1.06 percent asphalt by weight, depending on the aggregate composition.

4. Some moisture is required in the mixtures produced by the drum-dryer process to aid in compaction. However, it is necessary to regulate the moisture content within a working range. Conventional methods of determining moisture content are very time consuming. The nuclear asphalt-content gauge would provide a rapid means of testing and monitoring moisture content in mixtures produced by this process.

5. Tests run on mixtures that contain emulsified asphalt and aggregate indicate that the gauge can be used effectively to monitor total liquid content (emulsified asphalt plus water) in the mixture within ±0.3 percent. The gauge could thus be used to indicate when the optimum moisture content has been reached for proper compaction.

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Abridgment

Recycling Asphaltic Concrete: Arizona's First Project

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Interest in Arizona in the possibility of recycling old asphaltic concrete pavement stemmed initially from a paper by Dunning, Mendenhall, and Tischer (1). In addition, the increase in the price of paving asphalt from approximately $44.20/Mg ($40/ton) in 1971 to $110.50/Mg ($100/ton) in 1975 caused us to realize the great potential savings represented by the approximately 4 percent residual asphalt in old asphaltic concrete. Consequently, Materials Services of District 3 of the Arizona Department of Transportation (DOT) began a testing program on old asphaltic concrete to determine if recycling of this material was feasible.

In the southeastern portion of Arizona, between Willcox and the New Mexico state line, part of the old asphaltic concrete being removed and disposed of on an $8.5 million Interstate highway project was salvaged, crushed, recycled, and used to overlay 8.53 km (5.3 miles) of US-666 from I-10 north to the Graham County line. The material was crushed, heated, and remixed and was checked by the Marshall method of determining asphaltic concrete mix designs. It was determined that adding 1.5 to 2 percent AR 2000 paving asphalt to the old asphaltic concrete resulted in a good mix.

On the basis of these preliminary tests, approximately 16 819 m^3 (22 000 yd^3) of old asphaltic concrete was salvaged from project I-10-6(50). This material was stockpiled near the south end of the proposed overlay project. It was later crushed by state maintenance forces with a Pioneer model 358S roll crusher.

Further laboratory testing indicated that blending coarse mineral aggregate with the crushed old asphaltic concrete at a ratio of 20 to 80 percent would give a job-mix formula with the desired gradation, percentage voids in mineral aggregate, and effective voids. The average gradation for these two materials is given in the following table (corresponding U.S. sieve sizes are 1, 0.75, 0.50, 0.375, and 0.25 in and nos. 4, 8, 40, and 200):

	Percentage Passing	
Sieve Size (mm)	Old Asphaltic Concrete	Coarse Aggregate
25	–	100
19	100	80
12.5	93	33
9.5	85	11
6.3	–	2
4.75	72	1
2.36	60	
0.425	26	
0.075	8.8	

The average residual asphalt in the old crushed asphaltic concrete was 3.2 percent.

It was determined that the cost of salvaging, hauling, crushing, and stockpiling the old asphaltic concrete was $1.65/Mg ($1.49/ton). In addition, coarse mineral aggregate was purchased, hauled, and stockpiled, ready for blending with the salvaged asphaltic concrete, for $3.14/Mg ($2.84/ton).

Arizona DOT Materials Services completed the design for the proposed recycling and overlay project on August 10, 1976. This design called for the 20-80 blend of coarse mineral aggregate and old asphaltic concrete previously mentioned. These materials were to be combined and mixed with approximately 2.2 percent of an AR 2000 paving asphalt and aromatic extender oil blend. Approximately 18 percent of aromatic extender oil, based on the weight of the asphalt, was recommended for the blend.

On October 14 and 15, 1976, representatives of District 3 and Materials Services contacted Robert Mendenhall of the Las Vegas Paving Corporation and discussed recycling of asphaltic concrete. They also observed the recycling procedure used on Nevada project I-015-1(50)0. Requirements in the special provisions for this project were later revised and adopted for the Arizona project.

