Ensuring Quality in Hot-Mix Recycling

ELTON R. BROWN

The experience of the U.S. Army Engineer Waterways Experiment Station in ensuring quality of hot-mix recycled asphalt concrete is discussed. This experience includes the use of low-viscosity asphalt and recycling agents to modify the existing aged asphalt and to provide the additional needed asphalt. Batch plants and drum mixers have been used to produce the hot-mix recycled asphalt concrete. These recycled mixtures have been satisfactorily used in the construction of binder courses and surface courses.

The state of the art of designing and constructing pavements composed of recycled materials has now advanced to a point where recycling can be considered as an alternative to conventional procedures for most paving jobs. In the past, engineers have been reluctant to consider recycling because (a) it was a new process with unknowns, (b) the technology and equipment needed were not sufficiently developed for recycling, and (c) it was simply not cost-effective for most jobs.

Over a period of years, a change in attitude of pavement engineers has been brought about by several factors. The oil embargo of 1973 stressed the point that there is not an unlimited supply of asphalt materials. Since the embargo, the law of supply and demand had pushed the price of asphalt to $200/ton by 1981. As recently as 1975, the price of asphalt cement was approximately $70/ton.

The amount of high-quality aggregate has become limited in many areas, which has caused the cost of these aggregates to increase substantially. In many locations, economics has forced the use of low-quality aggregates, which has resulted in pavements with reduced life. The use of recycled materials in these areas will provide high-quality materials at lower costs.

During the last few years, technology developed to the point that recycling is no longer in the experimental stage. Equipment has been developed that can properly remove the old pavement materials and mix these reclaimed materials with virgin aggregates, asphalt, and a recycling agent to produce a satisfactory recycled asphalt concrete. There still exist problems that are peculiar to recycling; however, the number and complexity of these problems have been reduced significantly in recent years.

This paper discusses procedures used by the U.S. Army Engineer Waterways Experiment Station (WES) to minimize problems during design and construction of recycled mixtures and thus to ensure quality in the hot-mix recycled asphalt concrete.

MATERIAL EVALUATION

Existing Materials

Existing reclaimed materials for hot-mix recycling generally consist of a mixture of asphalt cement and aggregates. It is essential to evaluate the properties of these materials to determine the aggregate and asphalt type that must be used to modify them to meet specification requirements. This initial evaluation is necessary to estimate the properties of materials such as the asphalt cement and recycling agent needed for the job. If possible, this information should be obtained before the project is advertised and be made a part of the bidding documents for information to the prospective contractors.

The analysis of the existing materials consists of extracting the asphalt binder from the mixture and recovering this asphalt from the asphalt-solvent solution. After the asphalt and aggregate have been recovered, tests should be conducted on each of these materials. In order to perform the mixture design for the recycled mixture, it is necessary to determine the apparent specific gravity, water absorption, and gradation of the aggregate and the specific gravity and asphalt penetration of the asphalt. Other aggregate properties that are generally not evaluated but may need to be in cases where the aggregate quality appears to be a problem include the Los Angeles (L. A.) abrasion, percentage of crushed faces, soundness, and amount of rounded natural sand in the mixture. The aggregate requirements should be the same as those for the aggregate to be used in a virgin mixture. The analysis of the asphalt binder should include as a minimum the determination of penetration and specific gravity.

New Materials

The new materials to be added to a recycled mixture generally include the aggregate, asphalt cement, and recycling agent. Depending on the gradation of the aggregate in the existing pavement, the new aggregate may or may not consist of fine and coarse sizes. The new aggregates and reclaimed aggregates when blended should meet the specification requirements for the gradation of total aggregate. If there is a limit on the amount of natural sand that is allowed to be used in a mixture, this limit should apply to the new aggregate to be added to the recycled mixture since the existing aggregate will more than likely already contain natural sand.

