Performance Assessment of Binder-Rich Polyethylene-Modified Asphalt Concrete Mixtures (Novophalt)

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A 7-in. overlay of polyethylene-modified asphalt concrete (using the Novophalt process) was placed at the William Hobby Airport in Houston, Texas, in December 1988. The mixture was somewhat binder-rich according to traditional mixture design methodology (i.e., Marshall and Hveem). The binder-rich mixture and the optimally designed polyethylene-modified mixture (optimum binder content according to Marshall design) were evaluated. This evaluation included compressive uniaxial creep compliance testing, uniaxial repeated-load permanent deformation testing, tensile creep testing, tensile strength testing, and resilient modulus testing. Binder-rich polyethylene-modified asphalt concrete proved to be significantly less sensitive to permanent deformation than the control mixture. The binder-rich mixture also demonstrated significantly greater resistance to fracture as verified by indirect tensile test data (toughness) over a range of temperature from 32°F to 104°F and by the slope of the steady-state region of indirect tensile creep plots. The response of the binder-rich mixtures also demonstrated a strong sensitivity to the initial level of compaction. Binder-rich mixtures compacted to air void contents between 5.0 and 6.5 percent were not substantially more susceptible to permanent deformation than the optimally designed mixture at the 104°F test temperature. Data from Italy verify the hypothesis that binder-rich polyethylene-modified asphalt concrete mixtures can perform successfully in certain specialized applications with acceptable resistance to permanent deformation, potentially superior resistance to fracture (reflection cracking and thermal cracking), and potentially superior durability of the low-permeability, binder-rich mixture.

Reconstruction of runway 17-35 at the William Hobby Airport in Houston, Texas, used 20,000 tons of Novophalt modified asphalt concrete. The Novophalt mixture was laid to depths of 7 in. below the surface of the central runway section and 3.2 in. below the shoulder sections. Construction took place between October 1988 and January 1989.

Novophalt modified asphalt cement is a biphase binder system containing polyolefin additives and paving-grade asphalt cement. Novophalt is prepared by incorporating polyolefins, primarily low-density polyethylene (LDPE), into paving-grade asphalt using a patented blending process. The properties of the polyethylene used for modification may vary. Virgin or recycled polyethylene characterized as follows is used:

Characteristic	*Description*
Physical	
Melt index:	1.0–15.0
Melting point (°C)	115–125
Density	0.910–0.940
Fire hazard	Noncombustible
Chemical	Inert hydrocarbon polymer

The mix design was carried out by an independent quality control laboratory before construction. The laboratory recommended a binder content of 4.8 to 5.0 percent. In the actual construction, Novophalt hot mix was placed at binder contents ranging from 4.8 percent (the optimum as established in the laboratory) to about 5.8 percent (20 percent above the optimum).

A laboratory evaluation of the actual mixtures used at Hobby Airport was conducted at the Texas Transportation Institute (TTI) of Texas A&M University. The objectives were to verify the mixture design and to investigate the ramifications of using binder-rich mixtures in the runway. Specifically, the effects of high binder contents on deformation potential and fracture potential were investigated. In addition, the effects of initial compaction on deformation potential of the binder-rich Novophalt mixtures were investigated.

PAVEMENT STRUCTURE AND DESIGN CRITERIA

Runway 17-35 at Hobby Airport lies over a native plastic clay with an approximate average annual resilient modulus of 4,900 psi. The subbase consists of a mixture of sand and shells. The main structural layer for most of the life of the pavement was a plain portland cement concrete pavement that had been subsequently overlayed with asphalt concrete to a depth of approximately 4 in.

The reconstruction process called for milling off the existing 4 in. of asphalt in the central runway section and replacing it with 7 in. of Novophalt. The shoulders were overlayed with approximately 3.2 in. of Novophalt. Before the Novophalt overlay was placed, a stress-absorbing membrane interlayer (SAMI) was laid to minimize the potential of crack reflection from the existing portland cement concrete through the Novophalt surface.

Because of the nature of the structural pavement design (i.e., Novophalt laid over the existing primary structural section of portland cement concrete), load-induced flexural fatigue cracking in the surface was not considered a design problem; tensile flexural stresses in the asphalt concrete surface are not induced by load in this type of pavement struc-

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ture. The major concern and primary design criterion was permanent deformation in the surface layer under the DC-9 aircraft. Permanent deformation in asphalt concrete surfaces is of primary concern in Houston because of the high pavement temperatures induced by the hot Texas summers.

MATERIALS SELECTED FOR RUNWAY OVERLAY

The aggregate selected for the asphalt mixture used in the overlay was a Scottish granite. The blend of aggregate used at the plant was approximately 35 percent coarse crushed granite particles, approximately 57.5 percent granite screenings, and approximately 7.5 percent clean sand. The job mix formula tolerances for the mixture are as follows:

Sieve Size	*Job-Mix Formula Tolerances (% passing)*
¾ in.	93.0–100.0
½ in.	86.6–100.0
⅜ in.	73.1–87.1
No. 4	56.0–69.3
No. 10	39.6–47.6
No. 40	21.2–29.2
No. 80	10.0–14.6
No. 200	3.0–7.0

The job mix range for the asphalt binder content was between 5.0 and 5.6 percent by total weight of the mixture.

