Empirical Evaluation of Olive Husk in Asphalt Cement Binder and Bituminous Concrete

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The results of an experimental study undertaken to evaluate quantitatively the effects of olive husk material on the properties of both asphalt cement binder and bituminous concrete mixtures are summarized. Olive husk material was added to asphalt cement at four levels, ranging from 0 to 15 percent by total weight of binder. For each husk-asphalt binder, physical behaviors of binder, including penetration at different temperatures, softening point, and ductility tests, were investigated. The previous husk-asphalt binders were used to prepare husk-asphalt mixtures. Three types of aggregate, including limestone, basalt, and granite, were used in this study. For each level of husk-asphalt and aggregate type, Marshall, stripping, Marshall immersion, and indirect tensile tests were performed on the laboratory-made specimens with 50 blows on each face. The results indicated that the addition of olive husk material up to 10 percent by total weight of binder would reduce the binder stiffness at low temperatures, increase the stiffness at high temperatures, and help reduce brittleness and temperature sensitivity of binders. For all types of aggregate mixtures, the addition of olive husk material improved workability and stability and reduced the optimum binder content compared with asphalt mixtures without olive husk. The inclusion of olive husk, up to 10 percent, in bituminous concrete mixtures improved stripping resistance, durability, water and temperature resistance, and resistance to both moisture and repeated freeze-thaw induced damage.

In the Mediterranean region, the climate and soil characteristics encourage farmers to plant olive trees on a large scale. Olive oil is obtained through a pressing process in an olive mill. One problem associated with this process is the formation of hundreds of tonnes of solid olive husk. The use of olive husk material is very limited, and it is adversely affecting vegetation and creating environmental problems, at least in Third World countries. In this paper attention is focused on the potential benefits of using olive husk material in asphalt mixtures.

The purpose of this study is to investigate the efficiency of using olive husk material as an additive and partial substitute for asphalt cement under both normal and freeze-thaw conditions. The physical behaviors of the husk-asphalt binder, including penetration, softening point, and ductility, were examined. Stripping resistances of husk-asphalt mixtures were determined by using Texas boiling and Scandinavian rolling tests. The basic engineering strength properties of the mixtures, including Marshall stability, Marshall immersion stability, and tensile strength under normal and freeze-thaw conditions, was investigated. Three types of aggregate, including limestone, basalt, and granite, and four levels of husk material were used in the study.

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LITERATURE REVIEW

Several studies have investigated asphalt chemical composition (*1–4*) and the influence of different additives and modifiers on the physical properties of binders (*5–6*) and asphalt mixtures (*6–8*). Other studies have focused on the effects of filler materials on the properties of asphalt binder and on such basic properties of the asphalt mixtures as stability, durability, flexibility, optimum asphalt content, and workability (*9–11*).

Asphalt is a homogeneous mix of many different molecules, which may be differentiated into asphaltenes, resins, and oils. Conversion of oils to resins and resins to asphaltenes takes place inside asphalt through chemical reactions when asphalt is exposed to heat, air, light, or other environmental physical actions (*1*). The conversion process increases the asphaltenes content and produces a more viscous asphalt. In addition, Epps et al. (*2*) indicated that mineral aggregate might absorb the oil fraction and may result in more hardening of the asphalt binder. Accordingly, Noureldin (*3*) suggested a range of oil, resin, and asphaltenes contents for some types of asphalt. Violations of these ranges have some detrimental effect on pavement mixtures. David and Thomas (*4*) pointed that asphalt that has too much asphaltenes content would result in a mixture with potential brittleness and thermal cracking, whereas low asphaltenes would result in moisture sensitivity and rutting problems. To avoid these problems, additives or modifiers are used to bring the asphalt to a suitable chemical composition for consistency and durability.

Additives/modifiers are known to react differently with asphalt, and they produce considerable changes in the physical properties of the binder. Epps (*5*) stated that the ideal modified asphalt binder would contribute to higher stiffness at high temperatures, lower stiffness at cold temperatures, and increase stripping resistance. Fernando and Guirguis (*6*) concluded that the addition of natural rubber to asphalt not only increased the stiffness modulus of asphalt at high temperatures but also reduced the stiffness modulus at low temperatures.