The new asphalt cement added to a recycled mixture provides the additional asphalt binder needed and in many cases modifies the properties of the existing asphalt binder. An AC-2.5 asphalt cement can often modify the existing asphalt binder to an acceptable level. To be acceptable, asphalt recovered from a recycled mixture should initially have an asphalt penetration between 40 and 70 for most climatic locations. Acceptable modification of existing asphalt binder depends on the properties of this binder, properties of the new binder, and amount of reclaimed asphalt concrete to be used in the recycled mixture. For instance, the asphalt binder from an existing mix with penetration in the range of 10-15 can generally be modified to satisfactory properties with an AC-2.5 when the amount of reclaimed asphalt concrete to be used in the mixture is 40-50 percent.

When the penetration of the existing asphalt binder is below 10 and/or when the amount of reclaimed mixture to be used in a recycled mixture is more than 50 percent, it is generally necessary to use a recycling agent to properly modify the existing asphalt binder. A small amount of recycling agent can generally modify the existing asphalt binder without satisfying the desired binder content. If additional binder is needed after the asphalt has been modified, this should be accomplished by the addition of an asphalt cement. When AC-2.5 asphalt is used for the additional binder, the amount of recycling agent needed is less than that required when a higher-viscosity asphalt such as an AC-10 is used because the AC-2.5 modifies the properties of the recovered asphalt more than the higher-viscosity asphalts.

At the present time, there is no widely accepted standard for specifying recycling agents. However, it is obvious that the recycling agent must be able to modify the properties of the asphalt binder to the desired characteristics (40-70 pen). The recycling agent must also be resistant to heat so that the properties will not be adversely affected during production of the recycled mixture at the asphalt plant. There are a number of recycling agents on the market with widely differing properties; therefore, caution should be used in specifying and using these recycling agents.

MIXTURE DESIGN

After the properties of the reclaimed materials and new materials have been determined, the mix design should be performed. The mix design establishes the percentage of each of the various materials to be used in the mixture to ensure that the combined aggregate properties, asphalt properties, and mixture properties are satisfactory. These properties should be evaluated in a similar manner to that for virgin materials and mixtures. The properties of the combined asphalt must be determined from asphalt recovered from the recycled mixture. Material and mixture properties used to evaluate and control asphalt mixtures are tabulated below:

Aggregate	Asphalt	Mixture
Specific gravity	Specific gravity	Stability
Absorption	Penetration	Density
L.A. abrasion	Ductility	Voids total mix
Soundness	Viscosity	Voids filled with asphalt
Percentage of crushed faces	Flash point	Flow
Flat and elongated particles	Thin-film oven test	Immersion compression
	Solubility	

The viscosity, ductility, flash point, solubility, and thin-film oven test are used to evaluate the properties of the virgin asphalt binder only. Penetration and specific gravity are used to evaluate the properties of the combined recovered asphalt.

The first step in the mixture design is to determine what percentage of each new aggregate and reclaimed asphalt concrete should be used. The amount of reclaimed asphalt concrete used in the mixture is usually limited to 70 percent when a drum mixer is used to ensure that a satisfactory mixture is obtained and pollution requirements are satisfied. When a modified batch plant is used to produce the recycled mixture, the amount of reclaimed material used in the mixture is generally restricted to a maximum of 50-60 percent. The availability of reclaimed material, economic considerations, pollution control requirements, and practical considerations of the type of plant to be used are usually considered in selecting the amount of reclaimed material to be used in the mixture. After the percentage of reclaimed material has been selected, the percentage of each virgin aggregate to be used in the mixture can be selected to provide a satisfactory blended gradation.

The second step is to determine the type of binder and/or recycling agent to be used in the mixture. For most areas within the United States, it is desirable that the penetration of the asphalt binder recovered from the recycled mixture be 40-70. These criteria can generally be met with the use of a low-viscosity asphalt (such as AC-2.5) when the amount of reclaimed material used in the mixture is 50 percent or less and when the penetration of the existing asphalt binder is 10 or more. If a low-viscosity asphalt cement can be used to provide additional asphalt and modify the existing asphalt binder to an acceptable range, a recycling agent should not be used.

