Quality-Assurance Considerations in Design of Recycled Asphalt Mixture

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A procedure that can be used by an engineer to design a recycled mixture by using material salvaged from an existing roadway is described. Special attention is directed toward quality-assurance factors that must be addressed to ensure that variations are kept within limits that will allow production of a mixture that will perform satisfactorily. Some of these quality-assurance factors are commonly overlooked and yet can dramatically affect the field performance of the material. Among these commonly overlooked factors are determining the causes of failures, locating sections with different characteristics, and developing a sampling plan for collecting material for laboratory studies based on the first two factors. After the causes of distress have been determined, the salvaged material is evaluated to determine whether softening agents are needed and whether virgin aggregate and asphalt should be added and, if so, how much. Also included are cautions for preparing candidate mixtures in the laboratory in a manner similar to field material processing. Suggested minimum values of engineering properties are included as well as sample plots to demonstrate areas of concern relative to quality assurance. Concerns for quality assurance in each step of the design process are summarized.

The purpose of this paper is to address the necessary procedures and considerations required to produce quality recycled-asphalt mixtures. In comparison with conventional mixtures, this requires greater care, since the basic materials used in recycled mixtures are salvaged from an existing roadway that has failed. Therefore, a special effort must be made to rejuvenate these salvaged materials. In addition, attention must be directed to detecting variations that occur in the salvaged material as a result of the original design and construction, previous maintenance and rehabilitative activities, and the effects of environment and traffic. In order to ensure the quality of recycled mixtures, these variational aspects must then be considered adequately in the sampling, design, and construction phases of the project.

After recycling has been selected as the most desirable and cost-effective alternative for rehabilitation, a series of steps must be conducted to ensure a satisfactory pavement. First, a sampling plan must be developed and materials secured for the design of the mixture. In addition, a three-phase design must occur that includes general design, preliminary design, and final design (1). General design includes evaluating causes of failure and determining whether the problems are related to mixture or structure. Preliminary design includes a laboratory evaluation to determine the behavior and effects of factors such as softening agents, new aggregates, and antistrip agents, if needed. Final design includes preparing specimens of the actual mixture in various combinations to determine the engineering properties of the mixture and to determine whether the mixture is satisfactory. This includes comparisons of test results for the recycled mixture with the ranges of properties that are expected to provide good field performance.

When construction begins in the field, it may be necessary to modify the final design to provide a mixture that will meet construction requirements; however, these changes should be very carefully recorded and their effect anticipated and monitored.

GENERAL DESIGN

The most common aspects of the general design category are to

1. Determine the nature and cause of distress,
2. Determine the gradation of the recycled aggregate,
3. Determine the residual asphalt content of the recycled mixture,
4. Determine the penetration and viscosity of the recycled asphalt, and
5. Specify the aggregate gradation after pulverization and the addition of new aggregate.

Perhaps the most significant activities in this category of design that affect the quality-assurance issue are related both to item 1 and to establishing the sampling plan for securing materials to be used in items 2, 3, and 4. In fact, the information secured in item 1 is crucial to prevent the engineer from assuming that a rejuvenating (softening) agent always needs to be included in the recycled mixture. The major discussion in this section will then deal with item 1 and the sampling plan.

Determine Causes of Distress

It is essential that the cause of the distress that led to the need for recycling be identified and corrected. Three of the most common causes of distress are (a) aging (brittleness) of the asphalt cement, (b) stripping of the asphalt from the aggregate, and (c) structural inadequacy. Texas experience would suggest that one or more of these causes are involved in most failures that lead to recycling.

A detailed condition survey should be conducted to determine the severity and extent of the distress present on the job for which recycling is being considered. The condition survey should be separate for each section of road that is determined to be different based on considerations of (a) surface thickness or mixture design, (b) presence of heavy maintenance discontinuously along the section, (c) seal or friction coat difference, and (d) half-section skin patching. For each section identified by using the suggestions described above, the types of distress and the severity should be evaluated to determine the primary cause of the distress.

