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MISCELLANEOUS PAPER GL-80-14

RECYCLED MATERIALS -- APPLICATIONS TO AIR FORCE PAVEMENTS

by

Elton R. Brown

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1980

Final Report

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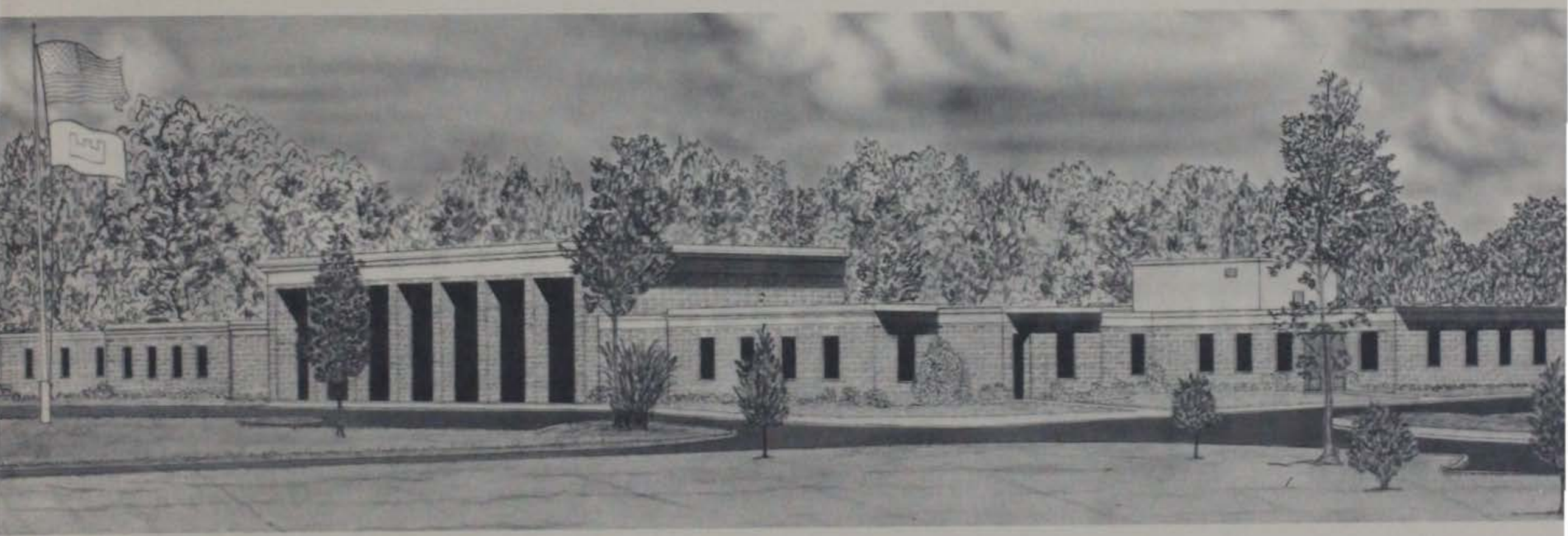

Prepared for Air Force Civil Engineering Center
(Air Force Systems Command)
Tyndall Air Force Base, Florida 32401

Under MIPR No. S-79-20

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Miscellaneous Paper GL-80-14

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
RECYCLED MATERIALS - APPLICATIONS TO AIR FORCE PAVEMENTS

5. TYPE OF REPORT & PERIOD COVERED
Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Elton R. Brown

8. CONTRACT OR GRANT NUMBER(s)
MIPR No. S-79-20

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Geotechnical Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Civil Engineering Center
Air Force Systems Command
Tyndall Air Force Base, Florida 32401

12. REPORT DATE
September 1980

13. NUMBER OF PAGES
38

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Airfields
Flexible pavements
Pavement performance and evaluation
Recycled concrete
Rigid pavements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the state of the art of pavement recycling. The objective of this study was to conduct a literature search on recycling of pavement materials and to list and briefly discuss those recycling processes that are applicable to Air Force pavements. A number of processes for recycling asphalt concrete pavements and portland cement pavements were reviewed. These processes included hot recycling, cold recycling, and surface recycling. The processes applicable to Air Force pavements are discussed and recommendations are made to develop guide specifications and a standard practice manual for these processes.

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

This study was conducted by the Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, for the Air Force Engineer and Services Center, Tyndall Air Force Base, Florida, under Military Intra-Departmental Purchase Request (MIPR) No. S-79-20. This report describes the results obtained from Phase I of the project entitled "Development of a Recycling Manual for Use on Air Force Pavements."

The study was conducted under the general supervision of Mr. J. P. Sale, former Chief of GL, and Dr. D. C. Banks, acting Chief of GL. Mr. E. R. Brown prepared the report.

COL Nelson P. Conover, CE, was Director of the WES during the investigation and preparation of this report. Mr. Fred R. Brown was Technical Director.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT	3
PART I: INTRODUCTION	4
Background	4
Objective and Scope	5
PART II: SURFACE RECYCLING	7
Heater-Planer-Scarifier	7
Grinder	11
Rejuvenator	16
PART III: COLD RECYCLING	18
In-Place Processing	18
Fixed Plant Processing	24
PART IV: HOT RECYCLING	29
General	29
Heat Exchanger Processing	32
Drum Mixer Processing	32
Conventional Plant Processing	32
Laydown Operation	33
Field Performance	34
PART V: CONCLUSIONS AND RECOMMENDATIONS	35
Conclusions	35
Recommendations	35
REFERENCES	36

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645329	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.852	kilometres
pounds (force) per square inch	6894.757	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.593276	kilograms per cubic metre
square feet	0.09290304	square metres
tons (2000 lb, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C - (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

RECYCLED MATERIALS - APPLICATIONS TO AIR FORCE PAVEMENTS

PART I: INTRODUCTION

Background

1. The state of the art of pavements constructed from recycled materials has now advanced to the point where recycling can be considered as an alternative to most paving jobs. In the past, engineers were reluctant to consider recycling because (a) it was a new process, (b) the technology and equipment needed were not sufficiently developed, and (c) it was simply not cost-effective for most jobs. Times have changed, however, and recycling is now considered to be a feasible process for many pavement maintenance and rehabilitation jobs.

2. Over a period of years, a change in attitudes of pavement engineers has been brought about by several factors. Initially, emphasis was placed on recycling for environmental reasons. Often the reconstruction of old pavements consisted of removing and wasting the old pavement material and rebuilding the pavement with new materials. This stockpiled waste material was unsightly and expensive to be disposed of properly. At this point, recycling began to be considered so that this waste could be used to benefit society and would not present a major disposal problem. Recycling did not catch on at this point, however, because it was not cost-effective and the technology and equipment for recycling pavements were not available.

3. The oil embargo of 1973 stressed the point that there is not an unlimited supply of natural materials. Since the embargo, the law of supply and demand had pushed the price of asphalt to $180 per ton* by early 1980. In 1975, the price of asphalt cement was approximately $70 per ton (Prody et al., 1975).

4. Not only the amount of asphalt available for construction is limited, but also the amount of high-quality aggregate. In many

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

locations, economical considerations are forcing the use of lower quality aggregates. The two economic factors involved are (a) the shortage of higher quality aggregate and (b) the cost of hauling long distances. The use of lower quality aggregates results in a lower quality pavement; therefore, recycling can relieve both problems.

5. After the oil embargo of 1973, the use of recycled materials in pavement construction began to increase but still on a small scale, since the technology and equipment for recycling pavements had not been sufficiently developed. During the last few years, however, the technology has developed to the point that recycling is no longer in the experimental stage but is approaching the status of conventional paving procedures. There still exist problems that are peculiar to recycling; however, the number and complexity of these problems have been reduced significantly in recent years. The time is now appropriate for recycling to become a major force in the field of pavement maintenance and rehabilitation.

Objective and Scope

6. The objective of this study was to perform a literature search on recycling of pavement materials and to list and briefly discuss those recycling processes that are applicable to Air Force pavements. It is anticipated that a follow-up study will be needed to prepare a standard practice manual and guide specifications for each of the recycling processes.

7. A number of processes for recycling asphaltic concrete (AC) pavements and portland cement concrete (PCC) pavements were reviewed. The recycling processes applicable to AC pavements are outlined in a study by White (1977). However, this outline is also applicable to PCC pavements as shown below.

Recycling of Portland Cement and Bituminous Concrete Pavements

A. Surface Recycling

1. Heater-Planing-Scarifying (AC)
2. Grinding (AC and PCC)
3. Rejuvenating (AC)

B. Cold Recycling

1. In-Place Processing (AC and PCC)
2. Fixed Plant Processing (AC and PCC)

C. Hot Recycling

1. Heat Exchanger Processing (AC)
2. Drum Mixer Processing (AC)
3. Conventional Batch or Continuous Feed Plant Processing (AC)

Many recycling jobs may include more than one of the processes outlined above.

