higher content of UCO in asphalt concrete mixture has reduced the stability. It is recommended that a similar study be carried out to consider mixes with UCO containing smaller increment of oil percentages than those used in this research. This would present a clearer picture regarding the effects of lower percentages of the UCO.

Table 4: Summary of Marshall test results

	UCO (%)			
Parameters	0	20	25	30
Asphalt cement (%)	5.050	5.480	5.160	5.110
Stability (kN)	10.064	3.550	5.030	3.346
Bulk specific gravity (g cm^{-3})	2.359	2.245	2.272	2.277
Void content (%)	4.013	4.534	4.332	4.385
Flow (mm)	3.323	2.510	2.460	2.500
Void filled asphalt (%)	68.576	71.846	70.617	73.721
Voids filled mineral aggregate (%)	15.495	17.446	17.300	17.226

Resilient modulus test, MR: In recent years, there has been a change in philosophy in asphalt pavement design from the more empirical approach to the mechanistic approach based on elastic theory. AASHTO (1986) this mechanistic approach in the form of elastic theory is being used by increasing numbers of highway agencies. Elastic theory based design methods require as input the elastic properties of pavement materials. Resilient modulus is the most important variable to mechanistic design of pavement structures. It is the measure of pavement response in terms of dynamic stresses and corresponding strains. Resilient modulus of asphalt mixtures, measured in the indirect tensile mode (ASTM D4123), is the most popular form of stress-strain measurement used to evaluate elastic properties. The resiliency modulus along with other information is then used as input to the elastic theories model to generate an optimum thickness design. Therefore the effectiveness of the thickness design procedure is directly related to the accuracy and precision in measuring the resiliency modulus of the asphalt mixture. The accuracy and precision are also important in areas where resilient modulus is used to as an index for evaluating stripping, fatigue and low temperature cracking of asphalt mixtures (Brown and Foo, 1991; Kulash, 1994; Tian *et al*., 1998).

Resilient modulus values were obtained at high temperature (40°C) for mixtures. It indicates that UCO modification has not improved the diametral resilient modulus of the modified mixes as compared to the control mix. The average resilient modulus of the control mix was found to be 2,625 MPa; this value decreased to 736 MPa for 20% UCO mixes. For the 25 and 30% UCO mixes, there was a decrease in the resilient modulus values as low as the 20% UCO mixes (Fig. 3).

The extensive decreasing of resilient modulus between control asphalt mixture and modified asphalt mixtures occurred because a several factors. A core factor is the role UCO in concrete mixes. With the presence of UCO in the asphalt mixtures, the mixtures have been