In addition to the role of additives/modifiers in improving the physical properties of binders, other additives are incorporated in asphalt mixtures to improve stripping resistance. The stripping of asphalt from aggregate is defined as the loss of the adhesion strength in the presence of water and has been recognized as a major cause of pavement distress (*7*). Pablo (*8*) indicated that the addition of hydrated lime improved the bonding properties of quartzite and dolomite sands, whereas the addition of amine additive was necessary to maintain good bonding in natural rounded gravel.

The role of mineral fillers has been investigated by many studies. Puzinauskas (*9*) stated that the mineral fillers fill the voids and provide contact points between coarser aggregate particles in the mixtures. Moreover, because of their fineness and surface characteristics, fillers may serve as active materials. Joseph et al. (*10*) investigated the physicochemical effect of the filler on the behavior of filler-asphalt systems and asphalt mixtures. They indicated that the most important filler asphalt interface property is the selective sorption (adsorption and absorption), which is influenced by the complex group composition of asphalt, the physical-chemical properties of the filler surface, and the internal pore structure of the filler particles. Also, they stated that because of the capillary effect of micropores, the filler particles absorb first the low-viscosity components of asphalt with lower molecular weight (oils fraction). The amount of asphalt absorbed is lost asphalt, which does not affect the mechanical behavior of mixtures.

Recently, interest has focused on the use of by-products to provide the benefits of recycling, reduce associated environmental problems, and act as an asphalt extender or as a partial substitute for the asphalt in asphalt mixtures. In a study by Al-Masaeid et al. (*11*), it was found that the substitution of oil shale ash, a by-product of the oil shale rock industry, up to 10 percent by volume of asphalt would improve the performance of mixtures under normal and freeze-thaw conditions. Peltonen (*12*), on the other hand, indicated that the addition of tall oil pitch, a by-product of the sulfate cellulose industry, improves the adhesion and water resistance of pavement mixtures. He also indicated that the addition of selected cellulose fibers from old newspaper materials improves the properties of asphalt mixtures.

In summary, several studies on the performance of different additives, minerals, and by-products have been carried out, but no information is available on the role played by olive husk material in bituminous mixtures. The olive husk particles have a subangular geometry with oily texture; they contain traces of oils. It is believed that this material might play a beneficial role in bituminous binder and mixture characteristics. Therefore, this study explored the possible permanent applications of olive husk material in bituminous binders and mixtures.

MATERIALS USED

One asphalt cement (80/100) penetration grade asphalt typically used in pavement construction in Jordan was used in the study. Table 1 presents the properties of the asphalt cement used.

Three types of aggregate were used in the study: crushed limestone, crushed basalt, and crushed granite. These are the major types of aggregate used in pavement construction in Jordan. Their gradations conformed to the Ministry of Public Works and Housing specifications in Jordan. The aggregate gradation is given in Table 2.

The husk material was obtained from Al-Nu'aemh's olive mill. The husk was piled in open space and was about 1 year old. Results of the pyrolysis test carried out at laboratories of the

TABLE 1 Properties of Asphalt Cement Used in Study

Properties	ASTM Test Designation	Test Result
Specific Gravity at 25°C	D 70	1.010
Penetration, (0.1 mm), 100 gm, 5sec	D 5	83.0
Softening Point (°C) Ring and Ball	D 36	47.5
Ductility (cm) at 25°C	D 113	130

TABLE 2 Aggregate Gradations Used in Study

Sieve Size	% Passing	Specification[a]
3/4 in.	100	100
1/2 in.	95	90-100
3/8 in.	85	75-90
# 4	60	45-70
# 8	45	33-53
# 30	25	15-33
# 50	15	10-20
# 100	7	4-16
# 200	5	2-9

[a] Jordan Specification Limits.

