Survey of State Highway Authorities and Asphalt Modifier Manufacturers on Performance of Asphalt Modifiers

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One of the key objectives in the first phase of a Strategic Highway Research Program (SHRP) contract was to identify asphalt modifiers with varying levels of pavement performance. Key pavement distress categories identified by SHRP were fatigue cracking, low-temperature cracking, moisture susceptibility, permanent deformation, and aging. These modifiers will be used in the second phase to evaluate laboratory binder and mixture tests suitable for development of performance-based specifications. Information on asphalt modifiers was obtained from state highway authorities and asphalt modifier manufacturers. The questionnaire results were analyzed, and modifiers with varying levels of performance were identified. Performance ratings for the modifiers evaluated are presented for each pavement distress category.

One of the key objectives in the first phase of a Strategic Highway Research Program (SHRP) contract was to identify asphalt modifiers with varying levels of pavement performance. Key pavement distress categories identified by SHRP were fatigue cracking, low-temperature cracking, moisture susceptibility, permanent deformation, and aging. These modifiers will be used in the second phase to evaluate laboratory binder and mixture tests suitable for development of performance-based specifications. Information on asphalt modifiers was obtained from state highway authorities (SHAs) and modifier manufacturers (MFGs). Information was secured by issuing questionnaires to the SHAs and MFGs. The data gathered were organized into two categories: (a) nonperformance-related data and (b) performance-related data.

Nonperformance-related data were gathered for future use in the second and third phases of the program to assist in developing the following:

1. Cost-benefit relationships,
2. Modifier implementation guidelines, and
3. Specifications.

The primary goal of the questionnaires was to obtain data about the historical performance of modifiers. These data were further separated into three performance categories:

1. Binder test data,
2. Mixture test data, and
3. Test pavement performance data.

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Figure 1 illustrates the approach used to determine modifier performance from the analysis of questionnaire data. The selected performance-related data, the methodology used to analyze the responses, and the questionnaire results are discussed.

The SHAs returned 45 questionnaires, a 90 percent response rate. The MFGs returned 30 questionnaires, a 42 percent response rate.

NONPERFORMANCE-RELATED DATA

The nonperformance-related inquiries on the SHA questionnaire were designed to collect information on the current uses of asphalt modifiers and to assist in projecting trends in the field.

One of the primary nonperformance-related questions was, What modifiers have been most commonly used by SHAs based on the modifier classification system presented in Table 1? Table 1 details the responses. More than half of the SHAs that responded have used some form of polymers, antistripping agents, and filler/fibers/extenders.

The second question was directed at determining the most common application of asphalt modifiers. Table 2 outlines the results. Based on these data, the construction of hot-mix asphalt concrete (HMAC) overlays is the most common use of asphalt modifiers.

The third inquiry was designed to establish why asphalt modifiers have been used. This was determined by identifying which of the key pavement distresses were expected to be improved by asphalt modifiers. The results in Table 3 indicate that all of the distresses are cited nearly equally. The nearly equal distribution of the responses is most likely because of required design criteria, regional variations in available construction materials, and variable environmental conditions.

The fourth inquiry was developed to give an indication of how modifier performance was being evaluated by SHAs. Many states are actively involved in field research projects designed to determine the long-term performance of modifiers. The responses in Table 4 indicate that detailed high-quality performance evaluations focused on long-term pavement performance are occurring throughout the SHAs.

The types of nonperformance-related data accumulated from the MFG questionnaire include the modifier's physical, chemical, and environmental characteristics; mechanism respon-