If it is necessary to use a recycling agent, the smallest amount that can be used to properly modify the existing asphalt should be selected. An excessive amount of a recycling agent will reduce the viscosity of the asphalt binder excessively, thus causing insufficient strength in the mixture. Too much recycling agent can also cause an oily film to form on the aggregate that will prevent satisfactory adhesion of the asphalt to the aggregate. The additional asphalt needed should be provided by the use of an asphalt cement. Since there are no widely accepted criteria for specifying recycling agents, the use of recycling agents that have shown satisfactory performance in the past is recommended.

The third step in developing a job-mix formula is to select the percentage of asphalt cement and/or recycling agent to be used in the mixture and to ensure that the mixture properties are satisfactory. The percentage of binder to be added is selected in a manner similar to that for virgin mixtures. Typical designs for a binder course that uses AC-2.5 asphalt and various amounts of reclaimed materials are shown in Figures 1-3. The optimum mixture properties for these designs are indicated in Table 1. When 40 percent reclaimed material was used, the modified asphalt did not provide the desired stability properties (modified asphalt binder did not possess satisfactory viscosity). When 50 or 60 percent reclaimed material was used, the mixture did possess satisfactory properties.

Potentially, the recycled mixture may consist of four aggregates (reclaimed material, coarse aggregate, fine aggregate, and natural sand) and three binder materials (reclaimed asphalt binder, new asphalt cement, and recycling agent). It is difficult in the laboratory to properly mix this large number of materials; therefore, a high variation in test results is expected. These materials can be properly mixed in large quantities at the asphalt plant, and consistent test results should be obtained. Full-scale plant production of recycled materials should never begin until a satisfactory field mixture design has been developed. This field mix design may be no more than a verification of the laboratory mix design, but it is necessary to determine that the mixture produced at the plant is satisfactory before full-scale production.

The mix design is normally performed on samples of material obtained from the existing pavement before milling or removing and crushing. When the existing pavement is milled or removed and crushed, there is generally more material passing the No. 200 sieve (dust) than that indicated by the original sample. This additional dust is caused by abrasion effects of the milling machine or crusher. Dust is also manufactured when producing recycled hot mix at an asphalt plant. In order to ensure that the amount of material passing the No. 200 sieve is not excessive, the original mix design should be well below the maximum limits for material passing the No. 200 sieve.

REMOVAL OF EXISTING MATERIALS

The quality of the in-place materials cannot be controlled; therefore, these materials must be used with consideration given to modifying the existing quality if necessary. When properties of the existing materials do not meet the specification requirements for the recycled mixture, the virgin materials (asphalt, recycling agent, and aggregate) when added must be able to modify these materials to meet these

requirements. Although the quality of the existing materials cannot be controlled, it is imperative that the existing material be milled and stockpiled in such a way that properties of the materials are consistent throughout the stockpile. When the properties are consistent, the material can be properly modified; however, if the stockpile properties are highly variable, an undesirable product will be produced.

The existing asphalt concrete must be uniformly removed to the desired grade without damage to the underlying material. When damage does occur to the base, it should be scarified, moistened if necessary, and compacted. Generally, the asphalt concrete is removed with a milling machine, but occasionally a ripper is used to remove the existing asphalt. After being ripped from the pavement, the material is transported to a crusher for further processing. When a milling machine is used, further crushing is not normally needed.

The use of a ripper generally requires that the existing asphalt concrete be removed full depth to the surface of the base course. When the existing asphalt mixture is ripped, particles from the surface of the base course may tend to adhere to the asphalt concrete being removed. A small amount of the base course in the asphalt mixture will not cause any problem so long as the amount adhering to the asphalt mix does not vary significantly between adjacent areas being removed.

The milling machine can remove the existing asphalt concrete to any desired depth. Generally,

Figure 1. Recycled asphaltic-concrete mix design: AC-2.5 asphalt binder and 40 percent reclaimed asphalt concrete.