TABLE 3 Olive Husk Gradations[a] Used in Study

Size, Micron[b]	Percent Finer
75	100
55	95
45	90
35	83
25	68
15	55
10	50
7	47
3.5	45
1	36

[a] Hydrometer Analysis
[b] 1 μm = 1* 10^{-6} m

Natural Resources Authority, Jordan, indicated that the olive husk material contains about 12 percent oils by total weight. Naturally, olive husk contains fatty amines. The husk fraction passing sieve No. 200 was used in the study. Table 3 gives its gradation by hydrometer analysis on selected samples.

TEST PROCEDURE AND PHASES OF INVESTIGATION

Physical behavior and stripping characteristics of husk asphalt binder were investigated. A Marshall test (ASTM D1559), a Marshall immersion test, and an indirect tensile test were performed on the laboratory-made specimens with 50 blows on each face. The specimen was 4 in. in diameter and 2.5 in. high. To achieve the objectives of this study, five phases of investigation were undertaken.

Phase 1: Physical Behavior of Husk-Asphalt Binder

The objective of this phase was to evaluate quantitatively the effect of husk level on the behaviour of husk-asphalt binder using penetration, softening point, and ductility. The variables in this phase were percent husk by total weight of binder (asphalt + husk) (0, 5, 10, and 15) and penetration 100 g and 5 sec (at 0°C, 10°C, 17.5°C, 5°C, and 35°C).

Asphalt was heated in an oven at 145°C. The required amount of husk was weighed and added slowly in small quantities to the asphalt and stirred into the asphalt at 145°C. Once the required quantity of husk had been added to the asphalt in this manner, mixing was continued for a further 10 min at 1,600 rpm to achieve a homogeneous binder mix.

Results of penetration at the specified temperature levels are presented in Table 4, and Table 5 gives the results of ring-and-ball softening point and ductility tests.

Phase 2: Optimum Husk-Asphalt Binder Content

The objectives of this phase were to determine the optimum husk-asphalt binder content by weight of total mix (conventional bituminous mix) and to evaluate the effect of husk level on the

TABLE 4 Penetration[a] of Husk-Asphalt Binder at Different Temperatures and Percentages of Husk (Results of Phase 1)

Temperature (°C)	Husk Percent[b]			
	0	5	10	15
0.0	3	21	33	29
10.0	13	30	44	38
17.5	27	40	52	47
25	83	101	110	108
35	195	192	198	196

[a] Penetration, 0.1mm, 100gm, 5 Sec.
[b] Husk percent by total weight of binder (Husk Plus Asphalt).

TABLE 5 Softening Point and Ductility of Husk-Asphalt Binder (Results of Phase 1)

Test	Husk Percent			
	0	5	10	15
Softening Point (°C) Ring and Ball	47.5	46.2	47.7	47.9
Ductility (cm) at 25°C	130	118	115	69

optimum binder content. The Marshall test (ASTM D1559) was carried out to determine the optimum binder content. The variables in this phase of study were as follows:

1. Aggregate type (limestone, basalt, and granite),
2. Percent husk by total weight of binder (asphalt + husk) (0, 5, 10, and 15), and
3. Percent binder by total weight of mix (3.5, 4.0, 4.5, 5, 5.5, 6.0, and 6.5).

The procedure used in preparing the bituminous mixtures and testing Marshall specimens is that outlined in Asphalt Institute Manual MS-2 (*13*). In the case of husk-asphalt binder, the binder prepared as explained in Phase 1 was directly added to the heated aggregate. During the course of the work, it was found that control mixtures (mixes with zero husk level) produced unworkable mixes at 3.5 percent binder content. Therefore, all control mixtures were started with 4.0 percent of binder instead of 3.5 percent. Three specimens were prepared for each combination of aggregate, husk, and binder level. Therefore, 81 specimens for each type of aggregate were made. Results of this phase, including optimum binder content and the associated mixture properties for each husk-aggregate combination level, are presented in Table 6.