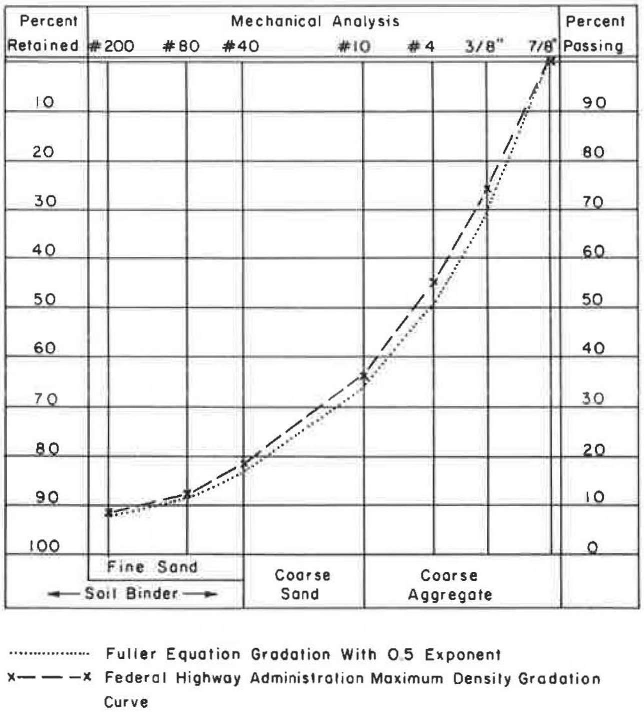
It is most important to identify whether these failures are associated with the characteristics of the mixture to be recycled or with the pavement structure, either locally or in general. In the case of mixture problems the failure can be categorized as either brittle or nonbrittle. An excellent guide to analysis of pavement failure was prepared by Finn and Epps (2).

Mixture Problems

Brittle failures occur when axle loads, thermally induced stresses, or shrinkage of underlying layers combines with aged asphalt cements to produce cracking, e.g., alligator, transverse, block (map), and longitudinal. When such an asphalt mixture is to be recycled, softening agents or soft asphalts typically must be added to restore the salvaged asphalt cement to its original viscosity.

Nonbrittle failures are usually associated with mixtures that are stripping or are exhibiting poor stability. Distresses typical of these conditions

Figure 1. Grading curves for dense-graded asphalt-concrete mixtures.



are rutting, shoving, corrugations, and bleeding. Rutting can also occur as a result of lateral flow of nonbituminous layers. The cause of rutting in each of these three cases is different and the treatment to alleviate the problem must be selected and applied either prior to or during the recycling operation if the recycled pavement is expected to perform adequately.

In the case of the stripping mixture, an appropriate treatment must be applied to the salvaged mixture to alleviate the stripping problem or the mixture must be discarded or used for other purposes such as low-volume road patching or shoulders. Once the stripping problem has been alleviated, the salvaged mixture can be evaluated and a new mixture design developed. Softening agents most often are not required and if included could produce a very soft and unstable mixture that is prone to shoving and rutting.

Poor stability often can be alleviated by adding new aggregate during recycling to improve gradation and introduce more angular aggregate particles. Better gradation may also result in a higher density, which would be beneficial with respect to moisture damage. It is also recommended that serious consideration be given to using approximately equal percentages of recycled material and new material; a recommended maximum is 70 percent recycled material.

Special attention should be given to the final gradation, including new aggregate if added. Grading curves similar to those shown in Figure 1 (3,4) have shown excellent performance. The grading curve should not have humps in the region of the No. 30 to No. 60 sieves nor should there be significant deviations, either coarser or finer, in the regions above the No. 10 sieve. Variations in these regions are especially important for certain types of material-distress combinations. Goode and Lufsey (4) have shown that humps in the region of the No. 30 to No. 60 sieves above the lines shown in Figure 1 produce tender mixes. In addition, these finer mixes can significantly lower stabilities. If the mix is both too coarse (gradations below the lines in Figure 1 for sizes larger than the No. 10 sieve) and made with strip-prone aggregate, the greater porosity of the mix may actually enhance the opportunity for water damage. In fact, some mixes being used by states today have such a small range of combinations of gradation and asphalt content that produce satisfactory mixes that runs only one day apart failed in two different modes, stripping in the open mixture and shoving and rutting in the mixture with slightly higher asphalt content (5). Therefore, the mixture with higher void content stripped, whereas the mixture with lower void content shoved and rutted under traffic.

Structural Problems

Structural deterioration may occur as the result of underdesign, increased traffic volumes and axle loads, decreased support values due to the action of water, and brittleness of the asphalt due to aging, all of which can produce increased stresses and strains. If these increased stresses and strains exceed limiting values, premature fatigue or longitudinal cracking in the surface layer or permanent deformations can occur. This cracking can be localized or can be quite extensive.