PART II: SURFACE RECYCLING

Heater-Planer-Scarifier

8. Heater-planing consists of heating the surface of a bituminous concrete pavement and planing the surface to the desired grade. The planing operation may take one or more passes to obtain the desired depth of cut. The equipment used to plane a pavement varies considerably. Some of the equipment is self-contained so that one piece of equipment can heat, plane, scarify, add binder and hot-mix, and then lay the material (Figure 1). Often planing and scarifying jobs are done with a number of separate pieces of equipment, such as a heater (heats and scarifies), a planer (usually motor grader), a distributor to add binder material, and a laydown machine. A heater-planer with scarifying teeth followed by a grader is shown in Figure 2. Usually when planing and scarifying are required, several passes may be necessary to plane the pavement to the desired depth before scarification

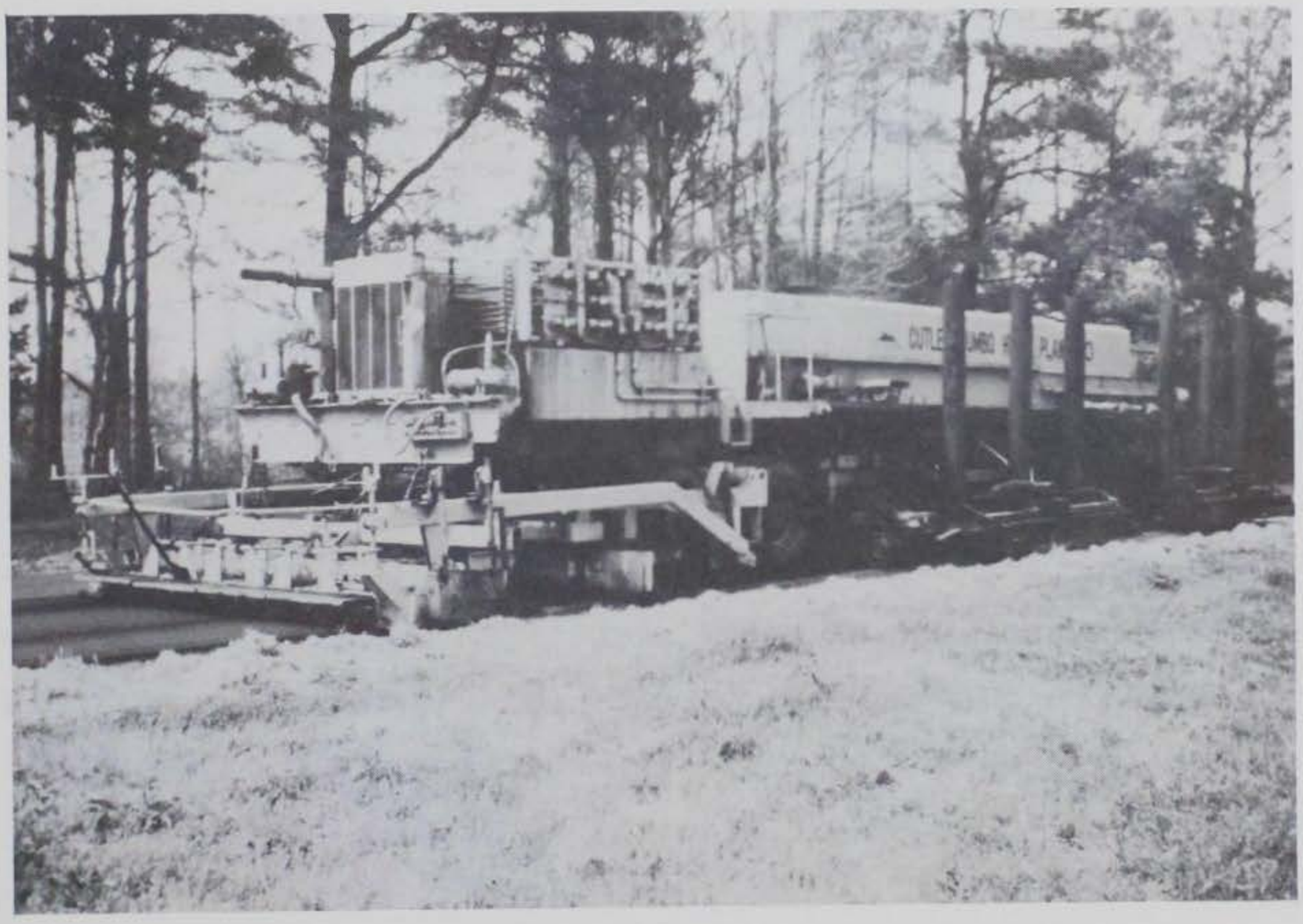

Figure 1. Self-contained heater-planer

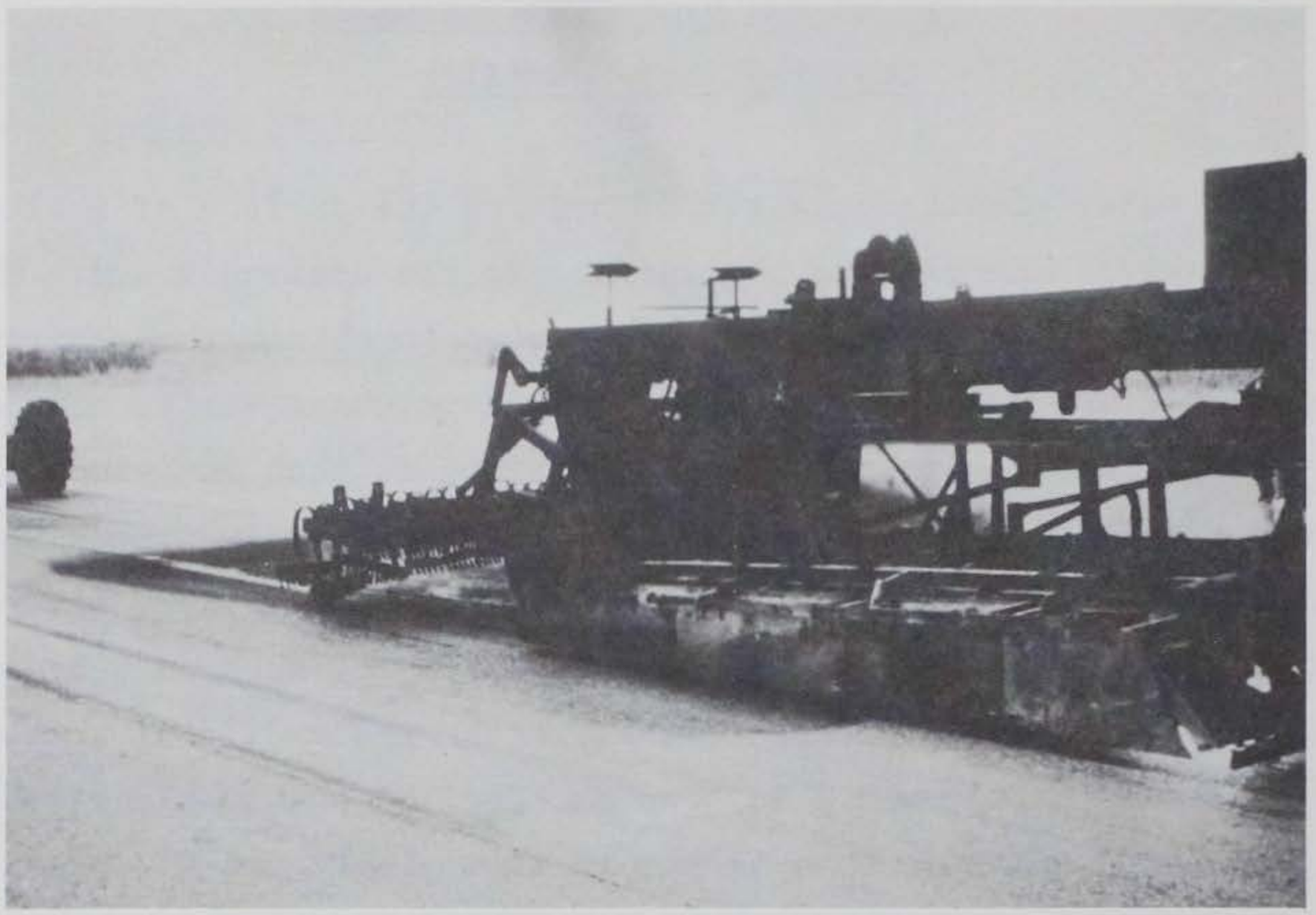

Figure 2. Heater and scarifying teeth followed by grader

(Figures 3 and 4). Care must be exercised to ensure the proper cut is obtained. The planed pavement is then reheated and scarified to a depth of 3/4 to 1 in. Some of the planers use direct flame to heat the pavement surface, while others use indirect heat. The heater in Figure 2 uses direct flame for heat, while the heater in Figure 1 uses indirect heat.