A Novophalt binder consisting of an AC-20 asphalt cement modified with 5 percent recycled LDPE was selected for the mixture. The asphalt was modified with the polyethylene using a Novophalt high-shear blender at the mix plant.

MIXTURE ANALYSIS

The mixture of granite aggregate and Novophalt was evaluated using Marshall and Texas mixture design procedures. These evaluations produced approximately the same optimum binder content of approximately 4.8 to 5.0 percent. The Marshall stability at this range of binder content ranged from 3,700 to 3,800 lb. The air void in this range of binder contents was approximately 4.0 percent. Marshall flow and voids in the mineral aggregate for the mixture meet requirements established by the Asphalt Institute (*1*).

When the binder content of the mixture was raised to 5.8 percent, the Marshall stability of the Novophalt mixture dropped to about 3,300 lb; the average air void content of the binder-rich specimens compacted at 280°F using 75-blow Marshall compaction was approximately 2.2 percent.

Hveem stabilities were above 40 for the mixture with optimum binder content and dropped to approximately 35 for the binder-rich mixture. Once again compaction was performed at about 280°F. Hveem stabilities and air void contents were also determined on samples compacted at 250°F for the Novophalt mixture. The reduction in compaction temperature significantly affected Hveem stability and air void content of the samples. The result of this effect is that the optimum binder content of the samples compacted at the lower temperature was about 6 percent higher than that of samples compacted at the higher temperature (4.6 versus 4.9 percent). This effect of temperature of compaction on optimum binder content indicates that the initial level of compaction affects the performance of the mixture. This concept has been espoused by Foster (*2*). The influence of level of compaction was evaluated in this study.

The compaction temperatures discussed refer to laboratory compaction. Substantially higher field compaction temperatures may be required to achieve satisfactory results.

STUDY APPROACH

Because the prime objective in this research was to evaluate the effect of binder-rich Novophalt mixtures in the Houston environment specifically for the Hobby runway reconstruction project, primary attention was given to mixture properties related to permanent deformation of the mixture at high temperatures. To evaluate deformation potential of the mixtures, the following tests were performed: (a) uniaxial compressive creep compliance, (b) repeated-load permanent deformation, and (c) incremental static compressive loading. During this testing the following variables were considered ("optimum" refers to optimum according to Marshall mix design):

Test	*Variables*
Creep compliance	Void content (level of compaction): optimum, low (standard, modified) Binder content: optimum, high Asphalt type: modified, unmodified Temperature: high
Repeated-load permanent deformation	Void content (level of compaction): optimum, low (standard, modified) Binder content: optimum, high Asphalt type: modified, unmodified Temperature: high
Incremental static compression	Void content (level of compaction): optimum, low (standard, modified) Binder content: optimum, high Asphalt type: modified, unmodified Aggregate: river gravel

In concert with the evaluation of mixture properties in compressive deformation testing, mixture properties were evaluated during testing in the tensile mode of loading. Specifically, indirect tensile testing (IDT Texas Test Method 226-F) (*3*) was performed at 32°F, 77°F, and 104°F; diametral resilient modulus testing (ASTM D4123) was performed at 4°F, 32°F, 68°F, 77°F, and 104°F; and indirect tensile creep testing was performed at 77°F. Each test was performed at two levels of binder content: optimum (approximately 4.8 percent) and binder-rich (approximately 5.8 percent).

All creep and repeated-load deformation testing results were based on the average of at least two replicate specimens per combination of variables (matrix cell). All tensile test results were based on the average of three replicate specimens per combination of variables.

COMPRESSIVE DEFORMATION TESTING

Testing Techniques and Sample Fabrication

Three types of compressive deformation testing were used: uniaxial compressive creep compliance, uniaxial repeated-load permanent deformation, and uniaxial incremental static creep. Testing was performed on mixtures with optimum binder content (4.8 percent binder) and on binder-rich mixtures (5.8 percent binder). All testing was performed at 104°F. This temperature was determined to be a representative average daily temperature of the upper 2 in. of an asphalt concrete pavement subjected to the climatic conditions in the Houston area during the hottest 180 days of the year (*4*).

All specimens tested were prepared according to the method in the VESYS Users Manual (*5*). The Cox kneading compactor was used for compaction. After compaction, each sample was conditioned in accordance with VESYS procedures. This conditioning consisted of subjecting the sample to three ramp loads and holding these loads for 10 min with minimal unload time between loads. The magnitude of the ramp load was selected so as to remain in the region of loading that would not produce excessive deformation of the sample (i.e., less than 2,500 microstrain). The load used in preconditioning was 10 psi at the 104°F test temperature. The conditioning exercise attempted to simulate the effects of thousands of wheel loads on the pavement. Although the proper conditioning methodology is controversial, the conditioning is expected to affect the final air void contents of the two mixture groups in a manner proportional to their susceptibility to traffic densification.