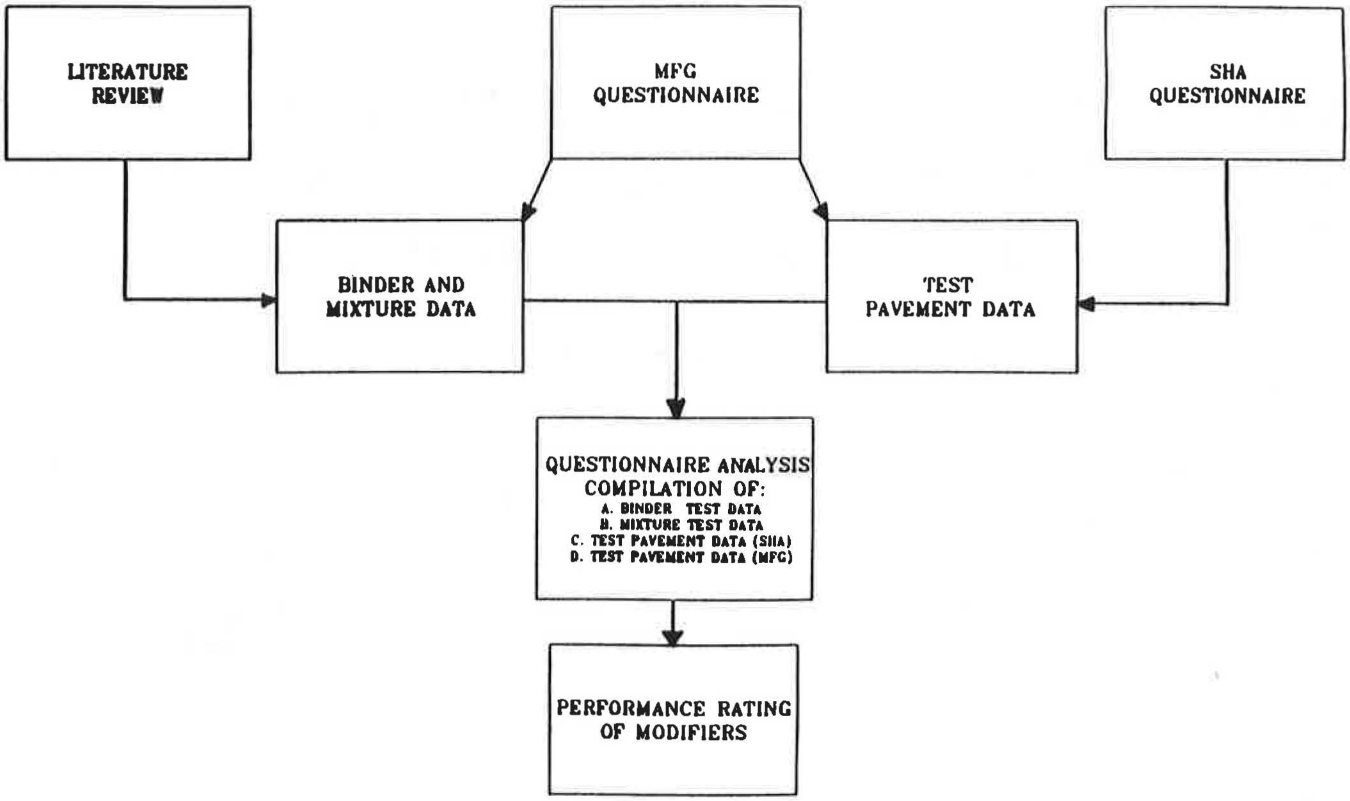

FIGURE 1 Flow chart for questionnaire data analysis.

TABLE 1 ANALYSIS OF SHA QUESTIONNAIRES: MODIFIERS MOST COMMONLY USED

Modifiers	Responses (Percent)
A. Polymers	86
B. Anti-Stripping Agents	77
C. Fillers/Fibers/Extenders	59
D. Recycling Agents	43
E. Catalyst	25
F. Aging Inhibitors	16
G. Others:	
Ground Tire Rubber	36
Gilsonite	9
Trinidad Lake Asphalt	7

sible for effectiveness; hot-mix production and laydown; cost analysis; and unique beneficial factors. The results from these data will assist in estimating cost-performance relationships and generating guidelines for the effective implementation of asphalt modifiers.

PERFORMANCE-RELATED DATA

Performance-related data accumulated from the SHA questionnaire, MFG questionnaire, and a literature review were used in the modifier selection process. As described earlier,

TABLE 2 ANALYSIS OF SHA QUESTIONNAIRES: TYPE OF CONSTRUCTION IN WHICH MODIFIERS ARE MOST COMMONLY USED

Type of Construction	Responses (Percent)
A. HMAC Overlays	49
B. Seal Coats	36
C. Asphalt Treated Base	10
D. Others:	
Open Graded Friction Course	4
Intersection Mixes	1

TABLE 3 ANALYSIS OF SHA QUESTIONNAIRES: PRIMARY TARGETED PAVEMENT DISTRESS

Distress	Responses (Percent)
A. Permanent Deformation	24
B. Fatigue Cracking	20
C. Moisture Susceptibility	21
D. Low Temperature Cracking	20
E. Aging	15

TABLE 4 ANALYSIS OF SHA QUESTIONNAIRES: PERFORMANCE EVALUATION METHODS

TPDS Responses	Responses (Percent)
Condition Survey	
Visual	80
Accepted Industry Method	50
(Rating Index, PCI, etc.)	
Method of Performance Evaluation	
Lab Evaluation of Cores	71
Skid Tests	48
Deflection Measurements	43
Roughness Measurements	41
Rut Depth Determinations	16
Long-Term Evaluation Program	71