9. The heater-planer operation shapes the pavement surface to some desired section. The material that is removed could be used while hot to surface secondary roads or other locations where a low-quality mix would be acceptable (Cahoon, 1977). Kerosene or other solvents are often mixed with the removed material to form a cold-mix to be used later. Often, the quantity of material removed is small; for this reason, many times very little use is made of the planed material. Once the material cools and sets up, it is difficult to reuse the material.

Figure 3. Heater-planer operation

Figure 4. Cut in process during heater-planer operation

10. There are a number of reasons for planing the pavement surface (Lawing, 1976). The pavement surface over a bridge can be removed by planing before resurfacing to prevent an increase in the dead load on the bridge. Surface planing can be used to provide the grade prior to overlays for proper tie into curbs, manholes, and other desired structures. Heater-planing is often used to minimize the thickness of the overlay necessary to provide the desired grade. For instance, a pavement that has a large number of high and low spots will require a larger amount of bituminous mix to provide a smooth surface. Planing the high spots reduces the amount of material necessary to provide a smooth surface and lowers the overall cost of the job. Clearances in tunnels and underpasses can be maintained by heater-planing.

11. Scarifying the pavement surface can solve many problems. Often the pavement surface becomes glazed from the action of traffic. To promote a good bond between this existing glazed surface and an overlay, it is desirable to scarify the surface to provide a better bond of the old and new pavement layers. Scarification also breaks up the crack pattern and thus reduces the amount of reflective cracking that will appear in the overlay. Scarifying the top 3/4 to 1 in. of the surface allows additional asphalt binder or rejuvenating agent to be added to this scarified material. This procedure is used often on low-volume roads to provide a tight waterproof surface. In most instances, however, the scarification process is followed by a bituminous concrete overlay.

12. Two of the biggest disadvantages of the heater-planer-scarifier operation are pollution and workmanship. Pollution is created by the burning of asphalt under the heater. This pollution is minimized by the use of indirect heat, but the problem still exists. Most pollution occurs at locations where a crack filler or a seal coat exists.

13. The heater-planer-scarifier operation requires special knowledge; for this reason, it is extremely important that fully qualified, experienced personnel perform the job. The speed of the heater

and the amount of heat must be properly controlled. Good workmanship is necessary to ensure the proper depth of planing and scarification.

14. During the last 8-10 years, the heater-planer-scarifier operation has been used and evaluated by the state of Arizona (Burgin, 1977). Results in the state of Arizona show that pavements which are heater-scarified and then overlaid produce 10 percent of the cracks reflecting through the new pavements during the first 2 years and 40 percent of those reflecting through after 4 years. (The heater-planer-scarifier jobs in Arizona visually indicate less reflective cracking than the conventional overlay jobs.)

15. Overlay projects that have used some form of the heater-planer-scarifier operation for runways are Craig Air Force Base, Alabama (early 1970's); Galena and Shemya Air Force Bases, Alaska (1975 and 1976); and Thule Air Force Base, Greenland (1977).

16. Heater scarification and heater planing are both applicable to maintaining and rehabilitating Air Force pavements. The heater-planing operation has been used on many runway jobs to grade the pavement before applying the overlay and hence reduce the quantity of overlay material needed. This operation also results in considerable cost savings on the job. Heater scarification has been used on a number of Air Force jobs to reduce reflective cracking and to promote a good bond between layers. This method of surface recycling has also proven itself to be cost-effective.

Grinder

17. The grinding process is used to plane a bituminous or PCC pavement to some desired depth. This procedure planes the pavement without the use of heat (Figure 5). The grinder equipment can cut up to 4 in. of bituminous mix on one pass. Some of the equipment has direct control of the finished grade by having sensors that can follow a stringline grade reference. The cutting teeth in the grinder can be adjusted to provide the surface texture desired. If all the teeth are in position, the finished surface texture is relatively smooth;

Figure 5. Pavement grinder in operation

however, the surface texture can be made rougher by removing some of the teeth. The rougher the surface texture the better the skid resistance; however, the rougher surface also causes more tire wear.

18. Since no heat is needed, the pollution problem caused by burning bitumen (heater-planer) is eliminated. A problem with dust pollution occurs sometimes, but it can be solved by spraying a small amount of water in front of the grinder (Figure 5).

19. The reasons for using the grinder are much the same as those for the heater-planer. The grinder can remove bituminous or PCC pavement from bridges so that the desired dead load will not be exceeded because of a new overlay. Also, areas adjacent to curbs, manholes, and other structures can be planed before the overlay is applied so that the overlay thickness can be maintained adjacent to these structures.

20. One advantage the pavement grinder has over the heater-planer is its ability to plane PCC (Figure 6). This is particularly advantageous when planing a pavement that has some PCC that must be planed or removed, such as areas adjacent to manholes and patches.

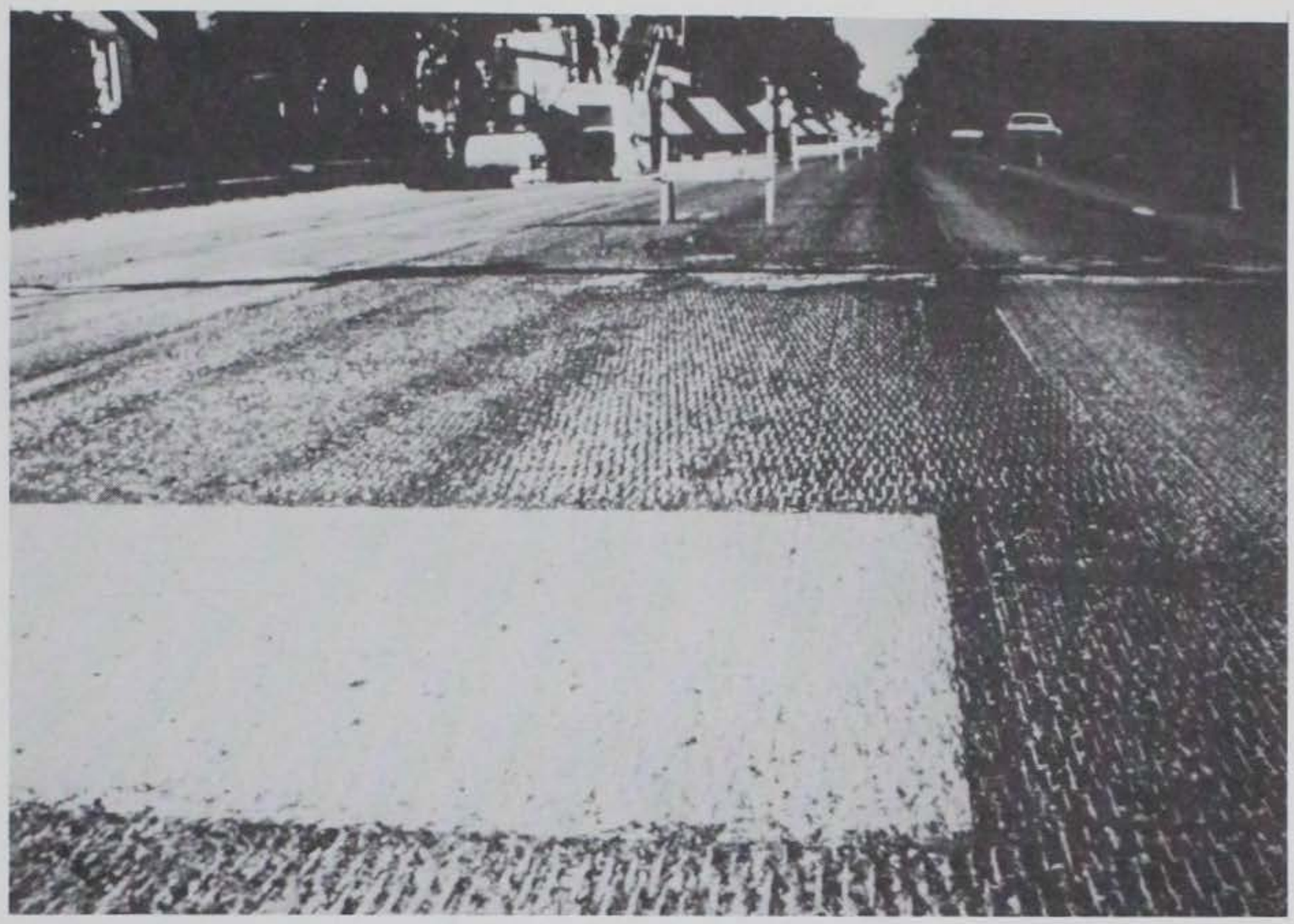

Figure 6. PCC patch planed along with AC pavement

21. Occasionally, when a pavement surface has been planed with a grinder, the surface is used as the riding surface for a period of time (Figure 7). For instance, assume a pavement does not have adequate skid resistance, but no immediate funds are available to overlay this pavement. One alternative is to grind the surface to give it a rough surface texture and thereby improve the skid resistance until it can be overlaid or otherwise treated. It is recommended, however, that the pavement be overlaid as soon after the grinding process as possible. Raveling may become a problem with AC pavements. The time before the overlay is applied probably should never exceed 1 year.