The initial test philosophy was to compact all mixtures, regardless of binder content, to within the same range of air void content (5.0 to 7.0 percent) and to condition the samples according to the VESYS procedure. This process was intended to simulate construction compaction followed by traffic densification, simulated by the conditioning phase. However, average final air void contents after conditioning and creep testing for the two binder levels were 5.1 and 6.3 percent for the 5.8 and 4.8 percent binder content mixture groups, respectively. The 5.1 percent void content for the mixture with high binder content was *not* thought to be representative of the level of air voids that could be achieved at this high binder content with greater compactive effort. Thus, an increased level of compactive effort was applied using the Cox compactor at 250°F and 280°F.

The level of compactive effort required to produce ultimate densification was determined by trail and error. The compactive efforts used in sample preparation are summarized as follows:

Standard Effort	*Modified Effort*
Layer 1: 30 tamps at 250 psi/tamp	Layer 1: 30 tamps at 600 psi/tamp
Layer 2: 60 tamps at 250 psi/tamp	Layer 2: 60 tamps at 600 psi/tamp
Layer 3: 140 tamps at 250 psi/tamp, 1,000 psi leveling load	Layer 3: 140 tamps at 250 psi/tamp, 1,000 psi leveling load

The average air void contents of the Novophalt mixtures produced by the modified compactive effort were as follows: 4.0 percent (4.8 percent binder, 250°F compaction temperature); 3.8 percent (4.8 percent binder, 280°F compaction temperature); 2.3 percent (5.8 percent binder, 250°F compaction temperature); and 1.6 percent (5.8 percent binder, 280°F compaction temperature). Control mixtures of crushed granite aggregate and AC-20 asphalt (unmodified) were compacted at 250°F using standard compaction efforts. The resulting average air void contents were 5.8 percent for the mixtures with optimum binder content and 1.8 percent for the binder-rich mixtures.

Findings

Results of uniaxial compressive creep testing are summarized in Figures 1 and 2. The data in Figure 1 demonstrate a very small change in creep compliance for the optimum and binder-rich Novophalt mixtures when the mixtures were compacted to air void contents from 5.0 to 6.5 percent. Note the very

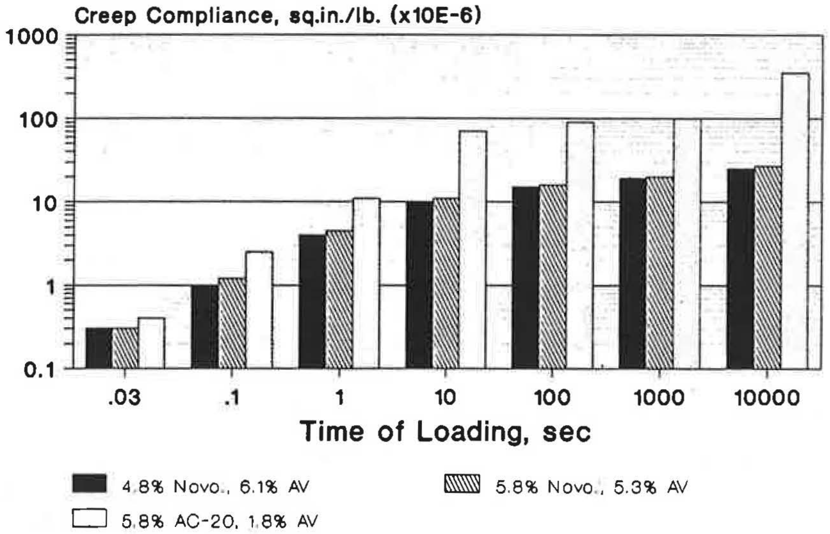

FIGURE 1 Creep compliance versus time of loading for optimally designed and binder-rich Novophalt mixtures compacted to 5.0 to 6.5 percent air void content and binder-rich control mixture.

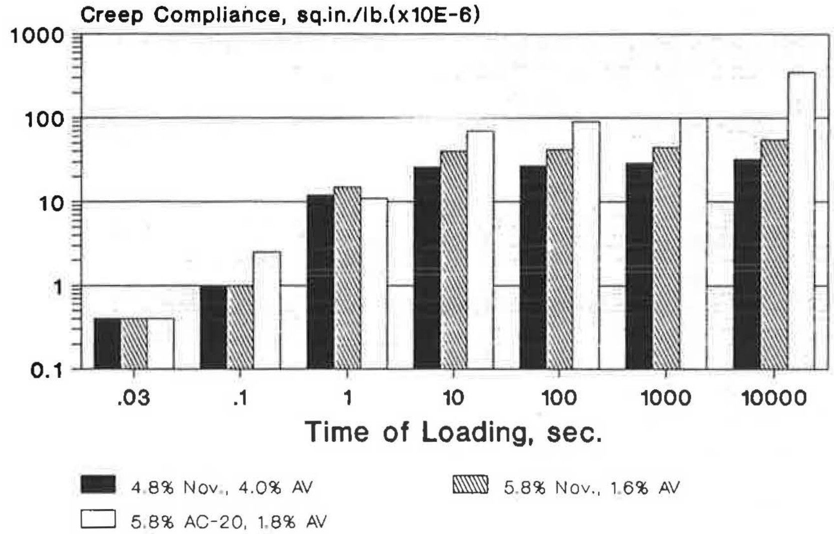

FIGURE 2 Creep compliance versus time of loading for optimally designed and binder-rich Novophalt mixtures compacted to ultimate (low) air void content and binder-rich control mixture.

high compliance for the control mixture, which is a binder-rich AC-20 mixture with a low air void content (1.8 percent). Figure 2 shows creep compliance data following compaction to ultimate air void contents. In this case, the difference between optimum and binder-rich Novophalt mixtures is more noticeable. However, the compliance of the binder-rich Novophalt mixture at 1.6 percent air voids remains substantially less than that of the AC-20 control mixture compacted to an air void content of 1.8 percent.