Phase 3: Moisture Sensitivity of Husk-Asphalt Mixtures

The objective of this phase was to investigate the effect of husk level on moisture resistance of husk-asphalt mixtures. Moisture sensitivity of mixtures, often attributable to stripping, was evaluated by using the Texas boiling test (*14*) and the Scandinavian rolling test. The Scandinavian rolling test is used by the Ministry of Public Works and Housing in Jordan. One hundred g of large aggregate ($^3/_8$- to 4-in. mesh size) was used in preparing each sample. Variables in this phase were as follows:

1. Test type (Texas boiling test and rolling test),
2. Aggregate type (as in Phase 2), and
3. For each husk level, the optimum husk-asphalt binder content obtained in Phase 2 was used to prepare the stripping samples.

TABLE 6 Optimum Husk-Asphalt Binders for Different Aggregate Types and Husk Levels and Their Associated Mixture Properties (Marshall Results, Phase 2)

Agg. Type	Husk Percent	Optimum[a] Binder Content	Marshall Stability lb, 60°C	Flow (0.01 in.)	V.T.M[b] (%)
Limestone	0	5.30	3695	12.1	3.8
	5	4.75	3804	11.0	3.2
	10	4.60	4100	12.0	3.1
	15	4.80	3855	13.5	3.0
Basalt	0	5.00	3660	15.7	4.5
	5	4.50	3780	11.5	4.2
	10	4.75	4338	13.5	4.2
	15	4.80	4220	13.0	4.0
Granite	0	5.00	3117	16.2	4.8
	5	4.50	3220	14.5	4.6
	10	4.66	3228	15.0	4.5
	15	5.00	3205	13.5	4.1

[a] Binder Content: percent by total weight of the mix.
[b] V.T.M: Air voids in the mix, percent by total volume.

For each type of test, 12 samples were prepared. The resultant amount of stripping resistance was determined by five observers and reported in terms of the observed percentage of asphalt coating retained on the aggregate. The results of this phase are given in Table 7.

Phase 4: Durability of Husk-Asphalt Mixtures

The objective of this phase was to evaluate quantitatively the effect of husk on the durability of bituminous mixtures using the Marshall immersion test. This test is recognized as a durability criterion for hot bituminous mixtures (*15*), and it evaluates the combined damaging effects of water and temperature on asphalt mixtures.

Type of aggregate and optimum husk-asphalt binder content were the same as in Phase 3. Marshall specimens were set into two groups. The first group of specimens was cured in air at room temperature for 24 hr. The second group was cured in a 60°C water bath for 24 hr.

For each aggregate type and husk percent in binder, three specimens were prepared. Therefore, 36 specimens for each group were prepared. Results of the Marshall test, which was performed at 60°C, are presented in Table 8.

Phase 5: Tensile Strength of Husk-Asphalt Mixtures

The objective of this phase was to evaluate quantitatively the effect of husk on the behavior of bituminous mixtures using an indirect tensile test, under dry conditions (normal) and under wet conditions after 10 cycles of freezing and thawing. The test was used to evaluate the mixture's resistance to moisture damage and repeated freeze-thaw-induced damage, specifically low-temperature cracking.

The indirect tensile test involved loading a cylindrical specimen with compressive loads that act parallel and along the vertical diametrical plan. Marshall specimens measuring 4 in. in diameter and 2.5 in. high were used in the study. To distribute the load and maintain a constant loading area, the compressive load was applied through a 0.5-in.-wide steel loading strip that was curved at the interface with the specimen and had a radius equal to that of the specimen. In this study, Marshall apparatus was used to apply load.

The theoretical relationship used in calculating the specimen tensile strength [TS (psi)] is as follows (*16*):

$$TS = 0.156PF/h \quad (1)$$

where PF is total load at failure (lb) and h is height of the specimen (in.).

Type of aggregate, optimum husk-asphalt binder content, and the number of specimens were the same as in Phase 4. Marshall specimens were set into two groups. The first group of specimens was cured in air at room temperature for 10 days. The second group was subjected to 10 cycles of freezing and thawing. They were put in plastic freezing bags, and about 10 mL of water was added to each bag; they were kept in a freezer at −18°C for 16 hr followed by 8 hr of thawing at 25°C (*11*). All specimens were kept at a constant temperature of 25°C for 24 hr before the indirect tensile test, which was performed at 25°C. Results of this phase are presented in Table 9.