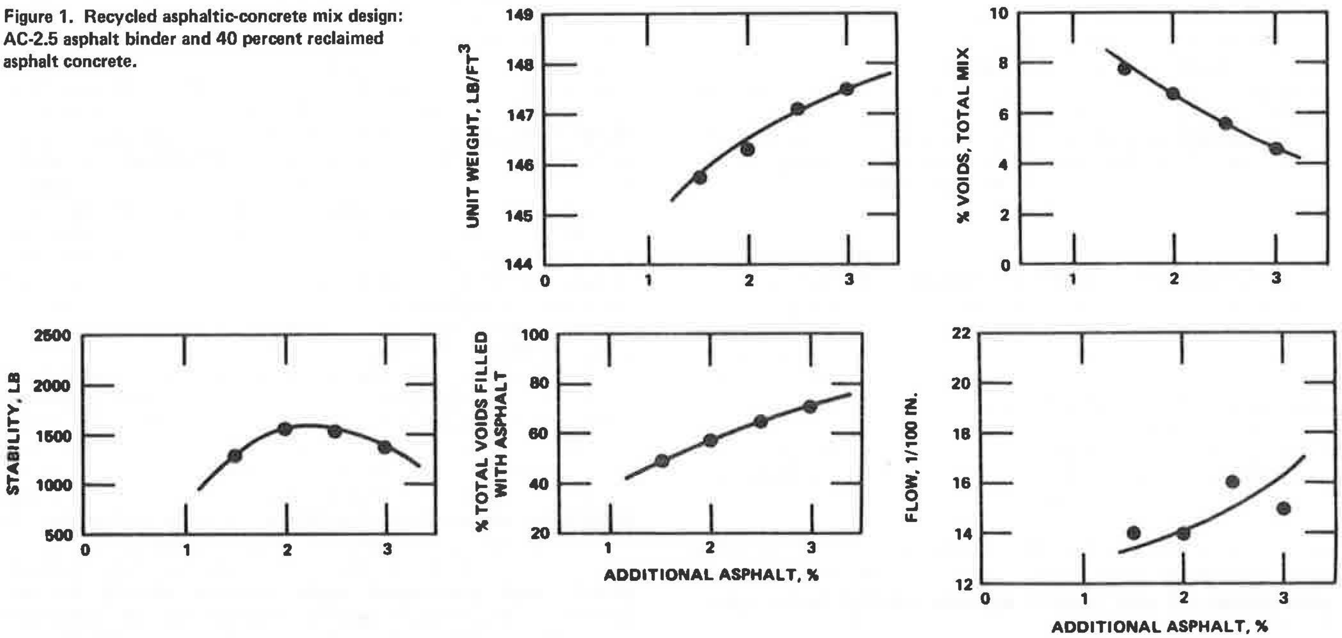


Figure 2. Recycled asphaltic-concrete mix design: AC-2.5 asphalt binder and 50 percent reclaimed asphalt concrete.