The Arizona project was finally advertised for bid with a bid opening date of January 7, 1977. A special provisions addendum called for a prebid conference to be held in Phoenix on December 28, 1976, and all prospective bidders were requested to attend. As a result of this conference, the requirement that aromatic extender oil and paving asphalt be introduced into the mixer through separate gallonage meters was deleted. In addition, after much discussion, air quality standards were relaxed because of the experimental nature of the project. Specifically, the particulate count was waived, and the allowable maximum opacity was 40 percent.

The bid opening was postponed until January 13, 1977, when it was learned that a U.S. patent had been approved for recycling of asphaltic concrete and for the aromatic extender oils used in the process. This delay gave the bidders an opportunity to review the patent and to make provisions, if necessary, in their bids for royalties claimed by Mendenhall, the patent owner.

The successful bidder, A.C. Speer Construction Company, participated in a preconstruction conference held in the District 3 office. Speer was granted a delayed starting date to March 7, 1977, so that necessary modifications to the company's drum mixer could be made.

The initial modifications to the drum mixer included installation of a special steel alloy "pyro-cone" 1.8 m (6 ft) in diameter and perforated with 25-mm (1-in) holes. The second major modification was the addition of a high-speed underfeed belt. The purpose of this belt was to throw the blended cold-feed material about 0.9 m (3 ft) into the drum so that the asphalt-coated particles of the crushed asphaltic concrete would be removed from the high temperatures near the inlet end of the drum as quickly as possible.

Another modification was the installation of a meter for blending the aromatic extender oil with the paving asphalt as the two materials were pumped into the asphalt storage tank. This method of metering worked fairly well but for one serious drawback: The percentage of extender oil in the blend of asphalt and extender oil could not be changed with any degree of exactness until the asphalt storage tank was almost empty.

Another important addition was six 9.375-mm (0.375-in) water sprays, three each to two 25-mm (1-in) feed lines, for the purpose of adding moisture to the cold-feed material. Each feed line was equipped with a valve and a pressure gauge for adjusting the amount of added moisture to help control emissions from the stack.

On March 14, 1977, the contractor began production at a rate of 136 Mg/h (150 tons/h). Water was applied to the cold feed by means of three water sprays at 483 kPa (70 lbf/in^2). The amount of added blend of paving asphalt and extender oil was 2.2 percent. The amount of extender oil in the blend was 18 percent, based on the weight of the paving asphalt.

The result of this first production was not satisfactory. Heavy smoke was emitted from the plant. The mix had a dry, lifeless appearance and lacked cohesiveness; the aggregate coating was not good; and the fine particles had a burned look. The water pressure on the cold feed was reduced from 483 to 207 kPa (70 to 30 lbf/in^2) and was finally discontinued; there was no apparent change in the opacity of emissions as a result of any changes that were made.

On the second day of operation, the contractor moved the discharge end of the asphalt line in the drum from 3.2 to 3.66 m (10.5 to 12 ft) from the inlet end of the drum. Several combinations of mix ingredients were tried in an effort to reduce the opacity of emissions but without success. It was apparent from all of these combinations that most of the smoke problem was caused by the burning of the finer asphalt-coated particles in the crushed old asphaltic concrete. It was soon determined that the plant would not meet the air quality standards for the project unless major changes were made.

A decision was made to further modify the drum mixer. The steel alloy pyro-cone was moved from 1.83 to 0.91 m (6 to 3 ft) from the inlet end of the drum. The burner was moved back an additional 0.61 m (2 ft) from the end of the drum, and a 0.61-m-wide steel collar was placed around the circumference of the drum extending toward the burner. The purpose of the modifications was to confine the burner blast and also to produce the effect of moving the cold feed farther away from the burner blast and the high temperature at the inlet end of the drum.

Operations began again on March 22, 1977. Adjustments were made to the exhaust damper and the air-fuel mixture used in the burner. The opacity of emissions still exceeded the allowable 40 percent. In the afternoon, 2 percent moisture was added to the 4 percent stockpile moisture of the blended cold-feed material. The application of this additional moisture considerably reduced emissions. At the end of the day, the addition of moisture to the cold feed was stopped, and emissions increased drastically.