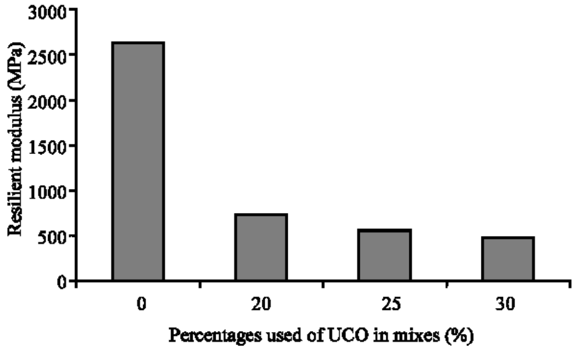

Fig. 3: Resilient modulus values at 40°C

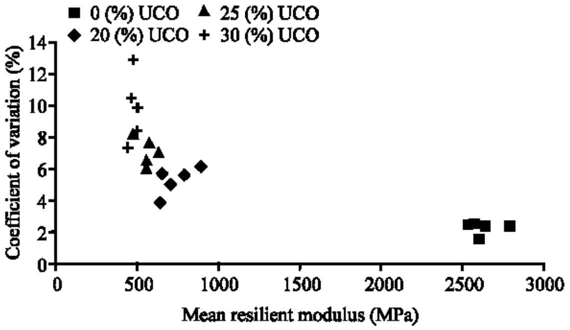

Fig. 4: Degree of variability in resilient modulus values at 40°C

higher in solubility and increased the solvency of the binder. This has been proven with the viscosity testing on asphalt-UCO (Table 2). This reason also was supported research by Park *et al.* (1997) with the performance of asphalt mixtures incorporate with pyrolyzed carbon black were conclude the stability and stiffness have strong relationship with the viscosity. The higher viscosity has appeared to lead to higher stability and stiffness. The lower viscosity in asphalt-UCO mixture has decreased bond between the binder and aggregate. With the increasing of UCO's content in the asphalt concrete mixtures has reducing the viscosity and when the load was applied, derailment was happened between the aggregate. With the higher the added percentages of oil, asphalt-UCO mixture unable to bond an aggregate with the strong bonding.

In Fig. 4 the useful information from the variation in resilient modulus. The coefficient of variation as a function percentages used of UCO in mixes. Resilient moduli are the repeatable test with an average coefficient of variation of about 2.41% for control sample. This value is considered consistent and compatible. Addition of 20, 25 and 30% oil to the concrete mixtures results in an increase of average coefficient of variation to 5.70, 7.72 and 10.41%, respectively. This value can be attributed to the inconsistent condition. It was conclude that resilient modulus measurement of asphalt-UCO mixes does not have a high degree of precision. The most effective way to decrease the variation in resilient modulus or increase the precision is to minimize the oil content of sample tested.

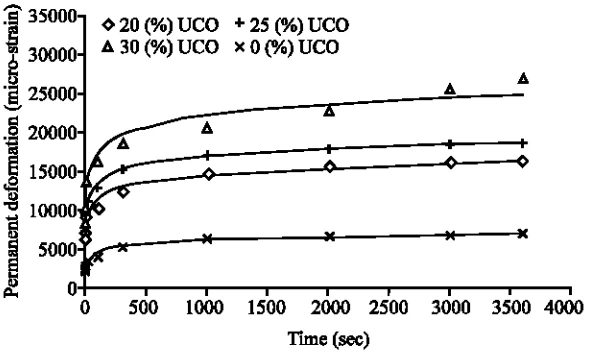

Fig. 5: Comparison of static creep behaviour of the different mixes at 40°C

According to the indirect tension test modified mixtures had lower elasticity modulus compared with control sample that mixtures had the lowest cracking resistance.

Static creep test: A static creep test is conducted by applying a static load to specimen and then measuring the specimen's permanent deformation after unloading. This observed permanent deformation of asphalt mixtures is then correlated with rutting potential. The values of static creep compliance obtained from the test are given in Fig. 5. According to the static creep and dynamic creep asphalt-UCO 20% mixtures show higher performance than the others modified mixtures.

According to Gabrielson (1992), strains less than 10000 micro-Strain indicate the pavement will perform well, while larger strains may mean the pavement will rut. According to this, the entire test results for modified asphalt mixtures are indicative not good quality and performance. The strain of modified asphalt concrete increased rapidly initially, but became stable later in the test. In contrast, the strain of modified asphalt concrete mixtures continues to increase with the time. It has been suggested that static creep test does not improve the performance of modifiers, which does not improve the elastic recovery of a materials. A large amount of permanent deformation shown by modified asphalt, which meant to higher rutting potential.

Dynamic creep test: Strength of the bituminous mixtures to the plastic deformation may be determined with the

Table 5: Effect UCO on the creep properties of mixes

	Used cylinder oil content (%)			
Properties	0	20	25	30
Core temperature (°C)	40	40	40	40
Contact stress (kPa)	9	9	8.6	9
Deviator stress (kPa)	137.6	137.6	137.6	137.6
Dynamic load (kN)	1.081	1.081	1.083	1.081
Permanent deformation (mm)	0.452	1.005	1.007	1.007
Resilient deformation (mm)	0.0317	0.109	0.094	0.106
Accumulated strain (%)	0.452	1.007	1.007	1.006
Resilient modulus (MPa)	406.5	305	284.6	272.1
Creep stiffness (MPa)	67.6	35.5	32.6	29.4