An evaluation of the strength conditions of the existing pavement structure can be made by performing and analyzing a Dynaflect survey or other nondestructive test. Such an analysis will help define the extent of soft spots and establish the limits on sections where the underlying support characteristics or layer thicknesses are different or inadequate. Application of these techniques and formulas for estimating moduli for underlying layers have been presented by Lytton and Machalak (6).

Sampling Plan

Each identified subsection should be treated as a separate design, and a representative sample should be secured from each. Sampling sites within each subsection should be selected randomly. The engineer should choose at least six sampling sites for each subsection and secure a minimum of 200 lb of material for subsequent laboratory analysis (7).

The effect of discontinuities or variation of material properties along the length of the pavement or across the width may lead to difficulties in securing representative materials. The effect of large discontinuous areas of patching, the addition of hot mixed overlays or seal coats to surface courses that were originally cold mixed, and many other combinations of different materials may make selection of representative samples to be used for a single mixture design for the entire pavement difficult, if not impossible. In such cases, further subdivision of the subsection may be necessary or perhaps the recycling alternative must be abandoned if only short subsections can be identified.

Of special concern in developing the sampling plan are the causes of failure and variations in asphalt content or gradations of the material to be salvaged. Since brittle and nonbrittle failures require different treatment of the salvaged asphalt cement, it is imperative that the first break in the sampling plan be based on type of failure. The second primary area of concern is that of variations in asphalt-cement content and aggregate gradations down the road. Since seal coats, other surface treatments, and patching, as well as sealing programs, do not necessarily involve the entire roadway, these maintenance operations will affect the selection of relatively homogeneous sections for mixture design considerations. If the materials are to be removed from the site, crushed, sized, and reblended, these problems are minimized but should be considered in developing the sampling plan. If the recycling is to be accomplished in place, careful laboratory studies should be conducted to determine the magnitude of systematic variations in asphalt content and gradations across the roadway and to evaluate the effect of those variations on stability, void contents, density, and strength. If these variations are significant enough to produce instabilities, high void contents, or other problems in portions of the recycled mixture, then the engineer should carefully consider whether the recycling option should be abandoned or whether to proceed but modify the construction sequence to eliminate or minimize these problems. A final decision on these factors could be delayed until more complete information is available on which to evaluate the effect of these variations on mixture properties.

PRELIMINARY DESIGN

The primary objective of the preliminary design is to select the type and amount of additive that can be used to recondition the asphalt or eliminate asphalt aggregate problems in the salvaged mixture, if necessary. If a brittle failure has occurred, this portion of the design involves the selection of an additive that will soften the existing asphalt and return it to its original or desired viscosity. A variety of materials are available, such as soft asphalt, commercially available softening agents, and combinations of these materials. If a nonbrittle failure has occurred, the techniques or type and amount of additive that will minimize distress, such as stripping, must be selected. Materials such as lime and chemical antistrip agents are believed capable of reducing stripping in asphalt-concrete mixtures. Nevertheless, to ensure a successful project, it is imperative that selected antistrip additives be tested to ascertain their effectiveness.

Softening Agents

Often a primary criterion in a preliminary design procedure is to reduce the viscosity or increase the penetration of the asphalt to a value representative of a virgin asphalt cement. The recommended steps usually involved are

1. Extracting and recovering asphalt from the salvaged mixture,
2. Mixing the recovered asphalt with the selected types and amounts of additives,
3. Measuring the viscosity or penetration of the treated asphalt cement,
4. Plotting the relationship between the amount of additive and the viscosity or penetration (Figures 2 and 3),
5. Determining which additives or combinations of additives will produce the desired consistency in the salvaged asphalt cement, and
6. Selecting acceptable additives or combinations of additives that warrant preparation of laboratory mixtures for further evaluation (factors to be considered in this selection are costs, availability, construction considerations, past reliability and experience, etc.).

Generally this portion of the design process is fairly standard. However, careful consideration must be given to the field mixing process and the method of blending the softening agent into virgin or reclaimed asphalt cement. It is conceivable that a particular softening agent could be chosen in this portion of the design that, when applied under field construction conditions, will not be so effective in rejuvenating the salvaged asphalt content as it was in the laboratory. Therefore, mixture preparations that use the selected softening agents and salvaged materials should closely simulate field conditions, including the method of adding the softening agent, mixing time and temperature, and compaction.