A critical level of creep compliance was calculated using the modified Shell procedure (*6*), cross-sectional data for the Hobby runway pavement, and contact tire pressure data for the DC-9 aircraft (100,000 passes). The modified Shell equation states

$$\Delta h_{\mathrm{Total}} = \sum_{i=1}^{n} \Delta h_i = \sum_{i=1}^{n} h_i \cdot A_i \cdot \sigma_i \cdot D_i$$

where

Δh_i = change in height of each sublayer;
h_i = thickness of each sublayer; and
A_i = stress factor relating laboratory stress (σ_{lab}, used in obtaining creep compliance D_i) to in situ stress within the sublayer σ_i, $A_i = (\sigma_i/\sigma_{\mathrm{lab}})^{1.61}$ after Regress 6.

By assigning a maximum tolerable deformation within the pavement of 0.125 in. for 100,000 applications of the DC-9 aircraft and by assuming an average annual daytime temperature of 104°F in the hottest 180 days of the year, a design or critical average creep compliance was calculated as 0.000060 in.^{2}/lb. This value is plotted in Figures 1 and 2. The plot of this value can be used to judge the adequacy of the mixture based on creep compliance data. The time of loading of 10,000 sec corresponds to 100,000 load applications (100,000 applications times 0.1 sec of dwell time per load application).

Based on the critical level of compliance (0.000060 in.^{2}/lb), both optimum and binder-rich Novophalt mixtures are quite acceptable when air void contents of the mixture are within the 5.0 to 6.5 percent range (Figure 1). When compacted to ultimate air void contents (Figure 2), the Novophalt mixture with optimum binder content is quite adequate; the binder-rich Novophalt mixture is adequate, although it approaches the design compliance at 10,000 sec; and the binder-rich AC-20 mixture compacted to ultimate air voids demonstrates a compliance at 10,000 sec (approximately 0.000350 in.^{2}/lb), which is approximately six times the design compliance (0.000060 in.^{2}/lb).

Figures 3 and 4 show accumulated permanent strain data versus loading applications. Once again, data in Figure 3 are for samples compacted using a standard compaction effort, and data in Figure 4 are for the modified compactive effort resulting in minimum air void levels. The trend is essentially the same as for the creep compliance testing. There is essentially no difference in the optimum binder content and the binder-rich Novophalt data when the samples are compacted to air void contents within the 5.0 to 6.5 percent range, as shown in Figure 3. However, when the samples are compacted to ultimate or low air void contents, as shown in Figure 4, a greater difference in deformation results between the optimum binder content mixture and the binder-rich mixture. However, the binder-rich Novophalt mixture is still substantially more resistant to permanent deformation than the control mixture, which failed at 20,000 cycles of loading.

Figure 5 further illustrates mixture sensitivity to binder content of polyethylene-modified binders. This figure shows the changes in the permanent strain determined from incremental static deformation testing on a siliceous river gravel mixture. The height of each bar in the figure represents the increase in permanent strain for the particular mix in question over the control mix at the same time of incremental loading. The control mixture was an optimally designed river gravel mixture with binder of either AC-20 or AC-20 plus LDPE (Novophalt). In the figure, binder-rich mixtures with the traditional and Novophalt binders were compared with the optimal

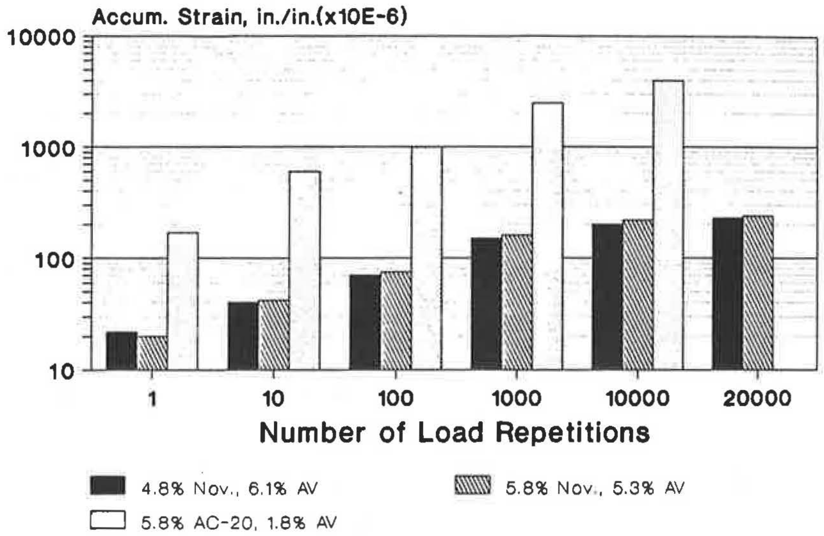

FIGURE 3 Accumulated permanent strain versus loading repetitions for optimally designed and binder-rich Novophalt mixtures compacted to 5.0 to 6.5 percent air void content and binder-rich control mixture.