TABLE 5 TESTS REPORTED TO CORRELATE TO PAVEMENT PERFORMANCE USED IN MODIFIER EVALUATION PROCESS

Distress	Binder Test	Mixture Test
Moisture Susceptibility		Indirect Tensile Strength Ratio *(1)*
		Immersion Compression *(2)*
Low Temperature Cracking	Penetration @ 4°C *(3)*	Resilient Modulus @ 4°C *(8)*
	Fraass Brittle Point[1] *(4)*	Creep Stiffness @ 4°C *(8)*
	Low Temperature Ductility *(5)*	
	PVN *(6,7)*	
Aging	Aging Index (Vis. @ 60°C) *(9)*	
Fatigue Cracking	Penetration @ 4°C[1] *(3)*	
	Asphalt Modulus[1] *(3)*	
	Viscosity @ 60°C *(10)*	
Permanent Deformation	Viscosity @ 60°C *(10)*	Resilient Modulus @ 25°C, 40°C *(11)*
	Penetration @ 4°C[1] *(3)*	Creep Stiffness @ 25°C, 40°C *(12)*
	Penetration @ 25°C[1] *(3)*	

Note: 1. Performed on aged residue.

the accumulated data were categorized into the following performance categories:

1. Binder test data,
2. Mixture test data,
3. Test pavement performance data submitted by SHAs, and
4. Test pavement performance data submitted by MFGs.

One of the initial tasks was to determine which binder and mixture test properties correlated to pavement performance. Numerous physical, chemical, and rheological tests are used to characterize asphalt binders and mixtures. However, only a few tests have been reported to correlate with pavement performance. A literature review was performed to identify binder and mixture test results reported to correlate to field performance.

Binder and Mixture Test Data

Table 5 provides an overview of binder and mixture tests that were reported in the literature to correlate with pavement performance (*1–11*, ASTM D175). Results from these tests reported in the questionnaires were used in the analysis.

The effect of a given modifier on the identified test result compared with that of the original asphalt was determined for the tests listed in Table 5. It was established whether the change represented a positive or negative influence on the performance of the binder or mixture.

Test Pavement Performance Data

The most important function of the questionnaires was to secure data on the field performance of modifiers. These data were gathered from test pavement data sheets (TPDSs) contained in the questionnaires. An example of a TPDS is presented in Figure 2. Three categories of information were se-

Test Pavement Data Sheet (TPDS):

A. Location of Test Pavement:

State: ________
Highway: ________ (Example: 2 mi. West of Houston on IH-10)
Lane: ________ (Example: West bound inside lane)
Traffic Volume: ____/____ (ADT/%Trucks)
Structural Cross-section: ____/____/____ (inches HMAC/inches of base/inches of sub-base)
Date test pavement was placed: __/__/__

B. Type of modifier used in the test pavement:
Name: ________________

C. Cite the methods used for the conditions survey:

[ ] None
[ ] Visual
[ ] Rating Index, PCI, etc.
[ ] Other, specify: ________________

D. Date of the most recent survey: __/__/__

E. Cite the method or methods used to determine roadway performance:

[ ]	None	[ ]	Visual
[ ]	Evaluation of cores	[ ]	Skid Test
[ ]	Deflection measurements	[ ]	Roughness measurements

F. Is there a long-term evaluation program?

[ ] Yes, specify interval of inspection: ________ [ ] No

G. What was the apparent effect of the modifier on the following performance categories?

	Adverse Effect	Minor Adverse	No Effect	Minor Positive	Positive Effect
Fatigue	[ ]	[ ]	[ ]	[ ]	[ ]
Low Temp. Cracking	[ ]	[ ]	[ ]	[ ]	[ ]
Permanent Deformation	[ ]	[ ]	[ ]	[ ]	[ ]
Aging	[ ]	[ ]	[ ]	[ ]	[ ]
Moisture Susceptibility	[ ]	[ ]	[ ]	[ ]	[ ]

FIGURE 2 Example of test pavement data sheet included in questionnaire.

cured from the TPDS. The first category of information solicited was qualifying data, such as environment, date of placement, structural cross section, and traffic volume. This type of data aided in the interpretation of results from the modifier performance response in the TPDS. The qualifying data are represented by Item A in Figure 2.

The second type of performance data in the TPDS was used to validate the responses associated with performance. These were condition survey, date of most recent survey, method of performance evaluation, and long-term evaluation program. These are represented by Items C, D, E, and F in Figure 2.

The final type of data solicited from the TPDS was a rating of the actual performance of the test pavement. The inquiry for pavement performance is represented by Item G in Figure 2.

The performance of the pavement was determined for each TPDS submitted. The TPDS results were then collated by modifier. The results for individual modifiers were evaluated to establish a level of performance for the modifiers.

Data Secured from SHA Questionnaires

Test pavement performance was the only performance-related data requested in the SHA questionnaires.