Figure 2. Typical relationships between penetration and percentage of softening agent for recovered brittle asphalt cement and four softening agents.

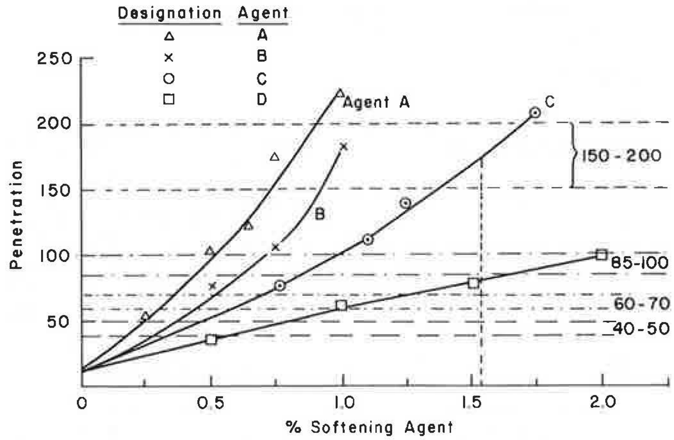
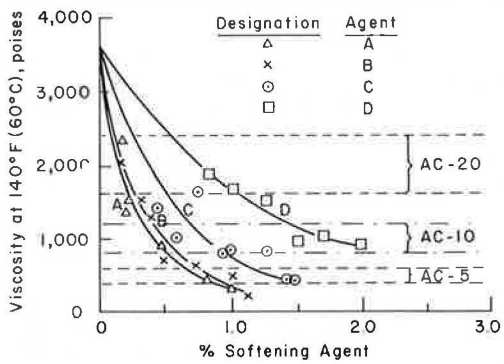


Figure 3. Typical relationships between viscosity at 140°F and percentage of softening agent for recovered brittle asphalt cement and four softening agents.



New Aggregate

According to Epps and Holmgreen (7), new aggregate may have to be added to the mixture for one or more of the following reasons:

1. To satisfy gradation requirements;
2. To improve the skid resistance to meet requirements for the new surface course;
3. To meet air-quality regulations associated with hot central plant recycling, typically 30 to 40 percent new aggregate;
4. To meet total pavement thickness requirements;
5. To improve the properties of the mixture, such as stability, durability, and flexibility; and
6. To be able to add enough modifier to restore the salvaged asphalt to meet specification requirements and still maintain required mixture properties.

In addition to these reasons for adding new aggregate to the salvaged mixture, one other factor should be considered--experience in recycled construction. Generally, it is recommended that not more than 50 percent salvaged material be used since the mixture is less forgiving at higher percentages of recycled material. With experience, higher percentages of salvaged material can be used; however, in general, it is recommended that no more than 70 percent salvaged material be included in the mixture.

Antistripping Agents

If it is determined that the action of moisture on the recycled mixtures has resulted in premature failure, the use of an antistripping agent should be considered. Chemical antistrip agents are commonly used. When use of one of these agents is specified, tests should be performed to evaluate the effectiveness of each proposed chemical antistrip agent when combined with the salvaged material. Preliminary results by Lee and Kennedy (9) have indicated that in many cases certain chemical antistrip agents, when combined with certain asphalt-aggregate mixtures, do not alleviate moisture damage and that the treated mixtures are still moisture susceptible. These results have also suggested that lime may be an effective antistrip agent when used properly. Nevertheless it is mandatory that any proposed antistrip additive be tested with the aggregate and preferably the asphalt cement to be used to ascertain their effectiveness. Possible test methods are the Texas freeze-thaw pedestal test, the boiling test, and static and repeated-load indirect tensile test with and without moisture conditioning. Preliminary indications suggest that the Texas freeze-thaw pedestal test may be quite valuable in evaluating potential antistrip additives and in detecting adverse moisture effects on various asphalt-aggregate combinations (10).