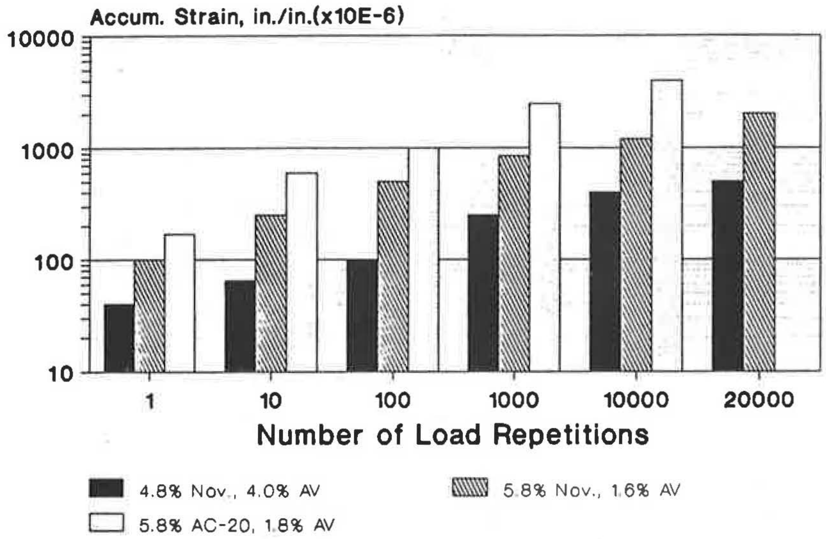

FIGURE 4 Accumulated permanent strain versus loading repetitions of optimally designed and binder-rich Novophalt mixtures compacted to ultimate (low) air void content and binder-rich control mixture.

(control) mix with the traditional and Novophalt binders, respectively. In each case (traditional and Novophalt) the binder-rich mixture consisted of 1.15 percent of the optimum level of binder.

Figure 5 clearly shows the significant influence of binder type (Novophalt versus unmodified AC-20) and level of compaction. For the granite mixture, Novophalt is substantially more resistant to deformation than the traditional mix for all conditions evaluated. Of most significance is the level of increase in deformation for the binder-rich Novophalt mixture compared with the level of increase for the binder-rich traditional mixture.

TENSILE TESTING

Resilient Modulus

Diametral resilient modulus testing was performed in accordance with ASTM D4123 at the nominal high average surface temperature of 104°F for a mixture containing the granite aggregate used at Hobby Airport and a river gravel aggregate used as a laboratory standard at TTI because of its sensitivity to binder properties and binder content. Figure 6 shows that the binder-rich modified mixture retains a resilient modulus that is substantially greater than that of the control mixture

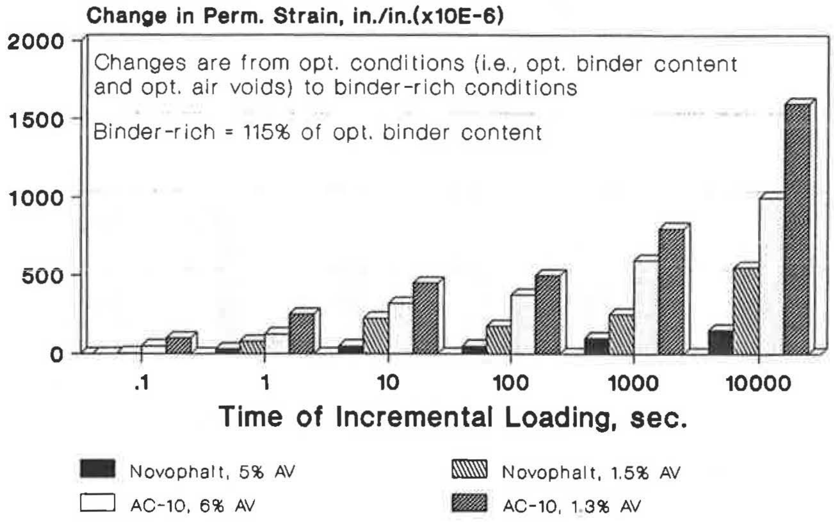

FIGURE 5 Changes in permanent strain comparing two binder-rich Novophalt mixtures (low and high levels of densification) with an optimally designed Novophalt mixture and two binder-rich traditional mixtures (low and high levels of densification) with an optimally designed traditional mixture.