A total of 337 TPDS were submitted by the SHAs. A data base of SHA TPDSs containing pertinent information associated with the individual test pavements was developed using Lotus-Symphony software. The data base is organized into 11 data fields. The data may be sorted for analysis as follows:

1. Location
   - State
   - Highway
2. Placement date
3. Modifier class
4. Modifier name
5. Modifier performance
   - Fatigue
   - Low-temperature cracking
   - Permanent deformation
   - Aging
   - Moisture Susceptibility
   - Overall

Some of the 337 TPDS submitted were not used in the selection process. These TPDS were eliminated for one or more of the following reasons:

1. Modifier was used in application other than HMAC overlay construction.
2. Pavement had been in service for too short a time for an adequate evaluation of modifier performance.
3. Judgment of performance was not submitted with the TPDS and could not be established through follow-up contracts with the monitoring agency.

Of the 337 TPDSs submitted, 126 TPDSs were used in the evaluation process.

Data Secured from MFG Questionnaires

Binder and Mixture Test Data

The results of 580 binder and mixture test results were accumulated for use in the questionnaire evaluations. A total of 254 binder and mixture test results were secured from the MFG questionnaires. This data set was complemented with an additional 326 results secured by the following:

1. Reviewing the available literature on asphalt modifiers,
2. Identifying articles with the appropriate test data, and
3. Converting the data into the format requested in the MFG questionnaires (i.e., percentage change in property).

Test Pavement Performance

A total of 195 TPDSs were submitted by the MFGs. The information from these TPDSs was organized and managed in the same manner as TPDSs submitted by the SHAs to create an MFG TPDS data base. The data organization and management was described above.

A total of 96 of the 195 MFG TPDSs submitted were used in the modifier evaluation. The remaining 99 MFG TPDSs were eliminated from the selection process for reasons stated in the discussion of the SHA TPDS.

QUESTIONNAIRE ANALYSIS

The method for analyzing data from the questionnaires is described. The range of scores resulting from the analysis is +100 to −100. Positive scores indicate a positive influence on pavement performance. Negative scores indicate a negative influence on pavement performance.

Determine Relative Worth of Performance Categories

The following four performance categories described earlier were used in establishing various levels of modifier performance:

1. Test pavement performance evaluations by SHAs,
2. Test pavement performance evaluations by MFGs,
3. Mixture test data, and
4. Binder test data.

Table 6 lists the relative-worth ranking assignments for each of the performance categories. The magnitude of these assigned weights was based on input from SHRP. The test pavement results reported by the SHAs were weighted highest at 40 percent for all pavement distresses except fatigue cracking, where it was weighted at 60 percent. This was done because of a lack of sufficient mixture test data for fatigue cracking

TABLE 6 RELATIVE WORTH ASSIGNED TO PERFORMANCE CATEGORIES

PERFORMANCE CATEGORY	PAVEMENT DISTRESS				
	Permanent Deformation	Fatigue Cracking	Thermal Cracking	Aging	Moisture Susceptibility
Binder Tests	10	10	10	30	0
Mixture Tests	20	(Note 1)	20	0	30
Test Pavements (SHA)	40	60	40	40	40
Test Pavements (MFG)	30	30	30	30	30
TOTAL	100	100	100	100	100

Note 1: Sufficient test data was not available.

from the MFG questionnaire. The second highest weight was assigned to the test pavement results as reported by the MFGs. This category was assigned a relative worth of 30 percent for all pavement distresses.

The primary factor considered in the analysis was the effect of the modifier on pavement performance. The combined worth for test pavement performance ranged from 70 to 90 percent of the total. Because of uncontrolled variables associated with test pavements, the binder and mixture test data were assigned an appreciable relative worth because they represented a consistent and controlled source of data.

A combined relative worth of 30 percent was assigned to binder and mixture test data. It was determined that assigning this relative worth to the binder and mixture data would not mask the actual results of pavement performance.

In two cases, it was necessary to combine the relative worth of the binder and mixture test data categories. Mixture test data were eliminated from the selection process for aging because aging was primarily considered to be a binder phenomenon. However, it is recognized that air void content influences aging in asphalt mixtures. The binder category was eliminated as a performance indicator for moisture susceptibility. This phenomenon was considered to be primarily controlled by asphalt-aggregate interactions.

Binder and Mixture Test Data Analysis

The binder and mixture test data available for the evaluation of the modifiers were sorted by individual test properties. A histogram was generated for the available test data for the individual tests.

Figure 3 is an example of a histogram illustrating the percentage change in the penetration of neat asphalts at 4°C resulting from modification with various modifiers. The horizontal axis represents the percentage change in a given property caused by the use of modifiers. The vertical axis labeled "count" represents the number of responses that fall in a given range. The second vertical axis, labeled "proportion per standard unit," is a probability density scale that represents the probability that a given response will occur in any given response range based on the theoretical distribution of the data.