22. The material obtained from grinder operations can be used in pavement construction. Material can be stockpiled; but care must be exercised not to stockpile AC material too high, especially in hot weather, since the material has a tendency to bond together that makes its use more difficult. In most cases, the material should not be stockpiled over 10 ft high. Occasionally, this planed material is used to surface secondary roads that otherwise would not be surfaced (Figure 8). Then some additional binder material, such as asphalt

Figure 7. Planed surface used as riding surface

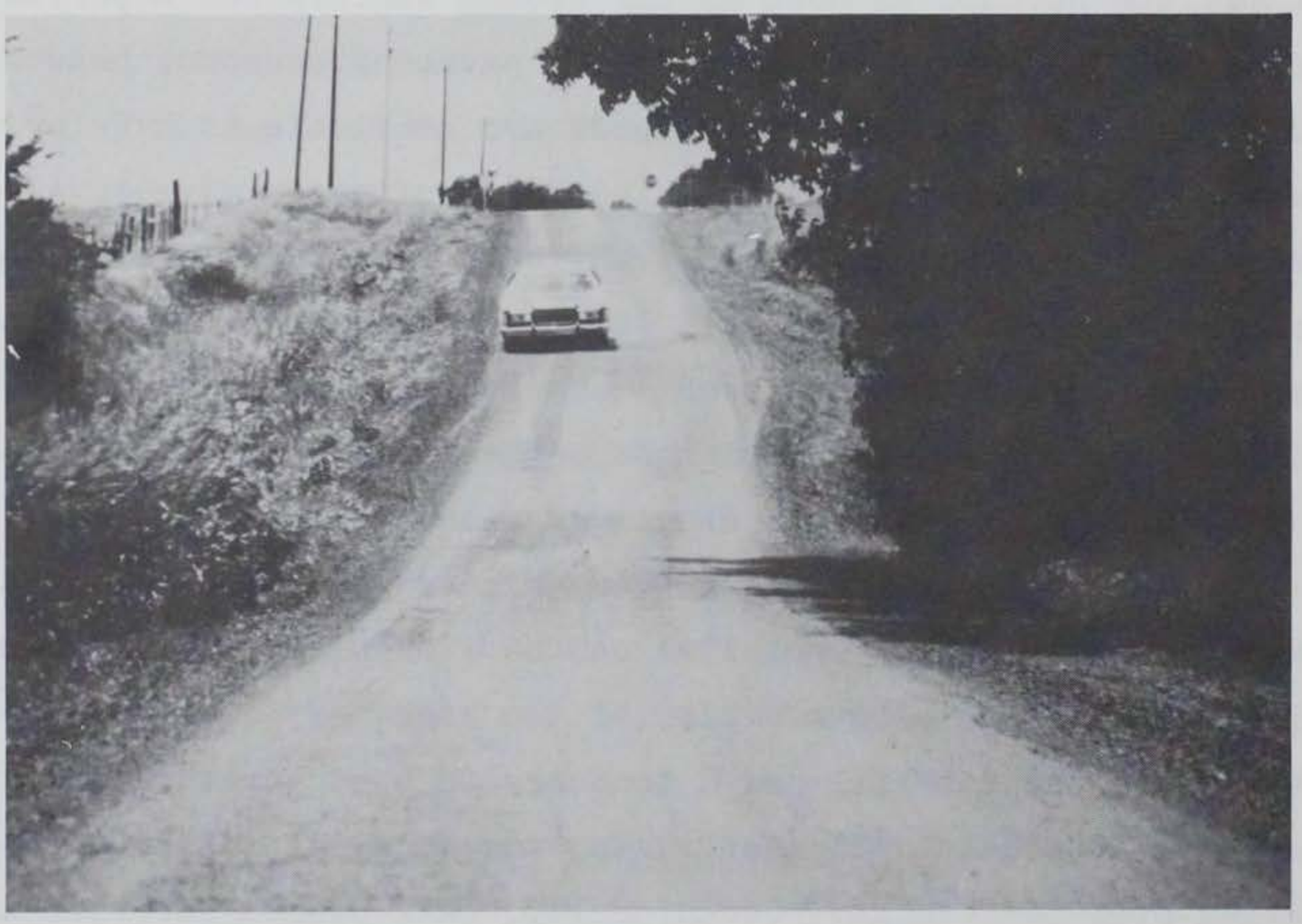

Figure 8. Trimmings from cold planer operation used to surface secondary road

emulsion or rejuvenator, is usually added to rejuvenate the old asphalt or improve binding qualities. This planed material can also be used as a base course for high-quality pavements. The material can be mixed in place with additional asphalt or removed and cold plant-mixed to produce a satisfactory base course. For high-quality airfield pavements, this material should be overlaid with at least 3 in. of AC mix. The hot-mix prepared from materials obtained by grinding is discussed in Part IV.

23. A pavement grinder known as a profiler was recently used at Myrtle Beach Air Force Base, South Carolina. The surface of the old pavement had oxidized and cracked. Rubber buildup was severe in touchdown areas. The profiler was used to remove the oxidized mix and rubber buildup to a depth of approximately 1 in. The pavement was then overlaid with 2 in. of new AC. The entire job was performed in less than 2 weeks. Other Air Force pavements have been profiled in Alaska, Maine, New Hampshire, Colorado, Oklahoma, California, and other locations.

24. The milling process has been used on many highways to correct pavement problems and to improve the rideability of roads. In North Dakota, a highway that had ruts in the wheel paths and a dangerous change in grade between the traffic lane and the paved shoulder was improved by the cold milling process (Federal Highway Administration, 1978). The traffic lanes were planed to remove the ruts, and the planed material was used to improve the transition between the travel lane and the shoulder. The planing corrected three problems: (a) low skid resistance, (b) ruts 1/2 to 1 in. deep, and (c) poor transition between the traffic lane and the shoulder.

25. The grinding process is applicable to Air Force pavements. The top 2-3 in. of old pavements can be planed to disrupt the crack pattern. This planed material can be mixed in place or at a plant with asphalt added, relaid, and recompacted to form a dense watertight layer. This allows an old pavement that is badly cracked to be overlaid with a minimum thickness and at the same time to retard reflective cracks. The grinding process has also been used to improve skid resistance. Pavements with low skid resistance have been planed, restriped, and opened to traffic. These planed pavements provide much better skid

resistance at a minimum cost until the pavement can later be overlaid or reworked.

Rejuvenator

26. Rejuvenators have been used extensively in surface recycling. They may be sprayed directly to the surface of a bituminous pavement or be used in conjunction with two other surface recycling processes (heater-planer-scarifier and grinder) (Boyer, 1977). Very little equipment is necessary for applying rejuvenator to the pavement surface; a bituminous distributor is the only major equipment needed (Figure 9).

Figure 9. Application of rejuvenator

27. The application of the rejuvenator partially restores the asphalt properties to or near their original properties. For a rejuvenator to be successful, it must possess the ability to penetrate the pavement surface and soften the asphalt binder. Most rejuvenators, depending on the pavement type, penetrate from 1/4 to 1/2 in. Usually the asphalt penetration (physical test on asphalt binder) of old pavements

is between 10 and 40. However, a penetration of at least 50 is often desired.

28. When a satisfactory rejuvenator is properly applied to pavement, it will retard the loss of surface fines and reduce the amount of cracking. However, the skid resistance is also reduced. A rejuvenator should not be added to bituminous pavements with an excess of bitumen on the surface or to a pavement with a minimum amount of air voids (amount of air voids should be at least 5 percent) as its use will significantly reduce the skid resistance or cause the mix to become unstable.

29. It is necessary that rejuvenators be allowed to penetrate and cure for 1-2 days before allowing traffic on the treated surface to prevent pickup of the rejuvenator material. If an excess of rejuvenator is applied, the surface will remain tacky and sanding of the surface will be required to remove the excess material.

30. The Air Force has used rejuvenators at Lajes Field in the Azores Islands; Wright-Patterson Air Force Base, Ohio; and other bases throughout the United States. Results have shown that rejuvenators, when properly applied, do improve pavement performance. Arizona has used rejuvenators extensively with the heater-scarifier operation, and results indicate good performance (Burgin, 1977).