FINAL DESIGN

The materials selected in the preliminary design are evaluated to select the final type and amount of additive required to either rejuvenate the asphalt cement or alleviate stripping and the amount of new aggregate to incorporate into the mixture. The final design involves determining whether the engineering properties of the mixtures selected in the preliminary design are acceptable. The steps to be followed are as follows:

1. Prepare duplicate specimens of mixtures containing the approximate amount of selected additives based on weight of recovered asphalt, aggregate, or mixture as determined in the preliminary design and various percentages of new asphalt or other additives. The aggregate gradation, including the salvaged aggregate plus virgin aggregate, should have a gradation curve similar to that shown in Figure 1.
2. Test the prepared specimens according to the standard tests used by the design agency.
3. Compare the results from step 2 with those required in the current specifications for conventional mixtures.
4. Test the prepared specimens by using the static and repeated-load indirect tensile test.
5. Compare the results from step 4 with those obtained for conventional mixtures. Properties recommended for consideration are tensile strength, static modulus of elasticity, and resilient modulus of elasticity. The relationships between the above properties and the amount of additive should be developed by testing recycled mixtures prepared at various additive contents. Sample relationships are shown in Figures 4 and 5. The resulting values should then be compared with desired values even though there is currently a limited amount of data to establish these desired values. Most specifications required minimum values for strength, etc. For recycled asphalt mixtures, the test values on the existing pavement material normally should be specified as a range including a maximum value, since the asphalt in the salvaged mixture is often extremely stiff and brittle.

   It can be seen that the effect of softening agents is quite different for materials that experienced brittle failures than for those that experienced nonbrittle failures. For the brittle materials, tensile strength (Figure 4a) decreases rapidly with additional additive, whereas for the nonbrittle material, tensile strength does not (Figure 4b) but generally changes only slightly. The same trend has been observed for static and resilient modulus. However, the stabilities in all cases are reduced dramatically as the percentage of additive increases for both the brittle and nonbrittle salvaged materials.
6. Determine the resistance of the recycled mixture to adverse environmental moisture conditions as previously discussed. The Texas freeze-thaw pedestal test procedure is tentatively recommended for use (10).
7. Evaluate the workability of the mixture by visual inspection and make necessary adjustments in the amount of virgin aggregate and additives to be included in the recycled mixture. However, extreme

Figure 4. Effects of amount of additive on tensile strength of salvaged mixtures (a) with brittle asphalt cement and (b) with nonbrittle asphalt cement.

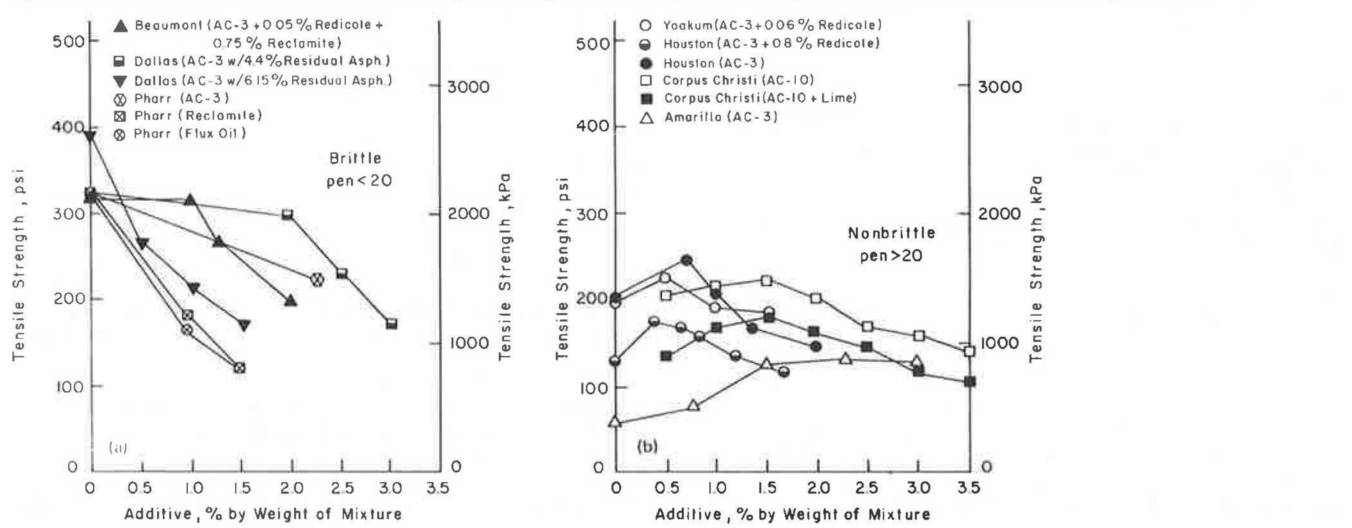


Figure 5. Effects of amount of additive on Hveem stability of brittle and nonbrittle recycled mixtures.