The identical exercise was performed for all of the test procedures listed in Table 5. Generating histograms was the first step in the process for the numerical analysis of the binder and mixture test data.

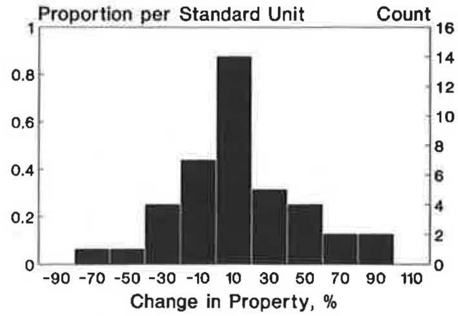

FIGURE 3 Histogram generated for change in penetration at 4°C, as the result of modification.

After the histograms were generated, they were reviewed to identify "natural breaks" in the data. These breaks were used to establish the boundaries of the response ranges. The response ranges were incorporated into the ranking guides. The ranking guides are score cards that were filled out from the collected data. Ranking guides were completed for all of the modifiers in each distress category. The score of the binder and mixture data sections were normalized to match the relative worths presented in Table 6.

Figure 4 is a histogram that shows the frequency distribution for percent change in penetration at 4°C as a result of asphalt modification. The histogram is divided into six areas that represent six natural breaks in the data. A decrease in penetration is represented by negative values. An increase in penetration at 4°C is reported to result in a higher susceptibility to permanent deformation (*2*). Therefore, a score of −8 implies that a modifier has a high susceptibility to permanent deformation. By comparison, a score of +8 implies that a modifier has an increased resistance to permanent deformation.

Three positive ranges and three negative ranges were identified. The exact score depends on the numerical value of the percent change. The ranking guides were developed from this scoring system. The section of the ranking guide for permanent deformation corresponding to penetration at 4°C is shown at the top of Figure 4. The values assigned to the response ranges are transposed into the ranking guide.

Test Pavement Performance Data Analysis

The questions in the test pavement performance section were divided into three categories to establish the effects of a given

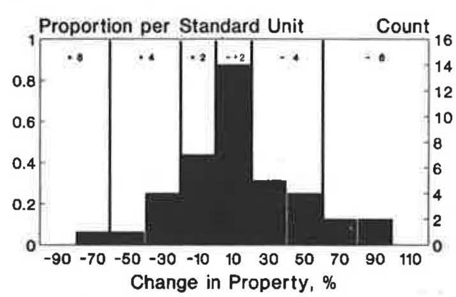

FIGURE 4 Histogram generated for penetration at 4°C with response ranges identified.

modifier on pavement performance. The first type of question was designed to solicit qualifying data. These questions aided in the analysis of a questionnaire respondent's judgment of the test pavement performance.

The second type of question was aimed at establishing the reliability or validity of the response. The third type of question was designed to establish an estimate of the modifier performance for each pavement distress category.

Questionnaire Responses Associated with Pavement Performance

To validate the reliability of the test pavement performance response, inquiries from the questionnaires were assigned a numerical value. These values were based on the positive or negative impact of the response on the validation of the performance of the test pavement (Table 7).

Positive responses indicated that a high degree of reliability should be assigned to the pavement performance response. If all responses are positive, the total score (S) is 7; if all the responses are negative, corresponding to poor reliability, S is -4.

Reliability Factor

Based on the score (S) achieved from the validation questions, a reliability factor (W) was established, which corresponds to the reliability of the responses discussed above. The reliability factor was based on the following scheme:

if $-4 > S < 0$, then $W = 0.6$
if $0 > S < 3$, then $W = 0.8$
if $3 > S < 7$, then $W = 1.0$

Performance Responses

In both questionnaires, questions associated with determining the influence of modifiers on pavement performance were posed. The potential responses were as follows:

Influence	*Value Assigned to Levels of Performance*
No effect	0
Minor adverse effect	−1
Adverse effect	−2
Minor positive effect	+1
Positive effect	+2

The numbers in the brackets represent the value assigned for quantification of the perceived levels of pavement performance. These values were regarded as uncorrected performance scores (P). To correct for the effects of reliability on the total ranking score for the test pavement performance, the following relationship was used:

Corrected test pavement performance score $= P \times W$

TABLE 7 VALUES ASSIGNED TO TEST PAVEMENT PERFORMANCE RESPONSES

Question	Response	Score
Condition Survey?	PCI, PSI, etc.	+1
	Visual	0
	None	−1
Roadway Performance Evaluation Methods?	Cores	+1
	Deflection	+1
	Roughness	+1
	Skid Test	+1
	Visual	0
	None	−1
Long-Term Pavement Performance Monitoring Program?	Yes	+1
	No	−1
Independent Agency Performs Program?	Yes	+1
	No	−1

The result of the corrected test pavement performance score was normalized to correspond to the relative worth represented in Table 6.