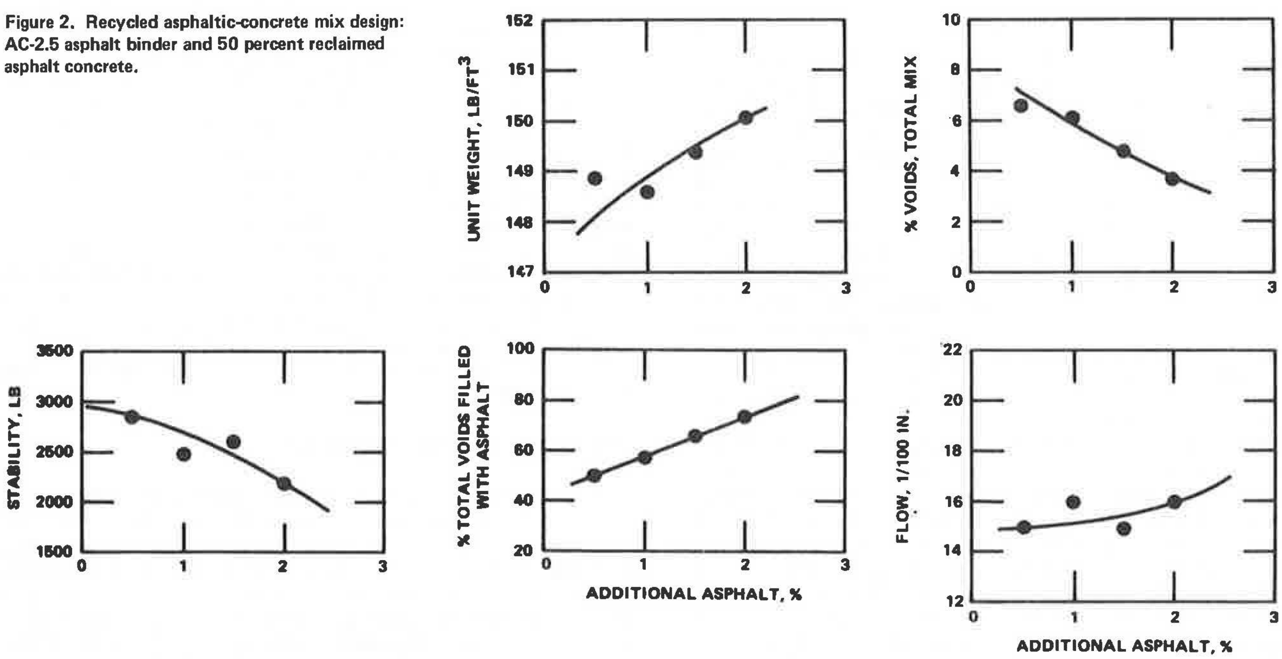


Figure 3. Recycled asphaltic-concrete mix design: AC-2.5 asphalt binder and 60 percent reclaimed asphalt concrete.

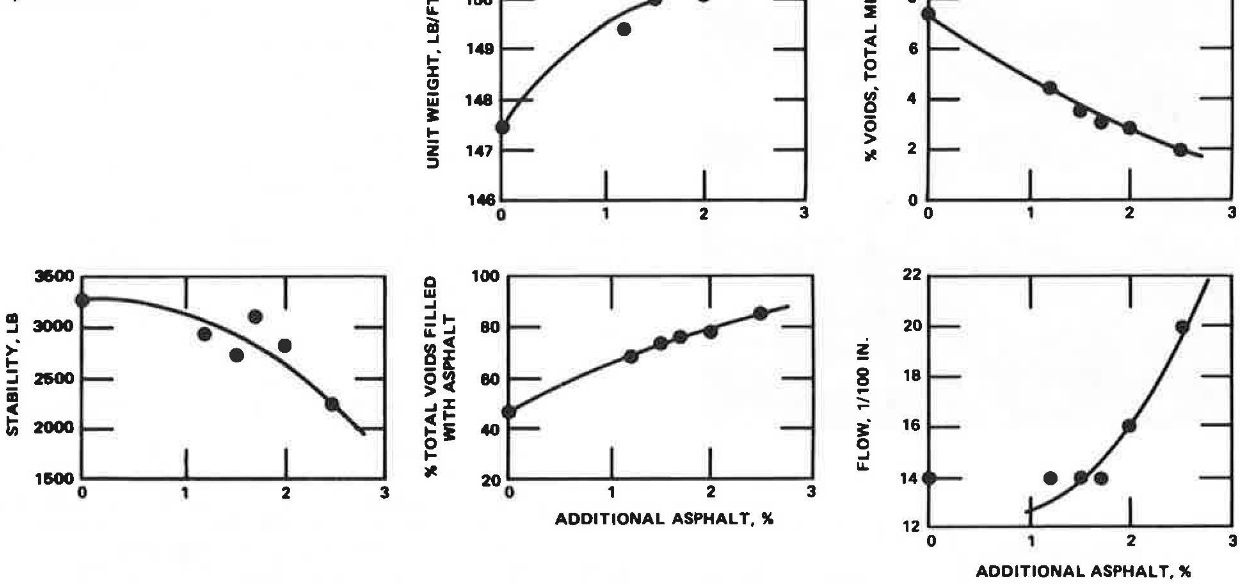


Table 1. Mix designs for recycled asphalt concrete at Pope Air Force Base.