31. The use of rejuvenators is applicable to Air Force pavements. Because of the possible reduction in skid resistance, it is recommended that rejuvenators not be used on runways (Brown and Johnson, 1976). However, rejuvenators could be applied to taxiways and other bituminous pavements where a slight reduction in skid resistance would not be critical. As previously mentioned, rejuvenators, when properly applied, do improve pavement performance; but when used in excessive amounts, they create a slipperiness problem.

PART III: COLD RECYCLING

32. Often a pavement has deteriorated to a point that surface recycling or a conventional overlay will not satisfactorily repair the pavement (Figure 10). In this case, the old pavement needs to be recycled to some required depth to retard reflective cracking.

Figure 10. Pavement applicable to full-depth recycling

In-Place Processing

33. In-place processing involves breaking up the in-place pavement, adding a binding agent or water, mixing, laying, and compacting. There are many ways of accomplishing in-place processing.

34. One method of processing in-place bituminous pavements involves planing the pavement to the desired depth with a grinder (Figure 5). A binding and/or lubricating agent is then added and mixed with the planed material. When water is added, the material is considered to be similar to a crushed aggregate base course. The optimum water content should be determined so that maximum dry density will be

obtained. The recycled material should be placed at the optimum water content to provide maximum shear strength. In this case, the water acts as a lubricating agent promoting good compaction and thus high shear strength. Cold-recycled material is susceptible to frost action if fines are excessive; however, the addition of small amounts of bituminous material will correct this problem (Rand, 1979).

35. An asphalt material, usually in the form of an emulsion, may be added during in-place processing. This emulsion may act as a lubricating agent, rejuvenating agent, and/or binding agent. Emulsions are used because they require little or no heat, provide good coverage of the aggregate, do not create pollution, and require no petroleum solvents as do cutbacks. The emulsion is normally added in sufficient quantity to provide optimum residual asphalt content. This optimum asphalt content may be determined based on Marshall design criteria or other design procedures. An emulsion should be selected that will provide desired asphalt properties when mixed with the asphalt binder contained in the planed material.

36. There are a number of ways of mixing the asphalt material with the planed material (Asphalt Institute, 1977). The travel plant offers a good mixing procedure for the mixed-in-place recycling process and, therefore, the best control of the asphalt content. The first step is to windrow the material to be recycled. The travel plant picks up the material and adds an asphalt binder based on the volume of material. The material is then mixed and laid down in a windrow

37. Rotary-type mixers are also used for mixing the in-place material. Additional asphalt may be added during the rotary mixing or by a distributor before mixing. The rotary mixer can be used to further mix and aerate the mixture before compaction. Several passes of the mixer are usually required to properly mix and aerate the recycled material.

38. Blade mixing is the least desirable of the in-place mixing processes. Additional asphalt may be added by a distributor before mixing. This mixing procedure involves working the material back and forth across the work area until the mixture is properly aerated and

mixed. However, it is difficult to prevent aggregate segregation and high variations in asphalt content.

39. Portland cement is often added to the planed material to provide strength to the recycled mix. When this is done, the recycled material can be treated as a cement-treated base course. To prevent excessive cracking, the cement factor should not exceed 4 percent.

40. When portland cement is added as a binding agent, usually the mixing is obtained with a rotary-type mixer. Again, several passes are necessary to ensure proper mixing of the portland cement with the planed material.

41. The surface grinder works very well for removing portions or all of an existing pavement. If a pavement is 10-12 in. thick, the grinder can remove the required number of inches from the pavement surface. If the pavement surfacing is only 3-4 in. thick, however, it is probably cheaper to use ripper teeth and then rip the entire surface (Figure 11). A ripper can be attached to a grader or a bulldozer and

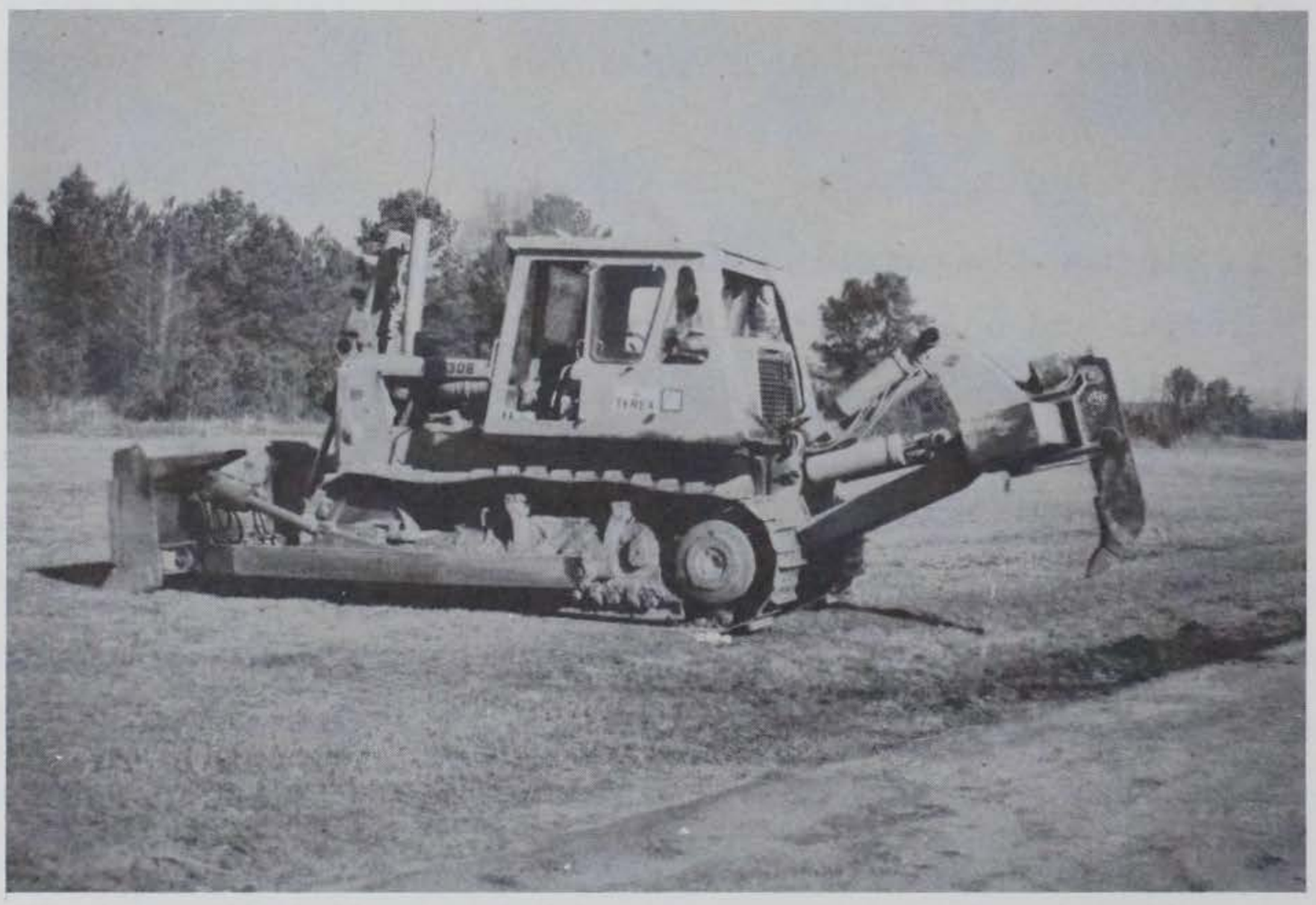

Figure 11. Pavement ripper attached to bulldozer

used to break the pavement into pieces that are less than 3-4 ft in size (Figure 12). Before ripping the pavement, the work area can be outlined by a sawcut so that the pavement being ripped will break off square at the edges and thus provide a satisfactory edge against which to lay the recycled material.

Figure 12. Pavement after being ripped with bulldozer

42. Additional breakdown of the chunks can be accomplished in a number of ways. A sheepsfoot roller is often used to provide further breakdown. A bulldozer can be used to track the pavement and provide additional breakdown. A traveling hammermill is often used to further break down the material (Figure 13). The material must be windrowed before using the hammermill. Several passes may be required to adequately break down the materials. Water may need to be added during this process to reduce pollution and to keep the hammers cool (Figure 14). A rotary-type pulvimixer is often used to provide additional breakdown of material. With the pulvimixer, the material does not have to be windrowed. After the material is broken to the desired size, mixing can be achieved with the travel plant, rotary mixer, or blade mixing process, as discussed above.