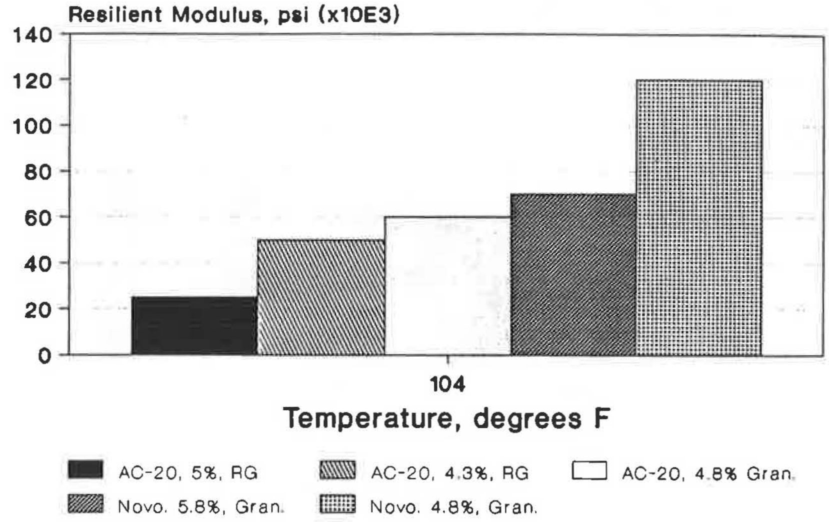

FIGURE 6 Comparison of resilient moduli at 104°F for selected mixtures of Novophalt and traditional asphalt.

at the optimum binder content. The optimum and binder-rich river gravel mixtures are included in the analysis simply to demonstrate the sensitivity of mixtures to binder content when traditional, unmodified binders are used. The ability of binder-rich polyethylene-modified mixtures to retain a higher level of resilient modulus is significant because this higher level indicates an improved load-spreading capability of the asphalt layer.

Indirect Tensile Testing

Indirect tensile strength testing was performed at three temperatures: 32°F, 77°F, and 104°F at a stroke rate of 2 in./min. Figure 7 summarizes the results of this testing for the optimum and binder-rich mixtures. All samples were compacted to ultimate (low) air void contents. This figure shows that the toughness, or area under the stress-strain plot, is significantly greater for the binder-rich mixtures than for the optimum mixtures of the polymer-modified (Novophalt) mixture.

Toughness is often used as a relative indicator of the resistance of an asphalt concrete mixture to fracture, either fatigue-related or temperature-related (7). High toughness values indicate greater resistance to fracture, and low toughness values indicate lower resistance to fracture. Materials with high toughness values have high potential to absorb energy without fracture. The primary significance of the data plotted in Figure 7 is that the binder-rich Novophalt mixture provides significantly higher toughness and thus greater resistance to fracture across the entire temperature range evaluated.

The trend toward greater resistance to fracture due to the use of higher binder contents is substantiated by the results of indirect tensile creep testing data, shown in Figure 8. These tests were performed at 77°F under a constant stress level of 20 psi. The slope of the binder-rich Novophalt mixtures in the steady-state region of the creep test is substantially higher than the comparative slope for the Novophalt mixtures with the optimum binder content. This slope indicates the rate of energy dissipation of the mixture under load. A faster rate of energy dissipation indicates the ability to absorb energy without fracture. Thus, mixtures with steeper slopes in the steady-state region of the tensile creep test indicate mixtures with lower fracture potential.

Schapery (*8*) has demonstrated that by applying viscoelastic fracture principles, the constants K_1 and k_2 in the phenomenological fatigue relationship [$\log N = \log K_1 + k_2 \log (1/e_t)$, where N is number of loading applications and e_t is the repeated level of tensile strain] can be calculated as a function of the slope of the steady-state region of the tensile creep curve. In fact, Schapery has shown the parameter K_2 to be very simply related to the slope of the steady-state region of the creep compliance curve (m) as $k_2 = 2/m$. Also, Al-Balbissi and Little (*9*) have established that the magnitude of the shift factor between laboratory and field fatigue data is directly related to the slope of the steady-state creep curve because this slope indicates the rate at which the mixture can relax and dissipate residual stresses.

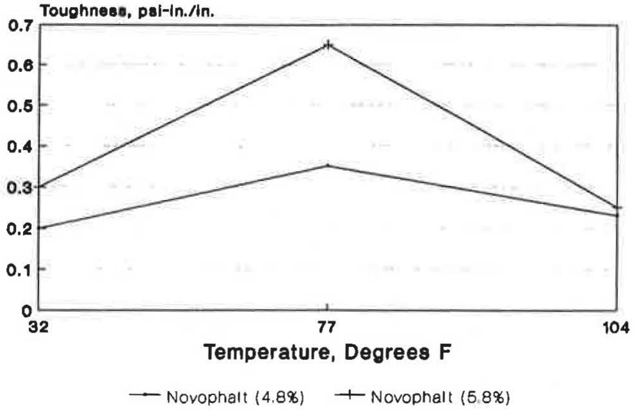

FIGURE 7 Comparison of toughness of optimally designed and binder-rich Novophalt mixtures determined from indirect tension testing at 32°F, 77°F, and 104°F.