Modifier Performance Ranking

The final steps in the analysis of the individual modifiers were as follows:

1. Select the most representative response from the binder and mixture data base available for a given test property and modifier.
2. Select the most representative score from the SHA and MFG TPDSs.
3. Input these results into the ranking guides.
4. Normalize the ranking guide results to correspond to the relative worths of the performance categories listed in Table 6.
5. Compile the scores of the individual performances categories.
6. Assign a final ranking score to the modifier.

A final ranking score for permanent deformation, fatigue cracking, moisture susceptibility, aging, and low-temperature cracking for each modifier was established. Bar charts were generated from the final ranking score data. Figure 5 is an example of a typical modifier ranking chart.

It was necessary to account for the influence that nonresponses (unanswered questionnaire inquiries) had on the final ranking score of the modifiers. Nonresponses were tabulated and reported as part of the total score. Noting nonresponses helped prevent incorrect conclusions on modifier performance (for example, when the primary reason for a low score may be a lack of data). The graphical presentation of the final ranking scores shown in Figure 5 represents the relative influence individual modifiers had on pavement performance. Positive scores indicate a positive influence on pavement performance. Negative scores indicate a negative influence on pavement performance. The number of nonresponses are identified by an "X" next to the numerical score in Figure 5. Modifiers with large numbers of nonresponses were not con-

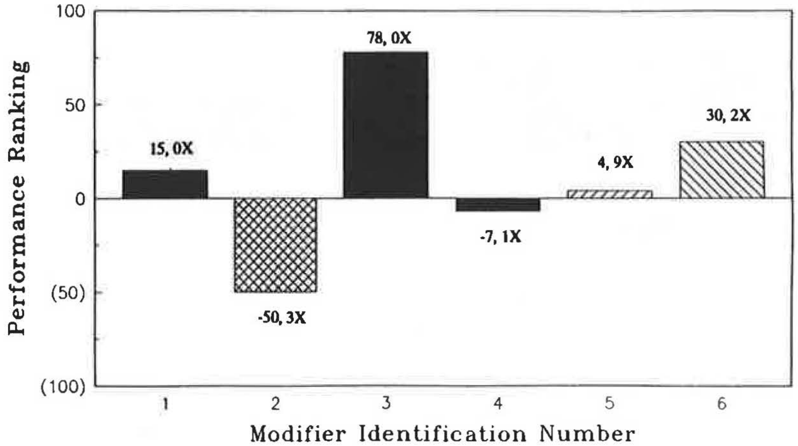

FIGURE 5 Example of modifier ranking chart for permanent deformation.

sidered in the questionnaire analysis because of the lack of data.

An example of the final modifier evaluation process is found in Table 8. Table 8 illustrates the steps taken to assign the final ranking score reported for Modifier No. 21 for permanent deformation. Table 8 presents the relative worth assigned to each performance category for permanent deformation and the scores received in the analysis of the data for Modifier No. 21. The final ranking score for Modifier No. 21 for permanent deformation is plotted in Figure 5 along with the other modifiers evaluated in this distress category.

Bar charts were generated ranking the modifiers in fatigue cracking, low-temperature cracking, aging, moisture susceptibility, and permanent deformation performance. Figures 6–10 illustrate the modifier performance rankings in each of the pavement distress categories based on the analysis of questionnaire data.

TABLE 8 EXAMPLE OF THE FINAL MODIFIER EVALUATION FOR MODIFIER NO. 21

Performance Category	Relative Worth Assigned the Performance Categories for Permanent Deformation [1]	Scores for Modifier No. 21
Binder Tests	10	5, 0X [2]
Mixture Tests	20	5, 2X
Test Pavement Data (SHA)	40	25
Test Pavement Data (MFG)	30	34
TOTAL	100	69, 2X