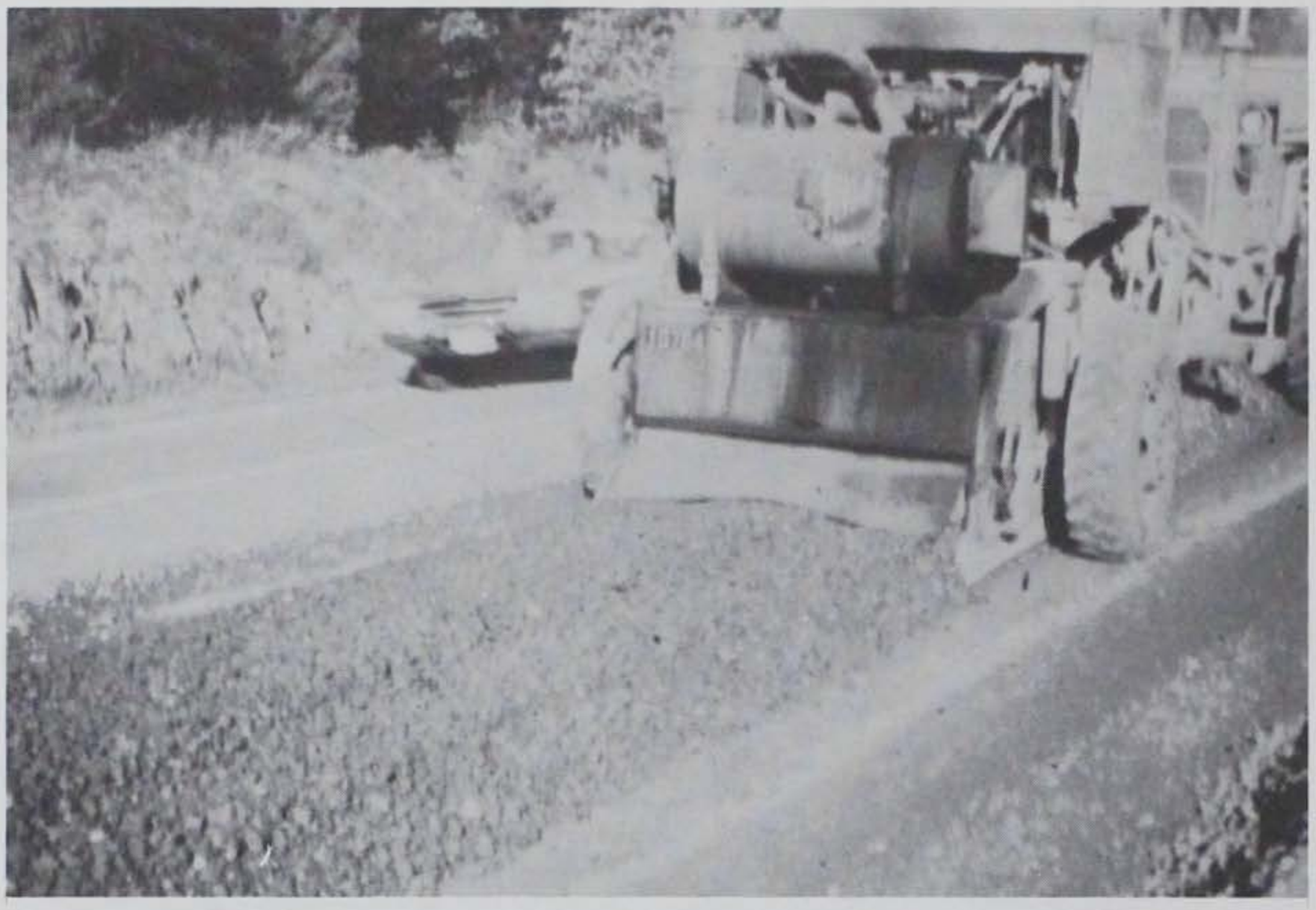

Figure 13. Traveling hammermill

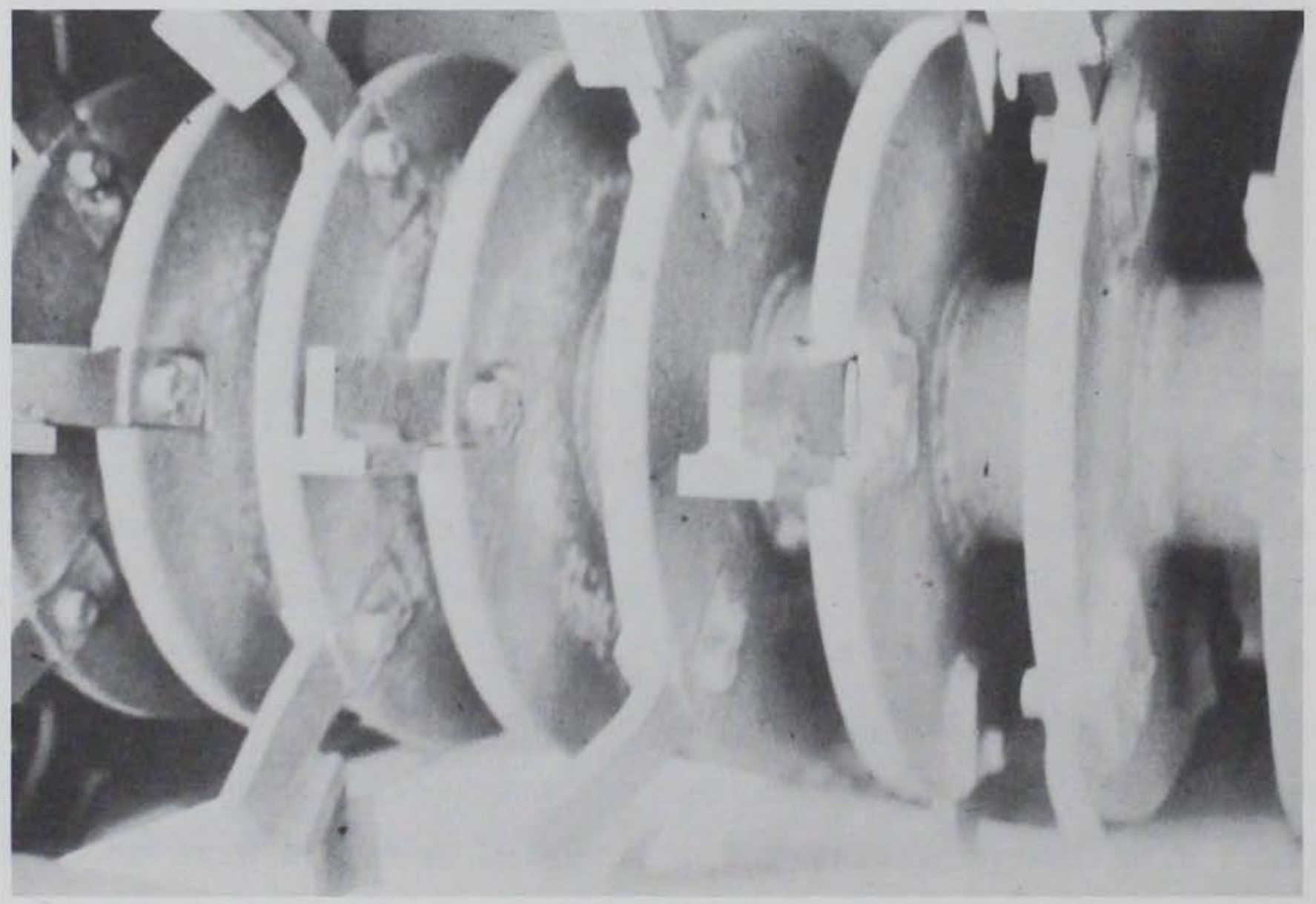

Figure 14. Close-up of hammers inside hammermill

43. Laydown of the mixed-in-place material can be attained by two methods. The material can be spread by a grader or a laydown machine. The use of a laydown machine is preferred. Some laydown machines can pick up windrows and properly lay the material, whereas other laydown machines require the material to be loaded in the hopper of the laydown machine.

44. The in-place cold-recycling process was used to reconstruct airfield pavements at Martha's Vineyard Island (Aikman, 1977). The pavements were ripped up, crushed with a traveling hammermill, thoroughly mixed at optimum water content, and compacted to meet Federal Aviation Administration specification requirements. The runway was then overlaid with 3 in. of AC, and taxiways and other pavements were overlaid with 4 in. of AC. It was estimated that conventional procedures for reconstructing the pavement would have cost 50 percent more than the cold-recycling procedure. Cost analysis of a cold-recycling job at Beverly Municipal Airport near Boston showed recycling to be competitive with conventional procedures.