The next day, a number of different production rates were tried. For all rates of production, 2 percent moisture was added to the cold feed. We also began experimenting with different allowable temperatures of the mix at the outlet of the drum. The contractor discovered that, to increase production and maintain allowable opacities, the outlet temperatures had to be reduced.

On the basis of these results, an order for a change in the project contract was initiated to lower the required temperature of the mix at the outlet of the drum. The contractor also agreed to cover the surge hopper and the conveyor belt from the outlet of the drum to the surge hopper to prevent loss of heat from the mix.

As the project progressed, further experimenting was done with temperatures and it was determined that, by lowering the temperature of the mix to between 93°C and 96°C (200°F and 205°F) at the drum outlet, production rates of 294 Mg/h (324 tons/h) could be achieved without serious smoke problems as long as 2 percent moisture was being added to the cold feed. Higher production rates might have been achieved, but the ultimate capacity of the exhaust fan for this particular plant was reached at this rate of production.

The gradation consistency of the mix was very uniform. And, with 50 percent aromatic extender oil in the blend of AR 2000 paving asphalt and extender oil, the most desirable mix was achieved with the addition of 2.7 percent of this blend. The resultant extracted asphalt content was 5.3 percent with a penetration of approximately 64 and a viscosity of about 218 Pa·s (2180 poises).

SUMMARY

1. The asphaltic concrete recycled on this project was dry and brittle with a penetration of 7 on the residual asphalt. It was easily crushed and did flow back together in the stockpile.

2. It was economically feasible to blend crushed asphaltic concrete and mineral aggregate and paving asphalt and aromatic extender oil in a modified drum mixer. The average production rate was 222 Mg/h (245 tons/h) based on actual plant running time. Most of the production was within the air quality standards established for the project. Production rates as high as 293.2 Mg/h (324 tons/h) were achieved, without opacity problems, when the mix temperatures at the drum outlet were lowered to 93°C to 96°C (200°F to 205°F) and 2 percent moisture was added to the cold feed.

3. Properties similar to new asphaltic concrete were obtained by 2.7 percent of a blend of AR 2000 and 50 percent aromatic extender oil with a blend of 80 percent crushed old asphaltic concrete and 20 percent new coarse mineral aggregate.

4. There was a savings of $3.73/Mg ($3.38/ton) when a comparison was made between the actual cost of the recycled asphaltic concrete on this project and the estimated cost of new asphaltic concrete on similar projects.

5. If the blend of AR 2000 and 50 percent extender oil, which was used in the later stages of this project, had been used throughout the project, an additional savings of $0.044/Mg ($0.04/ton) could have been realized. In addition, if the contractor's production rate in the later stages of the project could have been achieved throughout the project, an additional savings of $0.663/Mg ($0.60/ton) could have been achieved, or a total savings of $4.44/Mg [$4.02 ($3.38 + 0.04 + 0.60) per ton].

RECOMMENDATIONS

1. Temperatures of the mixture should be lowered to 93°C to 104°C (200°F to 220°F) at the drum outlet. Allowing lower temperatures undoubtedly reduced the flashing or igniting of the finer asphalt-coated particles, and smoking or opacity was greatly reduced.

2. Recycling projects of this type should be scheduled during warmer periods of weather to allow the lower mix temperatures suggested above without causing problems in obtaining density in the compacted mix.

3. It should be required that paving asphalt and aromatic extender oil be introduced into the mixer through separate, interlocked positive displacement meters. This will provide the capability of varying the percentage of extender oil as job conditions require.

4. More investigation is needed to determine the best possible location of the discharge end of the asphalt line in the drum mixer. In addition, more work needs to be done in determining the required exhaust for capacity for a drum mixer modified with a perforated steel alloy cone. Fan capacities must be increased so that proper dust collectors can be used in the future.

CONCLUSIONS

The process of recycling asphaltic concrete has not been perfected. The capabilities of other types of drum mixers need to be proven and modifications made as required. We feel confident that production rates will go up, costs will go down, and air quality standards will be met. We are only on the threshold of realizing great potential savings in both funds and natural resources.

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