Mixture Property	Binder-Course Criterion	Reclaimed Asphalt Concrete in Mix (%) 40	50	60
Optimum additional asphalt content (%)	-	2.3	1.1	0.6
Density (pcf)	-	146.6	149.2	148.4
Stability (lb)	1800 min	1440	2600	3200
Flow (0.01 in)	16 max	15	15	14
Voids total mix (%)	5-7	6.0	5.6	5.6
Voids filled with asphalt (%)	50-70	60.0	58.0	58.0

3-4 in can be removed in one pass. Grade-control devices can be used when close control of the grade is required. When the full depth of asphalt concrete is to be removed, approximately 0.5 in of asphalt mixture is generally left over the base course to prevent damage from the milling machine and to prevent water from entering and damaging the base course.

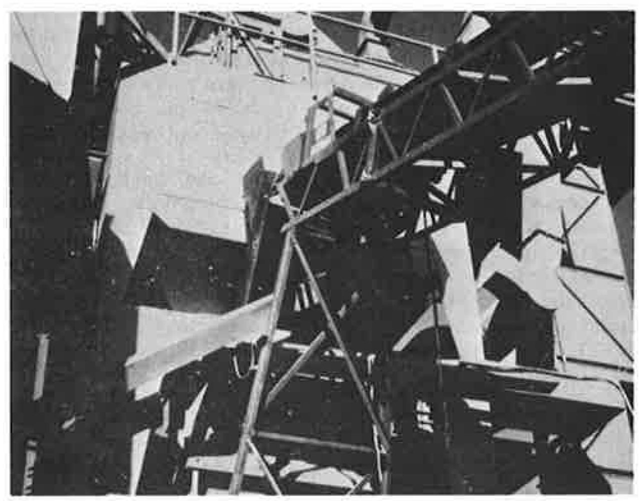
When the asphalt mixture is removed down to the base course, steps should be taken to protect the base course from water intrusion. These steps may involve the application of a prime coat or the placement of the bottom course of recycled asphalt mixture within a short time.

The cutting teeth of the milling machine must be replaced periodically. When the teeth become dull, oversized chunks of the asphalt mixture are produced. Milling with dull teeth near the bottom of the asphalt-concrete mixture can cause the mix to shear between the base course and asphalt mixture, which produces large chunks of asphalt concrete that will have to be removed from the mixture or broken down further before the mixture can be fed through the asphalt plant.

QUALITY CONTROL OF HOT-MIX RECYCLING JOBS

WES has been involved in the quality control for a number of hot-mix recycling jobs. These jobs have included recycling at Pope Air Force Base, North Carolina; Reese Air Force Base, Texas; and Lajes Air Force Base, Azores Islands, Portugal. These three jobs have provided experience for a range of material and equipment types.

Figure 4. Modified batch plant used at Pope Air Force Base.



The asphalt concrete on the runway at Pope Air Force Base was recycled in the summer of 1980 (1). A modified batch plant (Figure 4) was used to produce the recycled hot mixture, which consisted initially of 50 percent reclaimed asphalt-concrete materials and 50 percent new materials. A recycling agent was not needed for this recycled mixture. An AC-2.5 asphalt cement was added to modify the existing asphalt cement and to provide the additional asphalt binder.

The modification to the plant consisted of adding a hopper for the reclaimed asphalt mixture and adding a conveyor belt to carry this reclaimed asphalt mixture from the hopper to the scales. The virgin aggregate was fed through the dryer and heated to approximately 600°F. When the virgin aggregate, reclaimed asphalt concrete (approximately 50 percent of total mixture), and AC-2.5 asphalt

Figure 5. Drum mixer used at Lajes Air Force Base.

cement were mixed in the pug mill, the resulting temperature was approximately 275°F.

A 2-in screen was placed over the reclaimed asphalt-concrete storage bin to remove all large chunks while the bin was being loaded. The removal of the large chunks allowed the remaining reclaimed asphalt concrete to break down in the pug mill and properly mix with the virgin aggregate and AC-2.5 asphalt cement. A few chunks were noticed during the laydown operation, but these chunks were soft and were compacted under the rollers with no noticeable problems. The recycled mixture was used in the leveling course, whereas the virgin mix was used for the surface course.