45. Highways in various states have used the in-place cold-recycling process to reconstruct pavements (Elkin, 1979; Federal Highway Administration, 1978a and 1978b; Frascoia and Onusseit, 1979; and Rand, 1979). An analysis of these pavements has shown that this recycling process eliminates reflective cracks, provides a stronger, more durable pavement, and costs less than conventional procedures. Cold-recycling requires less energy than that necessary for other procedures (Beckett, 1979).

46. Cold-mix in-place recycling is applicable to Air Force pavements. It is recommended that use of the cold-mix material be confined to the base course for high-quality airfield pavements. Also, for airfield pavements, the material mixed in-place should be mixed with the travel plant or possibly the rotary mixer and placed with a laydown machine. The use of a grader to mix or spread material does not provide adequate control of mixing or grade during laydown.

Fixed Plant Processing

47. In the fixed plant process, the material is removed from the pavement area for processing. An old bituminous pavement may be broken up by the grinder or by ripper teeth. When the grinder is used, the planed material can be hauled to the plant and stockpiled for further processing. The recovered material can then be processed through the plant with water, asphalt, and/or cement being added. After mixing, the material is hauled back to the pavement site, placed, and compacted.

48. If the material is removed with a ripper, it must be crushed before being processed through the plant. Usually chunks 2-3 sq ft are obtained from the ripping operation and stockpiled for further processing (Figure 15). Care must be taken in stockpiling AC, because it bonds together and becomes difficult to remove. Normally, it is necessary to send this material through a primary crusher followed by a secondary crusher in order to obtain the desired material size.

Figure 15. Old AC stockpiled before crushing

49. Cold recycling indicates that no significant heat is added during the recycling process. Thus, for fixed plant processing, asphalt emulsion or cutback asphalt must be added to the crushed material to produce asphalt mix. Crushed AC (Figure 16) or crushed PCC (Figure 17) can be used as the aggregate for the cold-mix.

Figure 16. Old AC after crushing

50. Often the fixed plant process is used to process material obtained from PCC pavements. The PCC can be broken up and crushed to produce aggregate for the base course, econocrete (lean concrete), PCC, or AC. The slabs of concrete are first broken up with a pavement breaker into pieces 2-3 sq ft. If the concrete is reinforced, the steel is cut with torches before it is loaded and hauled to the crusher. After being hauled to the crusher, the material is processed through a primary crusher, during which the pieces are broken down into sizes no larger than 5-6 in. At this point, the remainder of the steel is removed, and the material is fed to a secondary crusher for further breakdown. Care should be taken to remove the steel before the concrete is added to the secondary crusher; otherwise, the crusher could be damaged.

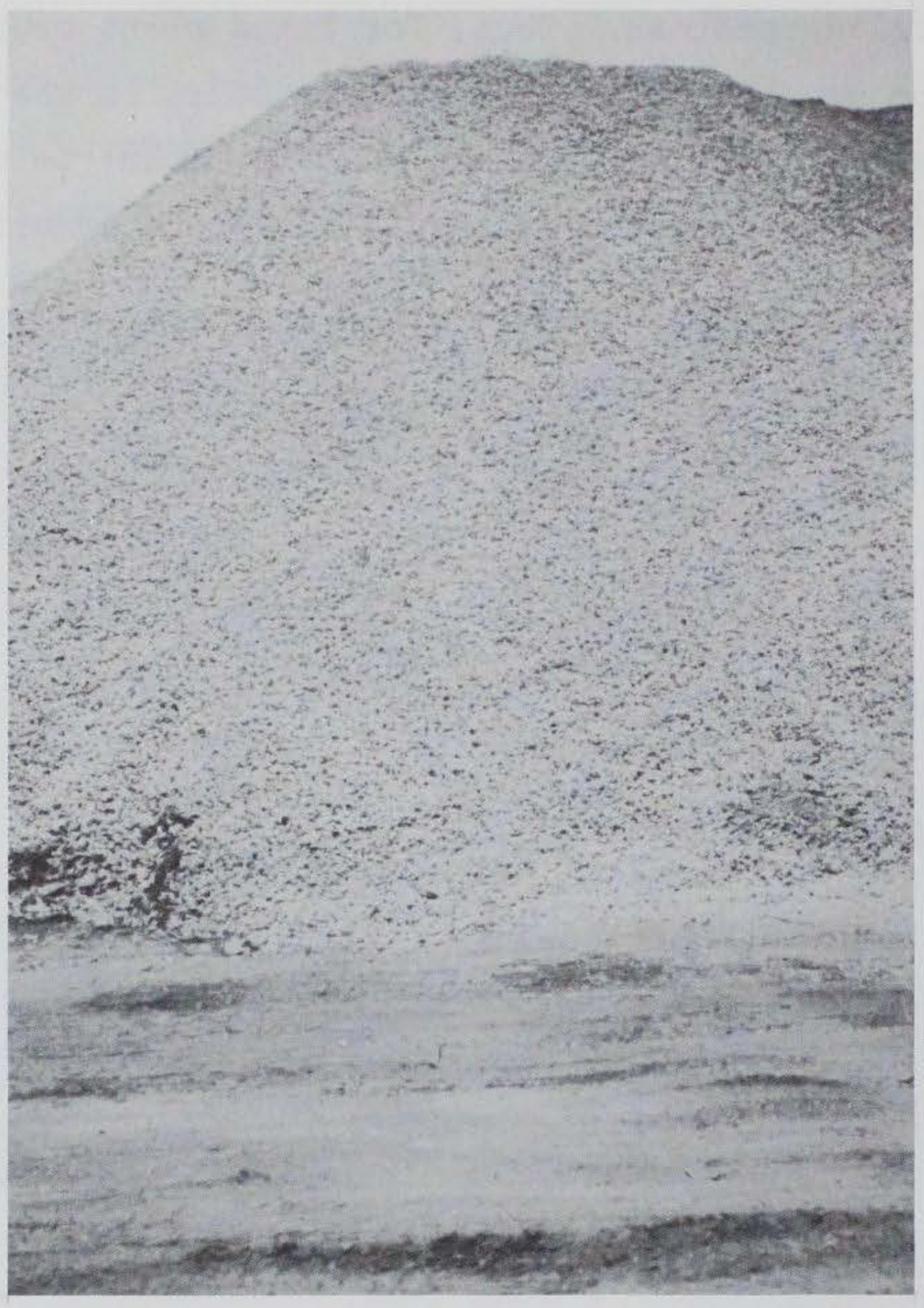

Figure 17. Old PCC after crushing

51. The crushed PCC can be used to construct a base course arable to or better than that produced with crushed aggregate. The crushed PCC should be mixed at the optimum water content before placing and compacting. The crushed PCC aggregate will set up with time and exhibit some cementing characteristics.

52. The PCC aggregate has been used for another application. A small amount of cement can be mixed with the aggregate and water to produce econocrete (Figure 18). This econocrete can be used as a base course for high-quality PCC. Since only a small amount of cement is added, econocrete is cheaper than PCC.

Figure 18. Econocrete being placed at Jacksonville, Florida

53. More cement can be added to the PCC aggregate to form a high-quality PCC mix (Figure 19). When the crushed PCC particles are used as aggregate for PCC mix, it is important that the particles meet the aggregate requirements for PCC. Tests such as Los Angeles abrasion, soundness, freeze-thaw, and gradation are important. Generally, the same requirements for virgin aggregates should be applied to the aggregate obtained from crushing PCC.

54. Crushed PCC can also be used for manufacturing bituminous concrete mix. The crushed aggregate, when mixed with bitumen, should possess properties similar to those for conventional bituminous mix.

55. Econocrete was used in the reconstruction of a runway at the airport in Jacksonville, Florida (Aikman, 1977). The old PCC pavement was 11 in. thick in the center portion and 13 in. thick for 500 ft on each end. The existing pavement was badly deteriorated (longitudinal cracking, transverse cracking, corner cracking, spalling, and settlement) because of pumping action and deficient thickness. A design analysis indicated that the center 50 ft should be removed and replaced with

Figure 19. PCC prepared from crushed old PCC in Iowa

6 in. of econocrete overlaid with 14 in. of PCC. The old concrete was broken out, crushed to a maximum size of 1.5 in., and mixed with approximately 240 lb of cement per cubic yard of mix to form the econocrete. The material had a slump of approximately 3 in. and a compressive strength of approximately 1000 psi at 28 days.

56. In Iowa, a concrete pavement with an asphalt overlay was removed and crushed (Ray, 1977). The crushed aggregate was mixed with natural sand to form a concrete that was slipformed at 9-in. thickness. This pavement was constructed in two layers. The cement factor for the 7-in. lower layer was 470 lb/cu yd, and the cement factor for the 9-in. upper layer was 564 lb/cu yd. Cost analysis for this job indicated that if the coarse aggregate had to be hauled over 40 miles, it would be cheaper to recycle.