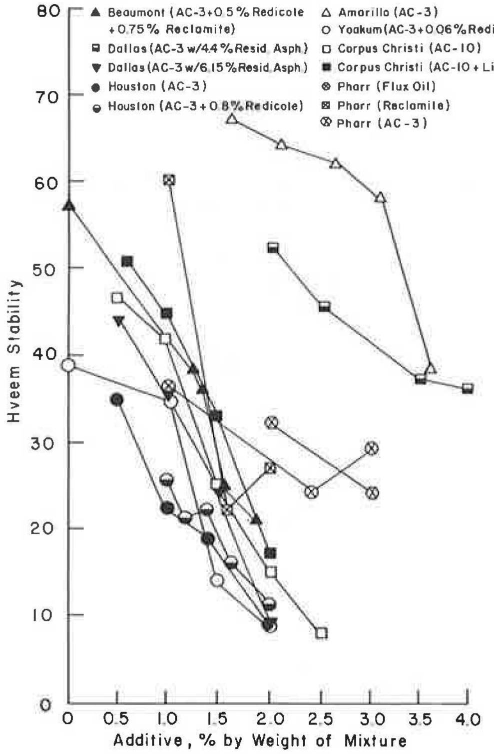


Figure 6. Determination of percentage of additive from selected range of tensile-strength values.

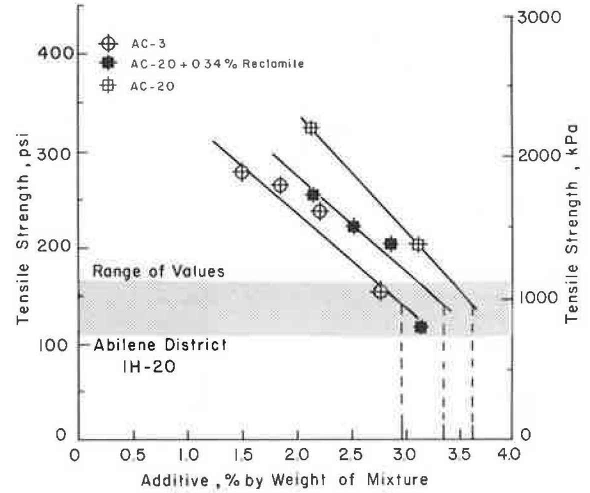
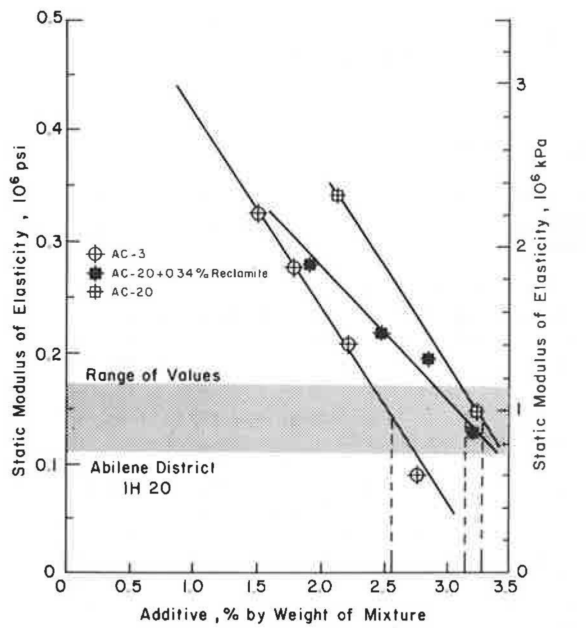


Figure 7. Determination of percentage of additive from selected range of values of static modulus of elasticity.



care should be exercised to prevent workability requirements from adjusting gradations and binder content to the point that unstable mixes are produced.

RECOMMENDED INDIRECT TENSILE DESIGN VALUES

Results from previous studies have been used to evaluate the tensile strength, static modulus of elasticity, and resilient modulus of elasticity of both laboratory-prepared and in-service asphalt mixtures. Since these materials are performing satisfactorily in the field, they represent a guide to the level of engineering properties that should provide satisfactory service for recycled mixtures.