The material that was removed had been designed to satisfy surface-course requirements. The recycled mixture designed to satisfy binder-course requirements resulted in the addition of only 1.3 percent new asphalt binder to the recycled mixture. This low percentage of new asphalt cement produced a combined asphalt binder with an asphalt penetration of 27. When the amount of new asphalt was increased to 1.5 percent, the asphalt penetration rose to 37. Subsequently, when the amount of new asphalt was increased to 1.8 percent and the amount of reclaimed asphalt concrete decreased to 45 percent, the resulting mixture met the surface-course requirements with a recovered asphalt penetration near 50. This final mixture was considered to contain the proper asphalt content and asphalt quality.

The asphalt concrete on the runway at Reese Air Force Base was recycled in 1981 to produce a binder course before overlaying with a new asphalt-concrete mixture. A drum mixer that had to be modified to produce recycled asphalt concrete was used on this job. The modification provided for the addition of the reclaimed asphalt-concrete materials to the drum mixer. The mixture design required that 50 percent reclaimed asphalt-concrete materials be used in the recycled mixture. It was necessary to add 0.4 percent recycling agent and 2.5 percent AC-5 to the recycled mixture to provide the additional asphalt needed and to properly modify the asphalt binder. The penetration of the resulting asphalt binder was approximately 50.

The asphalt concrete on several taxiways and parking aprons at Lajes Air Force Base was recycled in 1981, and the asphalt concrete from additional areas is scheduled to be recycled in 1982 to produce material for binder courses and surface courses for these areas. A drum mixer that was designed and constructed to produce recycled mixtures or new mixtures was used to produce the recycled asphalt concrete (Figure 5). The mixture design required that 50-60 percent reclaimed asphalt-concrete materials be used in the recycled mixture. The addition of approximately 0.7 percent recycling agent and 3.1 percent AC-2.5 to the recycled mixture resulted in an average penetration of recovered asphalt binder of 48. A screen was placed over the reclaimed asphalt-concrete storage bin to prevent oversized material (primarily chunks of asphalt concrete) from getting into the recycled mixture.

During the plant operation, a number of tests on the materials and mixture must be conducted to ensure quality in the recycled asphalt-concrete mixture. Basically, these tests are the same as those for conventional mixtures, but a few additional tests are needed. Tests on conventional mixtures include extraction of the asphalt binder from the mixture, which allows the gradation of the aggregate and the asphalt content to be determined. When recycled mixtures are tested, it is necessary to recover the asphalt from the extract and conduct penetration tests on the asphalt binder to ensure proper asphalt consistency. Recovery of the asphalt should be done in such a way that the amount of mineral filler in the recovered asphalt is minimized. The recovery procedure requires that the reflux extraction be used to extract the asphalt binder or that some method such as the high-speed centrifuge be used to remove the mineral filler from the asphalt-solvent solution if the rotorex method is used for extraction. Other than the recovery of the asphalt binder and the penetration test, all other tests are the same as that for conventional mixtures. A summary of the tests required in the field laboratory for conventional mixtures and recycled mixtures is shown below:

Both Mixtures	Recycled-Asphalt Mixtures
Marshall compaction and test: stability, flow, density, voids total mix, and voids filled with asphalt	Asphalt recovery
Aggregate gradation	Asphalt penetration
Asphalt extraction	
Temperature	
Density: laboratory and field cores	

The variability of aggregate gradation and asphalt content is important to the performance of asphalt-concrete mixtures. Due to the small amount of elapsed time since the beginning of construction of recycled asphalt concrete, very little has been published on the variability of properties of recycled mixtures. This information on variability has been published for new asphalt-concrete mixtures (2).

The average and standard deviation can be used to conveniently summarize a large amount of data and yet describe the variability of that data. An analysis of the data for the three recycled asphalt-concrete jobs and a comparison with the variability of new mixtures are given in Table 2.