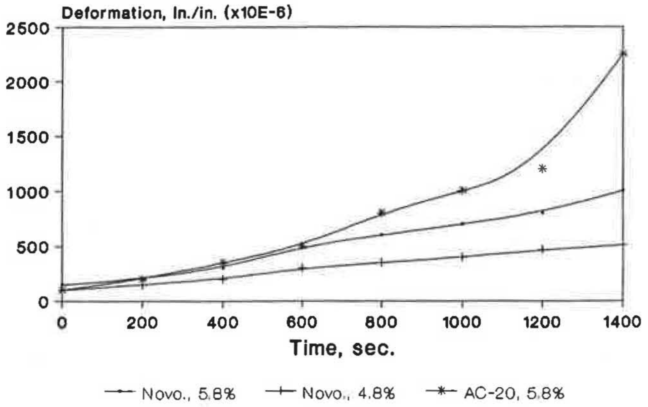

FIGURE 8 Indirect tensile creep data at 77°F, 20 psi stress level, comparing optimally designed and binder-rich Novophalt mixtures and unmodified AC-20.

The control mixture shown in Figure 8 is a binder-rich AC-20 mixture. This mixture exhibits an even higher slope than the binder-rich Novophalt sample. However, the steady-state region of this mixture is substantially less under the 20-psi stress level. The time to rupture of the binder-rich control mixture is substantially shorter than the time to rupture for either Novophalt mixture. Time to rupture indicates flexural fatigue potential. Kennedy (*10*) has empirically demonstrated a relationship between time to rupture in the indirect tensile creep test and number of loading cycles to failure in repeated-load indirect tensile fatigue tests. Thus, a middle ground must be sought in optimizing mixture properties related to fracture and fatigue. This middle ground is characterized by the ability to effectively dissipate energy without fracture and at the same time resist accumulated damage (plastic damage) leading to fatigue failure. In this case, the binder-rich Novophalt mixture appears to achieve this middle ground.

Another indication of the linkage between fracture potential and binder content is work done by Molenaar (*11*). Molenaar demonstrated the relationship between fracture toughness (K_{1c}) and air void content for a gravel and sand mixture (Figure 9). Note that reducing the air void content substantially improves the value of K_{1c}. Of course, reducing binder content lowers air void content.

DISCUSSION OF FINDINGS

This study indicates that the binder-rich Novophalt mixtures used at Hobby Airport should perform well and resist rutting and *may* have improved fracture resistance compared to the Novophalt mixture with optimum binder content. The results of this study point out some interesting general trends:

1. Binder-rich polymer-modified asphalt (Novophalt) mixtures are substantially less susceptible to rutting or permanent deformation than are binder-rich traditional mixtures even when the polymer-modified mixtures are compacted to air void contents well below the level producing plastic flow (less than 3 percent air voids) and are tested at high temperatures (104°F).
2. The level of initial compaction has a pronounced influence on the deformation potential of the polymer-modified mixtures.
3. Binder-rich polymer-modified mixtures demonstrate a higher resistance to fracture than do mixtures with optimum binder contents.

These trends indicate that certain specific pavement applications may be better satisfied by polymer-modified mixtures (Novophalt) that are slightly binder-rich. These mixtures would provide increased resistance to cracking due to thicker binder films and improved durability mainly because of substantially

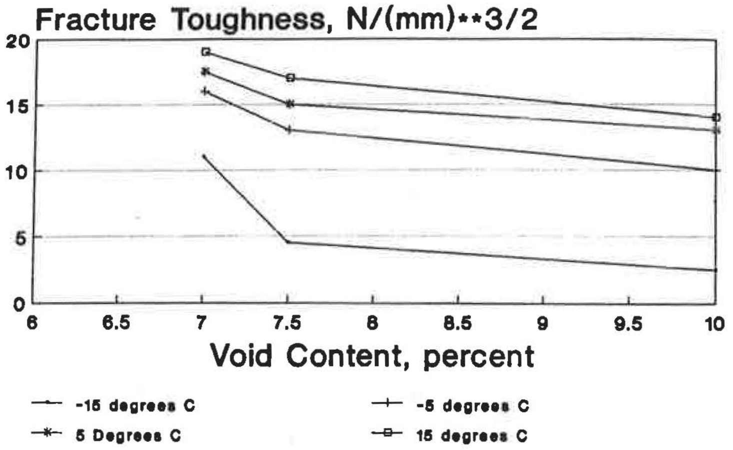

FIGURE 9 Influence of void content and temperature on fracture toughness of gravel sand asphalt mixes (*11*).

reduced permeability to air (oxidation) and water (stripping). Pallotta (*12*) has provided evidence that supports the use of binder-rich polyethylene-modified asphalt concrete on bridge decks in Europe. Pallotta reported on Novophalt in Italy with binder contents in the range of 20 to 25 percent above the optimum binder level; these mixtures were still mechanically more stable than a comparable unmodified mixture at the optimum binder content. Based on these Italian data, binder-rich Novophalt mixtures have been laid whenever impermeability and durability were a major concern. The preferred air void content range was 2 to 3 percent for the binder and wearing courses, based on the Italian data (*12*). Actual air void contents in the range of 1 to 2 percent provided stable Novophalt mixtures.