Note:
1. See discussion on Table 6
2. X represents number of non-responses

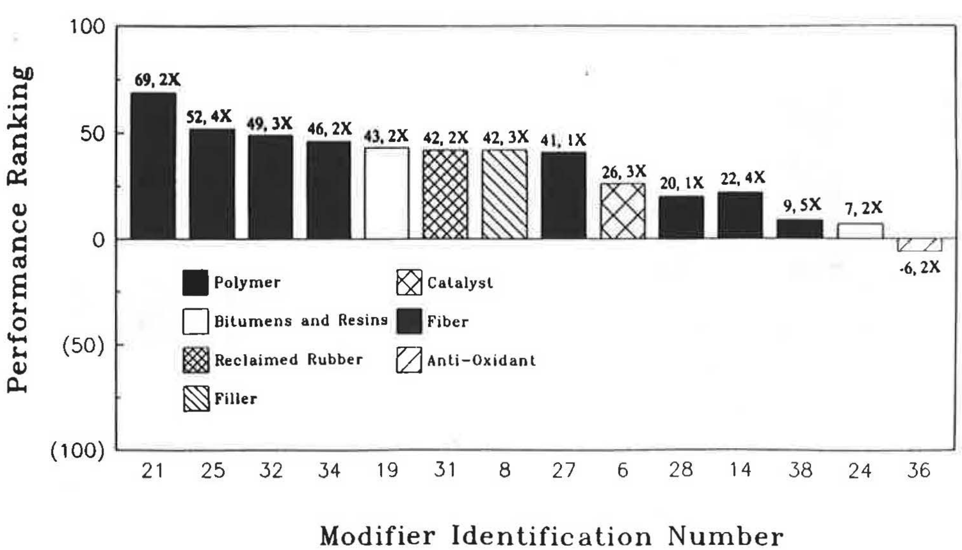

FIGURE 6 Modifier ranking chart for permanent deformation.

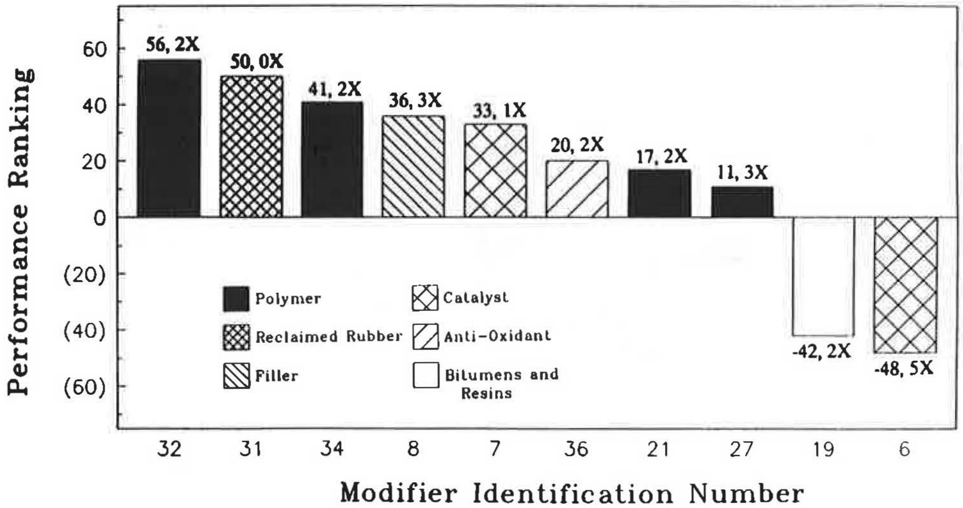

FIGURE 7 Modifier ranking chart for low-temperature cracking.

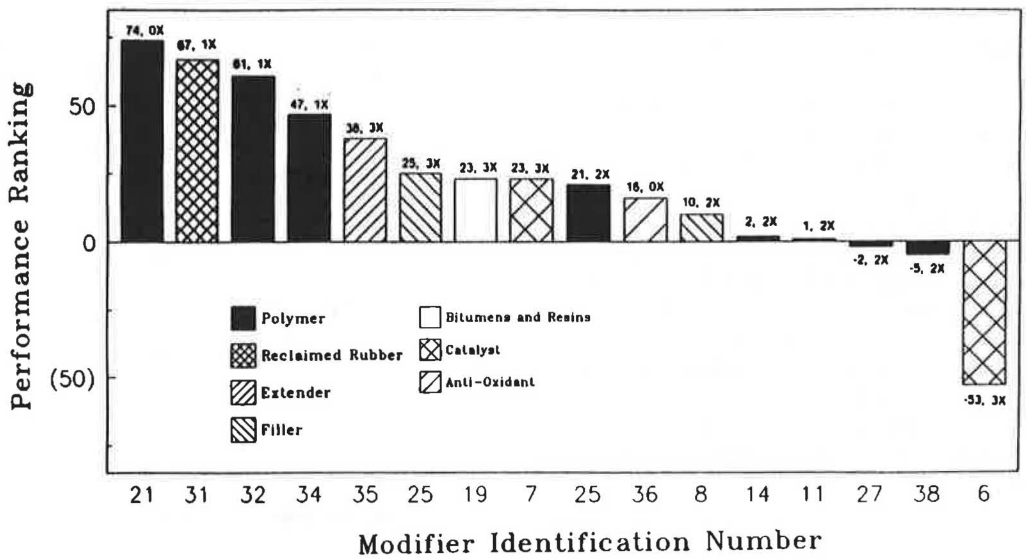

FIGURE 8 Modifier ranking chart for fatigue cracking.