Based on the results reported (11-13) for various types of asphalt mixtures, typical values of mixture properties were obtained and are shown below (1 psi = 6.89 kPa):

Property	Design Value (psi)
Tensile strength	73-203
Static modulus of elasticity	$0.10\text{-}0.51 \times 10^6$
Resilient modulus of elasticity	$0.25\text{-}0.94 \times 10^6$

It is recommended that desirable values of engineering properties be determined for the particular location and function of the proposed recycled material.

An example of the use of the desired range of material properties to select the percentage of additive is shown in Figures 6 through 8. Specimens are prepared and tested at various additive contents and the results are plotted as in Figures 6 through 8. At the point where the line of best fit for the test results intersects the middle of the acceptable range of properties, the optimum percentage of additive for the property is obtained. For example, in Figures 6, 7, and 8, these percentages of additives are shown for each combination of asphalt or asphalt and additive. The individual optimums for the AC-3 are 2.9, 2.6, and 2.7 for tensile strength, static modulus, and resilient modulus of elasticity, respectively. It should be noted that other additives could be investigated and might be acceptable.

QUALITY-ASSURANCE RECOMMENDATIONS

Based on the experience gained to date on designing mixtures for 15 recycling jobs and observing the construction process in the field in the state of Texas, the following recommendations on areas of quality assurance are proposed as the most significant. By paying careful attention to these areas and exercising adequate controls in the field, variations can be kept to an acceptable level. The result will be a reliable product that is expected to perform satisfactorily for its entire design life.

Figure 8. Determination of percentage of additive from selected range of values of resilient modulus of elasticity.

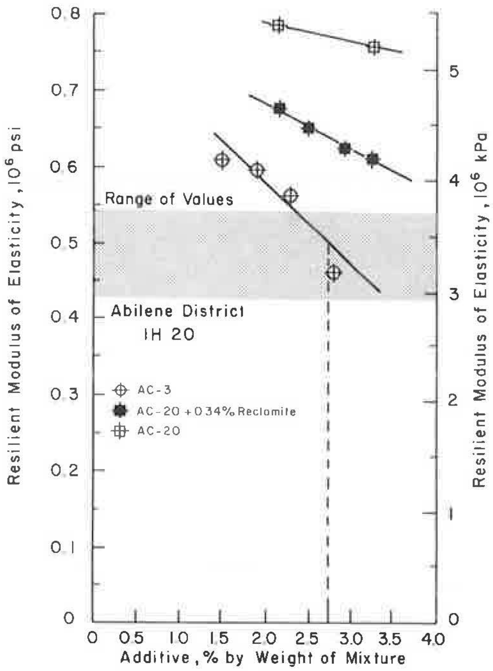
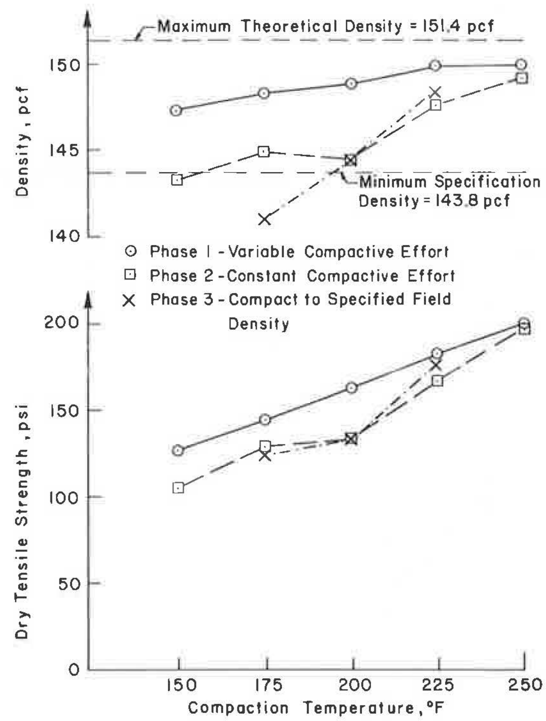


Figure 9. Dry tensile strength for three phases of compaction study of recycled mixtures on IH-10 near Winnie, District 20, Beaumont, Texas.



In General Design

The primary areas of concern for quality assurance lie with the effects produced by variations in the following:

1. Subsection identification and sampling: Use not only design differences but also differences in maintenance and rehabilitation actions as well as type and cause of distress to subdivide for design. Sample within each subsection to secure representative materials so that material variations can be identified and evaluated.
2. Gradations: The designer must know how the material is to be removed, crushed, and blended in order to be able to evaluate variations and their propensity for generating performance problems.
3. Asphalt content: Total variations in extracted-asphalt content along the roadway can be significant. In Texas the construction tolerance on asphalt content is ± 0.5 percent and data from dryer drum mixers indicate that as much as 30 percent of the extraction values exceed that tolerance (5). This construction variation plus additional variations produced by maintenance and rehabilitation operations may increase the inherent variation.