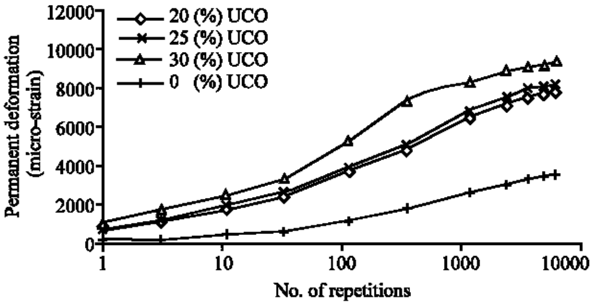

Fig. 6: Comparison of repeated creep behaviour of the different mixes at 40°C

dynamic creep test. Three samples (100×63.5 mm) from each UCO percentage were tested and the values of the accumulated permanent and resilient strains at failure, accumulated strain slope at failure, resilient modulus, creep stiffness, permanent and resilient deformations were recorded (Table 5). For high temperature (60°C), repeated creep test failed because of the sample destruction.

Figure 6 shows the relationship between the number of repetitions and the axial accumulated permanent deformation for the four tested groups. In asphalt concrete testing at high temperatures (dynamic creep at 40°C), the control mixture showed smallest strains (indicating better resistance to rutting) as well as highest modulus. Adding UCO into bitumen showed no or positive effects on the rheological behaviour (decrease in stiffening). Adding UCO made asphalt concrete more sensitive to permanent deformation. The reason for this behaviour could be some instability problems from the chemical reaction between UCO and asphalt mixtures. The phenomena may be explained by the scrutiny under microscope about the chemical reaction between UCO and asphalt.

The UCO was reduced the amount of improvement of the creep resistance due to the loss of cohesive and plastic properties of the asphalt mixtures. Based on the previous research by Asi and Assaad (2005), were studied the affect of oil shale fly ash on asphalt mixes was support this study where Asi and Assa'ad (2005) were faced same problem an additive was used has reduced the improvement of creep resistance. This can be attributed to the same reasons mentioned for the resilient modulus testing. However, the corresponding positive effects could not be shown in dynamic creep testing of asphalt mixtures containing these modified binders. The UCO did not improve in the performance of the modified asphaltic concrete.

CONCLUSIONS

For the mixtures evaluated in this study the following conclusions are derived.

The physical test results of the modified asphalt-UCO binders suggest that the UCO should not be used until it is subjected to further treatment, in order to fulfill the basic rheological requirements of binders.

The presence of the UCO in the conventional binder weakened the stability provided by the maltenes in the binder and increased the solvency of the binder.

Using UCO in modified asphalt concrete has decreased Marshall stability and increased the optimum binder content every each percentages of UCO were added into binder compared with control mixture.

According to the indirect tension test, UCO modification has not improved the diametral resilient modulus of the modified mixes as compared to the control mix. The presence of the UCO in the concrete mixtures have reduced elasticity modulus and weakened the bonding between the aggregate provided by binder that is that mixtures had the lowest stiffness as compared.

Creep tests do not improve the performance of modifier, which does not improve the elastic recovery of materials. Adding UCO made asphalt concrete more sensitive to permanent deformation. The UCO was reduced the amount of improvement of the creep resistance due to the loss of cohesive and plastic properties of the asphalt mixtures.

In general, the addition of UCO to the bitumen has reduced the solvency of maltenes. The higher the added percentages of UCO, the softer the UCO binders. It is believed that the higher the %age of the used oil engine, the lower the ability of the mixes to resist deformation.

It is recommended that a similar study be carried out to consider mixes with UCO containing smaller increment of oil %ages than those used in this research. This would present a clearer picture (regarding the effects of lower percentages of the UCO) of the ability of bituminous mixes to increase the stability and resist deformation.

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