TEST RESULTS AND DISCUSSION

In Phase 1, the effect of husk level on the behavior of husk-asphalt binder was evaluated using penetration, softening, and ductility. Results of penetration indicated that the relationship between the logarithm of penetration (log P) and temperature (T) is linear, as shown in Figure 1. That is,

$$\log P = A + BT \quad (2)$$

where A is the constant of the regression line and B indicates the temperature sensitivity of the logarithm of the penetration. Values of A and B as a function of husk level in the husk-asphalt binder are given in Table 10. It can be seen in Table 10 and Figure 1 that penetration increases with increasing husk level up to 10 percent at relatively low-temperature conditions, whereas penetration decreases with increasing husk level up to 10 percent for temperatures higher than 30°C. This result suggests that husk may be used as an additive or softening agent for asphalt. It contributes

TABLE 7 Stripping Resistance of Husk-Asphalt Binders (Results of Phase 3)

Test Type	% Husk	% Asphalt Coating Retained on Aggregate		
		Limestone	Basalt	Granite
Texas Boiling Test	0	95	82	54
	5	95	88	56
	10	97	93	65
	15	99	94	79
Scandinavian Rolling Test	0	78	65	30
	5	82	74	35
	10	90	80	50
	15	93	86	52

TABLE 8 Marshall Stabilities for Husk-Asphalt Mixtures (Results of Phase 4)

Agg. Type	Husk Percent	Marshall Stability (lb)		Index of Retained Marshall Stability (Wet/Dry)
		Dry[a]	Wet[b]	
Limestone	0	3692	2936	0.795
	5	3812	3318	0.870
	10	4088	3589	0.878
	15	3850	3268	0.849
Basalt	0	3660	3360	0.918
	5	3750	3402	0.907
	10	4245	3876	0.892
	15	4222	3695	0.875
Granite	0	3120	2837	0.909
	5	3218	3040	0.945
	10	3225	2877	0.892
	15	3198	2446	0.765

[a] Specimens were cured in air at room temperature for 24hr.
[b] Specimens were cured in a 60°C water bath for 24hr.

TABLE 9 Indirect Tensile Strength at 25°C (Results of Phase 5)

Agg. Type	Husk Percent	Marshall Stability (lb)		Index of Retained Marshall Stability (Wet/Dry)
		Dry[a]	Wet[b]	
Limestone	0	103.60	84.74	0.818
	5	113.51	96.30	0.848
	10	132.20	119.56	0.904
	15	119.30	106.39	0.892
Basalt	0	86.11	73.13	0.849
	5	90.48	77.50	0.857
	10	102.21	89.11	0.872
	15	95.53	82.12	0.860
Granite	0	62.40	50.05	0.802
	5	63.46	51.04	0.804
	10	69.76	58.60	0.840
	15	68.64	54.66	0.796

[a] Specimens were cured in air at room temperature for 11 days and tested at 25°C.
[b] Specimens were subjected to 10 cycles of freeze-thaw and tested at 25°C after 24 hours at 25°C.

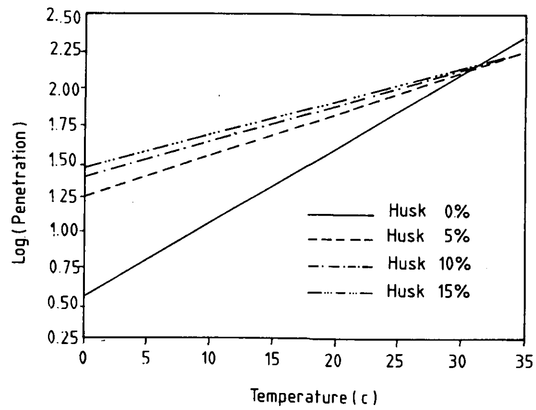

FIGURE 1 Relationship between log (penetration) and temperature at different olive husk levels.

to lower stiffness at relatively low temperatures and higher stiffness at higher temperatures. Moreover, the addition of husk material to asphalt cement reduces the temperature sensitivity of binder (*B* values).