As given in Table 2, the variability of the aggregate gradation and asphalt content for recycled mixtures is higher than that for new mixtures. This higher variation may be caused by a number of factors. First, the data for new mixtures were obtained primarily from batch plants, whereas two of the three recycled jobs were produced with drum mixers. Since a batch plant rescreens the aggregate and weighs the aggregate fractions and asphalt in each batch, the variation of asphalt concrete produced in a batch plant should be less than that

Table 2. Variability of recycled asphalt-concrete materials.

		Standard Deviation			
			Recycle at:		
Property	Avg	New Mixtures	Pope Air Force Base	Reese Air Force Base	Lajes Air Force Base
Aggregate gradation (percent passing)	95	2.0	2.5	2.0	2.5
	90	2.5	3.0	4.0	3.5
	80	2.5	3.5	4.5	4.0
	70	2.5	4.0	5.0	4.5
	60	2.5	4.0	5.0	4.5
	50	2.5	4.0	4.0	4.0
	40	2.5	4.0	3.5	3.5
	30	2.0	3.5	2.5	2.5
	20	1.5	2.5	2.0	2.0
	10	1.0	2.0	2.0	1.0
	5	1.0	1.0	-	1.0
Asphalt content	-	0.20	0.32	-	0.58
Stability (%)	-	10	10	13	13
Flow	-	-	0.8	2.0	1.4

produced in a drum mixer. Hence, the differences in variation of the gradation and asphalt content for new mixtures and recycled mixtures may be partly caused by the type of plant used in the analysis.

Second, very little can be done to control the variation of the reclaimed asphalt-concrete materials. In other words, the more variability that exists in the aggregate gradation and asphalt content of the reclaimed materials, the more variation that will occur in the aggregate gradation and asphalt content of the recycled mixture. This variation in properties of the recycled mixture can be minimized by proper handling but cannot be controlled as closely as that for new asphalt-concrete mixtures.

Third, two asphalt products are often added to the recycled mixture. These two products are generally an asphalt cement and a recycling agent. Adding two liquid materials to the recycled mixture provides more chance for error and thus causes a higher variability in asphalt content with recycled mixtures than with new mixtures.

The high variation in aggregate gradation and asphalt content for recycled materials is undesirable, but the variation is not so large that unacceptable material is necessarily obtained. The variation in stability and flow indicates that the variation in asphalt content and gradation did not excessively affect the properties of the mixture. This high variation does require continuous monitoring of the production quality so that adjustments in the mixture design can be made as needed.

CONCLUSIONS AND RECOMMENDATIONS

Recycled asphalt mixtures should be designed and controlled by using the same techniques as those for conventional mixtures.

Additional testing is necessary during the mix design of recycled mixtures to extract the asphalt from the reclaimed asphalt concrete so that the asphalt content and asphalt properties, such as penetration and specific gravity, can be determined. The amount of new asphalt and/or recycling agent to be used in the mixture must be selected so that the mixture properties as well as the properties of the combined asphalt are satisfactory.

Additional tests are required during plant production to ensure that the recycled asphalt-concrete mixture is acceptable. These tests include recovery of the extracted asphalt and a measurement of the penetration of this recovered asphalt.

With the exception of additional tests on recycled asphalt mixtures to evaluate quality of the combined asphalt binder, recycled-asphalt mixtures should be designed, produced, and placed by using the same techniques as those for conventional mixtures. Based on the analysis of three hot-mix recycled jobs, it appears that the variation in aggregate gradation and asphalt content for recycled mixtures is larger than that for new mixtures. This increase in variability requires that recycled asphalt-concrete construction jobs be continuously monitored so that mix adjustments can be made as needed.

REFERENCES

1. E.R. Brown. Hot-Mix Recycling at Pope Air Force Base. Proc., New Mexico Paving Conference, Albuquerque, NM, Jan. 1981.
2. T.D. White and E.R. Brown. Statistical Quality Control Procedures for Airfield Pavement Materials and Construction. TRB, Transportation Research Record 652, 1977, pp. 36-42.

Publication of this paper sponsored by Committee on Quality Assurance and Acceptance Procedures.