In Preliminary Design

The primary areas of concern for quality assurance lie with the effects produced by variations in the following:

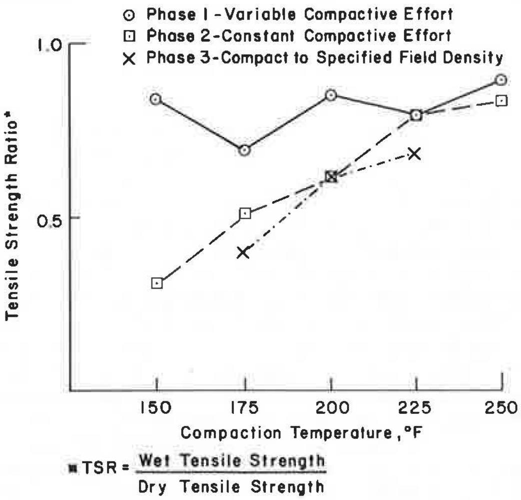
1. Quantity of new material: Strive for a well-graded mixture that produces a smooth grading curve. Avoid humps in the grading curve near the No. 40 sieve that produce a fine mixture that is tender. Mixtures that have 50-70 percent salvaged material seem to be more forgiving to variations in asphalt content, density, etc.
2. Softening agent selected: Ensure that the action of the agent on the salvaged asphalt is the same in the field as it is in the laboratory.
3. Antistrip agent: Test to ensure that it works. Several tests are currently available; however, it is recommended that the Texas freeze-thaw pedestal test be considered.

In Final Design

Of critical importance in this activity is that the designer ensure that the various mixtures to be evaluated be combined under the same conditions in the laboratory as those to be used in the field. For example, the standard hot-mix design procedure often specifies that the mixture ingredients are to be mixed and compacted at a relatively high temperature in the laboratory; however, if a dryer drum plant is used, the mixing and compaction temperature could be significantly less. Thus the recycled mixture should be mixed and compacted at the lower temperatures. This may be of particular importance with recycled mixes since the action of the rejuvenating agent or new asphalt cement may be totally different at the different temperatures and under different mixing conditions. In addition, the amount of water present in the new aggregate as well as the salvaged mixture will almost certainly be different if one set of materials is prepared under standard mix design conditions while the other is run through the dryer drum plant. The combined effect of variations such as these between laboratory procedure and field conditions could be larger than all others, and the mixture produced in the field could have significantly different properties from those produced in the laboratory.

For example, Figure 9 (8) shows the effect of varying the compaction temperature for a laboratory study designed to simulate observed field densities and compaction procedures. The compaction temperature behind the laydown machine and range of field densities observed were used to set the ranges for the study. It can be noted in Figure 9 that the dry tensile strengths vary significantly with laydown

Figure 10. Tensile-strength ratios for three phases of compaction study of recycled mixtures on IH-10 near Winnie, District 20, Beaumont, Texas.



temperatures for all phases of the study. It should also be noted that all but two of the specimens had densities that met the minimum specifications. A set of specimens was also compacted and tested in a wet condition, and the tensile-strength ratios were calculated and plotted in Figure 10 (8). It should be noted that for the specimen compacted at constant compactive effort but at varying temperatures, the tensile-strength ratios are significantly lower at the lower temperatures. This lower ratio reflects the increased water susceptibility for mixes compacted at lower temperatures. However, if the compactive effort is increased as in the phase-1 curve of Figure 10, the tensile-strength ratios are much higher. Also, as the compaction temperature increases, the efficiency of the compactive effort is shown by the converging phase-1 and phase-2 curves. This convergence points out the necessity of maintaining proper compaction temperature, especially when roller patterns are used instead of density control.

In summary, an important point to be emphasized is that in the design of recycled mixtures, special care must be exercised to ensure that the laboratory heating, mixing, and compaction conditions correspond as nearly as possible to those expected in the field. Diligence in applying such control will pay off by having a mixture in the field that reacts to variations in a manner similar to that of variations observed in the laboratory specimens.

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