Pfeiffer and Van Doormaal (*17*) defined the penetration index, PI, as

$$PI = (20 - 500B)/(1 + 50B) \quad (3)$$

where *B* is the temperature sensitivity of the logarithm of the penetration. Values of PI as a function of husk level are included in Table 10. The results presented in Table 10 indicate that penetration index increases with increasing husk level up to 10 percent. Except for the control level (binder with zero husk level), all binders (5, 10, and 15 percent husk levels) exhibit substantially non-Newtonian flow behavior (PI more than +2). Therefore, it can be said that the addition of husk material reduces the brittleness of asphalt cement at low temperatures.

Results of softening point using the ring-and-ball test and ductility test are given in Table 5. Table 5 indicates that there is a slight improvement in softening point associated with higher husk levels. In contrast, a substantial reduction in ductility was associated with higher husk levels. Typical pavement asphalt required a ductility of 1 m or more; therefore, addition of up to 10 percent of husk would not violate the ductility specifications.

In Phase 2, mixes were made with husk-asphalt binder to determine optimum binder content and to evaluate the effect of husk material on mechanical and strength properties of husk asphalt mixtures. For each type of aggregate, asphalt mixtures with zero percent husk represent the control mix. Optimum binder content was computed as the average of values resulting in maximum unit weight, maximum stability, and 4 percent air voids in the total mix. Results of this phase are presented in Table 6.

For each type of aggregate, optimum binder contents as a function of husk level are shown in Figure 2. The results indicate that husk material has a considerable effect in reducing the optimum binder content compared with the pure asphalt binder (binder with zero husk level). As shown in Figure 2, a minimum optimum binder content is achieved at 10 percent husk in the case of limestone aggregate and at 5 percent husk in the case of basalt or granite. However, as indicated in Table 6, maximum stability at optimum binder content is associated with 10 percent husk in all types of aggregate mixtures.

Results of this phase suggest that the addition of husk material not only improves the workability and stability properties of bituminous mixtures but also reduces the optimum binder content. In the case of limestone mixtures with 10 percent husk level, the potential saving in the amount of asphalt was about 15 percent compared with mixtures with 0 percent husk level (pure asphalt binder).

Results of the Texas boiling test and Scandinavian rolling test (Phase 3) are given in Table 7. Stripping resistance increases with the increase in husk level for all types of aggregate. The same trend is observed in the results of both tests. In fact, olive husk has an oily texture and some traces of oils and resins. These chemical components might bring the asphalt to a suitable chemical composition for durability and consequently provide better bonding properties between the binder and aggregate even in the presence of water.

Results of the Marshall immersion test (Phase 4) are presented in Table 8. The retained stability of limestone mixtures increases with the increase in husk level up to 10 percent, that of basalt mixtures slightly decreases with the increase in husk level, and that of granite mixtures slightly increases at 5 percent husk level. Furthermore, for all types of aggregate and husk levels in this study, Marshall immersion results comply with the durability criteria for hot bituminous mixtures (75 percent retained strength is recommended as a criterion in many studies). Therefore, it can be said that the addition of husk material improves bonding properties between the binder and aggregate and results in a high water and temperature resistance. In addition, husk particles constitute part of the mineral aggregate. They fill space and improve the interlocking bond between larger aggregate particles.

TABLE 10 Regression Coefficients and Penetration Index

Husk Percent[a]	Regression Coefficient		Penetration Index
	A	B	
0	0.5346	0.0521	-1.678
5	1.2362	0.0287	+2.320
10	1.4425	0.0229	+3.986
15	1.3754	0.0247	+3.423

[a] Husk Percent by total weight of binder (Husk Plus asphalt).