57. The fixed plant processing is applicable to Air Force pavements. With the fixed plant, the control of mixing is better, but the cost is higher than that of in-place processing. The fixed plant processing can be used to recycle AC or PCC.

PART IV: HOT RECYCLING

General

58. Hot recycling consists of taking up old pavement; crushing the old mix; mixing the crushed mix with virgin aggregate, virgin asphalt, and/or recycling agent; and laying the recycled mix using the same procedures as those for a conventional mix. This procedure can produce a bituminous concrete mix having the same quality as that of a conventional bituminous concrete mix.

59. Tests have shown that hot mixes prepared from recycled materials have a higher fatigue life than those from conventional materials (Kennedy and Perez, 1978). Tests also indicate that recycled hot mixes are no more susceptible to water than conventional mixes (Terrell and Fritchen, 1978). Structural coefficients for layers consisting of recycled materials have been determined to be as good as those for conventional mixes (Little and Epps, 1980). Although these findings are somewhat limited, they do indicate a significant potential for the use of recycled paving materials.

60. Virgin aggregates are added to recycled AC materials for a number of reasons. Without the addition of new aggregate, air pollution during mix production for most plants would far exceed the allotted quantities. With the addition of new aggregate, a satisfactory mix can be produced while meeting the minimum requirements for air pollution.

61. Also, the aggregate gradation is modified and improved when virgin aggregates are added. Many times old pavements in place do not contain the proper aggregate gradation; and if they do, the gradation may be changed during the crushing operation. The addition of virgin aggregate allows the gradation to be modified to an acceptable range. Often the quality of the aggregates in an old mix is not acceptable, even though the gradation is satisfactory. One example of this is an excess of natural rounded sand. Rounded sand is a poor bituminous concrete aggregate; but because of its abundance and low cost, it is often used in excess in AC mixes. The addition of a new high-quality

aggregate can reduce the percentage of low-quality aggregate and, therefore, improve the quality of mix.

62. The asphalt binder in old pavements is generally oxidized and requires some modification during recycling to produce an acceptable mix. If no new aggregate is added to the mix, the addition of asphalt or a recycling agent to produce satisfactory asphalt properties may produce a mix that is too rich. In this case, the old asphalt cannot be properly modified without producing a rich mix; hence, a brittle mix or an overasphalted mix will be produced. In the design of a recycled mix, provisions must be made to ensure that the resulting mix is not excessively rich.

63. There are two methods of modifying the old asphalt in a mix. A recycling agent or a low-viscosity asphalt cement can be mixed with the recycled mix to produce an asphalt binder with acceptable properties. Normally, it is desirable to modify the asphalt binder so that its properties approach the properties of a new asphalt that would be selected for a conventional mix.

64. A number of recycled agents exist, and caution must be exercised when one of these agents is selected and used. A recycling agent must be compatible with asphalt, must be able to restore the old asphalt so that it possesses desirable qualities, and must improve life expectancy of restored asphalt (Davidson et al., 1978). Many recycling agents appear to improve the properties of old asphalt before the mix is heated, but after heat has been applied, the modified asphalt seems to lose these desirable properties (Gannon et al., 1980). The flash point can be used to help establish the amount of volatiles in a modifier and thus the effect that heat will have on the modifier (Dunning and Mendenhall, 1978). The thin film oven test is a good indication of how well a modified asphalt will perform after being plant-mixed. A high loss in weight and a high reduction in penetration after the thin film oven test indicate that the recycling agent will probably lose much of its effectiveness during the plant-mixing operation. In practice, it must be realized that modifiers do not react immediately with the asphalt to form a homogeneous binder (Carpenter and Wolosick, 1980).

The Marshall criteria with minor modifications should be used to design recycled bituminous concrete mixes. All recycled bituminous concrete mixes should be properly designed by a qualified laboratory before mix is produced.

65. The use of recycling agents may cause an oily film to form on the coarse aggregate and thus prevent satisfactory adhesion between the aggregate and the asphalt (Figure 20). However, evidence is insufficient to indicate that this film exists regardless of the agent used, but attention should be given to this problem during mix design and lay-down operations. Normally, it is recommended that a soft asphalt cement instead of a recycling agent be added to form the recycled material.

Figure 20. Oily film formed on coarse aggregate in recycled mix

66. The standard practice has been to overlay recycled AC pavements with a wearing course (Williams, 1978). This wearing course normally consists of a thin layer of AC or a porous friction course. Performance generally indicates that a recycled pavement that is not overlaid will present some surface deterioration problem, such as

raveling. It is believed that this need to overlay recycled pavement can be overcome with time, but more knowledge concerning performance of recycled AC is needed.

Heat Exchanger Processing

67. One of the plants used to produce hot-recycled AC is the heat exchanger (Prody et al., 1975). Since the mix is heated by conduction, the flames do not come in contact with the aggregate or recycled mix. Thus the asphalt is not damaged excessively and pollution is minimized. However, the fuel cost for heating the mix is high because the efficiency is greatly reduced. With the efficiency low, the production rate is also lower than desired.

Drum Mixer Processing

68. A drum mixer is often used for recycling AC. The desired procedure is to feed the virgin aggregate at the end near the flame and to add the old asphalt mix about midway of the mixer. The additional asphalt binder is then added after the old asphalt mix. The virgin aggregate is heated to a higher temperature than the old mix since it is inside the drum longer and the additional heat transfers by conduction to the old mix. The virgin aggregate also acts as a shield to prevent the flame from excessively damaging the old and new asphalt binder and minimizes the air pollution that is produced. This type of drum mixer uses the heat very efficiently, and the production rate is high. Pollution is sometimes a problem; then the mix design has to be adjusted, or some other modification made to minimize the pollution.

Conventional Plant Processing

69. Conventional plants can be modified to produce recycled AC. When a conventional plant is used, the virgin aggregate is superheated in the dryer and sized in the hot bins. The old asphalt mix is added

directly to the pugmill where the superheated aggregate and the new asphalt binder are added and mixed. Since the old asphalt mix does not travel through the dryer, pollution is no problem. The superheated aggregate simply heats the mix by conduction. This procedure does require that a significant amount of new aggregate be used, usually more than 50 percent, to allow for proper heating of the mix without having to excessively heat the aggregate.

Laydown Operation

70. Conventional equipment is used for laydown and compaction of the recycled AC. Recycled AC looks similar to conventional mix during the laydown operation (Figure 21). When a recycling agent is used, an oily film on the coarse aggregate may be apparent. This oily film is undesirable since it prevents a bond between the asphalt and the aggregate. Inefficient burning of the heating fuel may also cause the oily film.

Figure 21. Recycled bituminous pavement materials during laydown operation

Field Performance

71. A hot-mix recycled job was performed on the George Washington Memorial Parkway near Washington, D. C. (Highway and Heavy Construction, 1979). Approximately 7000 tons of hot-mix was placed, of which 50 percent was virgin aggregate and 50 percent old mix. A recycling agent and soft asphalt were added to the mix. The old mix was broken up and crushed to pass the 1-in. sieve. The heat transfer method was used to produce the recycled mix. (Aggregate was superheated and mixed with the old crushed mix.) The aggregate was heated to 500°F. Two 2-1/2-in. layers were placed with a 3/4-in., open-graded friction course over the surface. Depending on the location and other factors, this article points out that a cost savings of $3 to $8 per ton can be realized using this method of recycling.

72. Many pavements have been recycled to produce AC in Texas (Epps et al., 1978). PCC pavements have been broken up, crushed, mixed with asphalt, and placed to form base course and surface course materials. AC pavements have been recycled also to form new AC pavements. In general, these recycled pavements have performed satisfactorily.

73. Hot-mix recycling is applicable to Air Force pavements. The old AC or PCC pavements can be removed, crushed, and mixed with asphalt binder to produce hot-mix AC that will provide acceptable performance. Pavements that are severely deteriorated are ideal candidates for pavement recycling.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

74. Based on this study, the conclusions are as follows:

a. Recycling of flexible and rigid pavements is applicable to the maintenance and rehabilitation of Air Force pavements.

b. Recycling should be considered a viable option on many maintenance and rehabilitation jobs.

c. The cost-effectiveness of recycling improves each time the price of asphalt cement, portland cement, or aggregate increases.

d. Pollution is a major problem to contend with when the hot-recycling process is used.

Recommendations

75. It is recommended that:

a. Mix design, pavement procedures, and performance criteria be provided for each of the processes discussed.

b. Guide specifications be written for each of the processes discussed.

c. A standard practice manual be prepared giving guidance on when and how to use each recycling process.

d. A better understanding of the durability, strength, and fatigue resistance of recycled pavements under various climatic conditions be developed.

e. Recycling agents for bituminous pavements be evaluated and criteria be developed for the use of these recycling agents.

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