A U.S. Army Corps of Engineers study (*13*) provides additional evidence that binder-rich mixtures provide better resistance to permanent deformation even at very low air void contents than do traditional mixtures. This study compared properties of asphalt mixtures modified with several different modifiers including oxidants, styrene-butadiene-styrene, ethylene–vinyl acetate, polyethylene, and AC-40 asphalt cement. Three variables were evaluated in mixtures with each modifier: (a) binder content, (b) modifier content, and (c) asphalt cement source. Binder contents evaluated were optimum, 80 percent of optimum, and 120 percent of optimum.

The Corps of Engineers study (*13*) states that "the polyethylene-modified blends were less sensitive to all three matrix variables as a whole when compared to most of the modifiers of this study."

The variation in air void contents in this study produced by varying the compactive effort and compaction temperature had a pronounced effect on the susceptibility of the mixtures to uniaxial compressive repeated-load permanent deformation. Binder-rich polyethylene-modified mixtures compacted to air void contents of 5.0 to 6.5 percent produced substantially reduced permanent deformation when compared with binder-rich mixtures compacted to ultimate (low) air voids (1.0 to 2.0 percent). In fact, the binder-rich mixtures compacted to high air void contents demonstrated a permanent deformation potential that was essentially identical to that of the optimally designed mixture.

The influence of level of compaction on ultimate air void content, and hence rutting potential, has been addressed by Foster (*2*) for traditional (unmodified mixtures). In this study, Foster states:

> Review of existing literature shows that densification occurred at a very rapid rate in the first few months of traffic followed by a much slower rate for the next five years after which no further densification occurred. This review shows *conclusively* that the density to which a pavement is rolled controls the density that develops in both stages.

Foster further presents data demonstrating that the ultimate densities of mixtures with both soft and stiff binders are controlled by the construction density. The stiffer binders, as expected, allow considerably less additional densification than do the soft binders. These results are shown in Figure 10. This trend indicates not only the importance in initial compaction but also the influence of binder stiffness. It is logical to extend this trend to polymer-modified binder systems, which are less resistant to plastic deformation than are traditional mixtures at high temperatures. Thus, the deformation of the polymer-modified asphalt may well be more greatly influenced by initial compaction than would traditional mixtures.

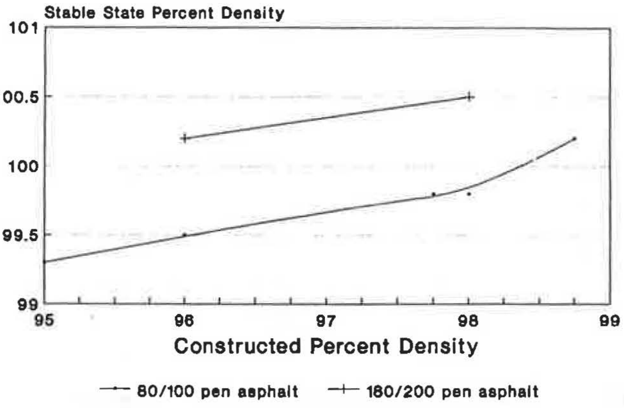

FIGURE 10 Evaluation of effect of construction densification on stable-state air void content of asphalt concrete (*2*).

CONCLUSIONS

1. Binder-rich polyethylene-modified mixtures (Novophalt) are substantially more resistant to permanent deformation than are binder-rich traditional systems.

2. Even when binder-rich polyethylene-modified mixtures are compacted to air void contents below 3 percent, their resistance to permanent deformation is substantially superior to that of binder-rich traditional mixtures.

3. Binder-rich Novophalt mixtures are sensitive to the level of initial densification. Reducing the level of initial densification from the 1.0 to 2.0 percent air void range to the 5.0 to 6.5 percent air void range results in permanent deformation in binder-rich Novophalt mixtures that is not significantly greater than that of optimum binder content Novophalt mixtures. It appears that mixtures prepared using modified binders are substantially more resistant to densification than are traditional (unmodified) mixtures even if the mixtures are binder-rich. This conclusion is based on results of repeated-load permanent deformation testing of polyethylene-modified and unmodified mixtures. Apparently the rheological change in the binder caused by polyethylene modification is responsible for the resistance of the mixture to postconstruction densification and hence superior resistance to rutting. This finding indicates that the resistance to permanent deformation of binder-rich polyethylene-modified mixtures can be significantly improved by controlling the level of density achieved at construction.

4. Binder-rich Novophalt mixtures with low air void contents, because of their ability to absorb energy, possess greater potential to resist fracture than do optimum binder content mixtures.

5. Binder-rich Novophalt mixtures may have applications in specialized situations that require lower air and water permeability and greater resistance to fracture while still maintaining acceptable resistance to permanent deformation. These applications have been demonstrated successfully in field applications in Italy.

6. These results in no way suggest that traditional mixture design methodologies and criteria be abandoned. The results simply indicate that polymer-modified binder systems such as Novophalt are very different rheological systems than traditional binder systems. Consequently, for certain applications, a polyethylene-modified mixture with a higher binder content may provide a more effective system.

7. Runway 17-35 at Houston Hobby Airport continues to perform well 2 years after construction with no signs of cracking or permanent deformation.

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