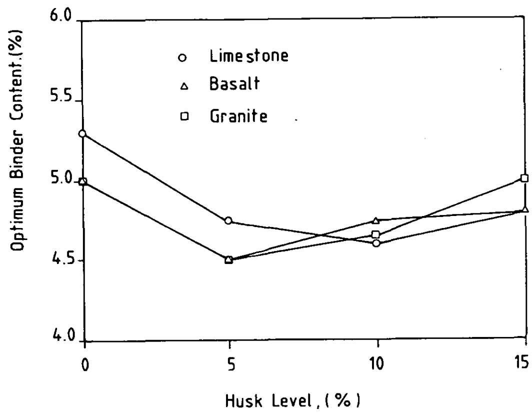

FIGURE 2 Relationship between optimum binder content and olive husk level for limestone, basalt, and granite mixes.

The indirect tensile test results (Phase 5) are presented in Table 9. They indicate that the addition of husk material resulted in a substantial increase in tensile strength up to 10 percent husk and a slight decrease at the 15 percent level. The same trend is observed for the retained tensile strength. These trends are observed for all types of aggregate in this study. For limestone and basalt mixtures, the tensile strength value (Table 9) at 10 percent husk in freeze-thaw conditions is still higher than that for the control mix (0 percent husk level) with no husk in dry conditions.

The results of this phase indicate that husk material has a significant effect in improving a mixture's resistance to moisture damage and repeated freeze-thaw-induced damage, and the beneficial effects were associated with 10 percent husk level in both dry and freeze-thaw conditions.

In summary, results of this study supported the belief that olive husk material has a beneficial role in bituminous technology. The study gave numerical values for husk asphalt binder and mixture characteristics at different husk levels—0, 5, 10, and 15 percent. On the basis of physical test results, the addition of husk material was found to reduce stiffness of binder at low temperatures, improve stiffness at higher temperatures, and reduce the temperature sensitivity of binder. Also, the basic engineering properties of asphalt mixtures were investigated using stripping tests, the Marshall stability test, the Marshall immersion test, and the indirect tensile test under freezing and thawing conditions. The results suggested that the addition of husk material improves stripping resistance, water and temperature damage resistance, freeze-thaw damage resistance, and the strength properties of mixtures. Furthermore, the addition of husk material was found to be effective in improving workability and reducing the optimum binder content. The optimum olive husk level is 10 percent, which fulfills the design criteria of strength, durability, flexibility, and workability of bituminous mixtures made from limestone, basalt, and granite aggregates.

CONCLUSIONS

The study evaluated the effect of olive husk material on binder and bituminous mixtures. On the basis of the results, the following conclusions are drawn:

1. The addition of up to 10 percent olive husk material to asphalt results in an increase in penetration values at low temperatures and a decrease in penetration values at high temperatures. This indicates that olive husk material reduces the binder stiffness at low temperatures and increases the stiffness at high temperatures.
2. The penetration index of husk-asphalt binder increases with the increase in husk level up to 10 percent. This suggests that the addition of olive husk material contributes to reduction in the brittleness and temperature sensitivity of the binder.
3. Slight changes in the ring-and-ball softening point were observed with high husk levels. In contrast, ductility was found to reduce substantially with increase in husk level. Up to 10 percent husk level, ductility values of more than 1 m were found.
4. The addition of olive husk material results in an appreciable improvement in both workability and strength properties. Moreover, the olive husk material reduces the optimum binder content for all types of aggregate mixtures.
5. For all types of aggregate mixtures, stripping resistance was found to increase with increase in olive husk level. This indicates that olive husk material has antistripping characteristics.
6. Similarly, olive husk material improves durability of mixtures. The results of the Marshall immersion test indicated that the retained stability of husk-asphalt limestone mixtures increases with the increase in husk level up to 10 percent, whereas slight changes in the retained stability of basalt and granite mixtures was observed up to 10 percent husk level. However, for all types of aggregate mixtures, the peak values of Marshall immersion stability were observed at 10 percent husk level. These results suggest that the inclusion of olive husk material in bituminous mixtures would reduce the combined damaging effects of water and temperature.
7. In evaluating the effects of olive husk on the mixture's resistance to both moisture and repeated freeze-thaw-induced damage, it was observed that the tensile strength of mixtures increases as the husk level increases, up to a husk level of 10 percent, and then decreases under dry as well as wet conditions after 10 cycles of freezing and thawing. For all types of aggregate mixtures, the same trend was observed for the retained tensile strength.