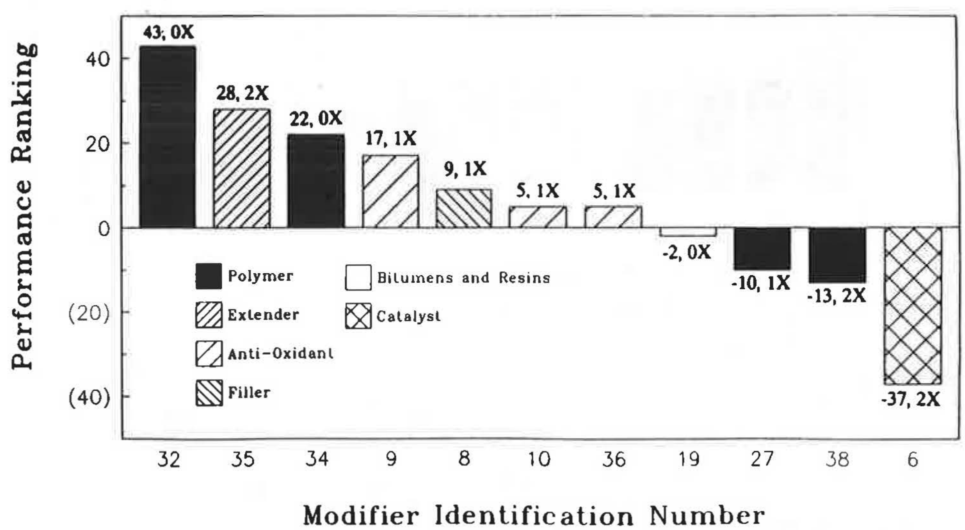

FIGURE 9 Modifier ranking chart for aging.

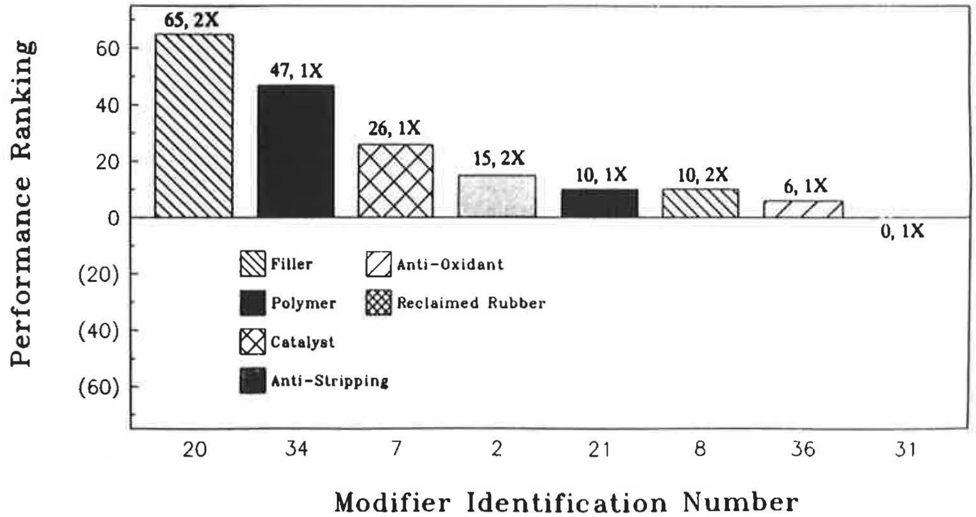

FIGURE 10 Modifier ranking chart for moisture susceptibility.

CONCLUSIONS

The performance of 38 modifiers was evaluated in the questionnaire analysis. Modifiers were classified according to the system outlined in Table 9. The modifiers were assigned an identification number to assist in presenting the questionnaire results in a confidential manner.

Modifiers from the same class were identified as having extremely wide variations in their effect on pavement performance within a particular distress category. This characteristic is illustrated in Figure 8 where eight polymer modifiers were evaluated for their effect on fatigue cracking. The final ranking scores for the polymer classification ranges from 74,0X to −5,2X.

The analysis of the questionnaire data successfully identified modifiers with varying levels of performance within each pavement distress category. Modifiers with positive, negative, and no effect on performance were identified for all of the distress categories, except moisture susceptibility. In this case, only modifiers with a positive or no effect were identified.

SHRP used the questionnaire results, results from a literature survey, and its experience to make the final selection of the asphalt modifiers to be used in the project.

TABLE 9 MODIFIER CLASSIFICATION SYSTEM USED IN QUESTIONNAIRE ANALYSIS

I	Polymer
II	Reclaimed Rubber Product
III	Filler
IV	Fiber
V	Extender
VI	Catalyst
VII	Anti-Oxidant
VIII	Bitumen and Resin
IX	Anti-Stripping Agent

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