REFERENCES

1. Rostler, F. S., and R. M. White. Composition and Changes in Composition of Highway Asphalt, 85-100 Penetration Grade. *Proc., Association of Asphalt Paving Technologists,* Vol. 31, 1962, pp. 35–89.
2. Epps, J. A., D. N. Little, R. J. O'Neal, and B. M. Gallaway. Mixture Properties of Recycled Central Plant Materials. *STP 662*, ASTM (L. E. Wood, ed.), Nov. 1978.
3. Noureldin, A. S. *Experimental and Statistical Evaluation and Improvements of Local 60/70 Asphalt Cement.* M.S. thesis. Cairo University, 1982.
4. David, R., and W. Thomas. The Asphalt Model: Results of the SHRP Asphalt Research Program. VTI rapport, 372A, Part 5, Swedish Road and Traffic Research Institute, 1991, pp. 1–13.
5. Epps, J. Asphalt Pavement Modifiers. *Civil Engineering,* ASCE, April 1986, pp. 57–59.
6. Fernando, M. J., and H. R. Guirguis. Natural Rubber for Improved Surfacing. *Proc.,* ARRB, Vol. 12, Part 2, 1984, pp. 121–130.
7. Curtis, C. W., and C. J. Brannan. An Investigation of Asphalt-Aggregate Interactions and Their Sensitivity to Water. VTI rapport, 372A, Part 5, Swedish Road and Traffic Research Institute, 1991, pp. 36–51.
8. Pablo, E. B. Moisture Susceptibility Behavior of Asphalt Concrete and Emulsified Asphalt Mixtures Using the Freeze-Thaw Pedestal Test. In

Transportation Research Record 1228, TRB, National Research Council, Washington, D.C., 1989, pp. 9–16.
9. Puzinauskas, V. P. Filler in Asphalt Mixtures. *Proc.,* Canada Technical Asphalt Association, Vol. 13, 1986.
10. Joseph, C., I. Ilan, and S. Arieh. Some Physico-Chemical Aspects of the Effect and the Role of the Filler in Bituminous Paving Mixtures. *Proc., Association of Asphalt Paving Technologists,* Vol. 47, 1978, pp. 558–588.
11. Al-Masaeid, H., T. Khedaywi, and M. Smadi. Properties of Asphalt-Oil Shale Ash Bituminous Mixtures Under Normal and Freeze-Thaw Conditions. In *Transportation Research Record 1228,* TRB, National Research Council, Washington, D.C., 1989, pp. 54–62.
12. Peltonen, P. *Asphalt Mixtures Modified with Tall Oil Pitches and Cellulose Fibers.* Ph.D. thesis. Technical Research Center of Finland, Espoo, Finland, 1992.
13. *Mix Design Method for Asphalt Concrete and Other Hot-Mix Types.* Asphalt Institute, MS-2, 1976, pp. 17–32.
14. Kennedy, T. W., F. L. Roberts, and K. W. Lee. Evaluating Moisture Susceptibility of Asphalt Mixtures Using the Texas Boiling Test. In *Transportation Research Record 968,* TRB, National Research Council, Washington, D.C., 1984, pp. 45–53.
15. Goode, J. F. Use of the Immersion Compression Test in Evaluation and Designing Bituminous Paving Mixtures. *ASTM SPT 252,* 1959, pp. 113–125.
16. Kandhal, P. S. Evaluation of Sulphur Extended Asphalt Binder in Bituminous Paving Mixtures. *Proc., Association of Asphalt Paving Technologists,* Vol. 51, 1982, pp. 189–221.
17. Pfeiffer, J. P., and P. M. Van Doormaal. The Rheological Properties of Asphalt Bituminous. *J. Inst. Petroleum Technology,* Vol. 22, 1936, pp. 414–440.

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