STATE-OF-THE-ART HOT RECYCLING

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Hot recycling pertains to the recycling or reprocessing of reclaimed pavement materials into hot mix asphalt in a central plant. Although reclaimed uncoated, aggregate and Portland cement concrete materials can be reprocessed into hot-mix asphalt, hot recycling is usually meant to specifically include the reprocessing of reclaimed hot-mix asphalt or asphalt treated aggregate. Reclaimed uncoated aggregate materials are reprocessed in the conventional manner as new aggregates, whereas reclaimed asphalt coated aggregates are reprocessed using slightly modified techniques. Both reclaimed uncoated and coated aggregate materials may be reprocessed into hot-mix asphalt during the same operation. In either case, the use of some additional new aggregate may be required in the recycling process for the purpose of producing a hot-mix asphalt which meets the stated quality criteria for the mix and/or for the hot-mix plant operation, itself, which requires a certain quantity of uncoated aggregate to operate efficiently and within air quality standards. In all instances new asphalt cement and/or a suitable rejuvenating agent will also be added as part of the recycling process to restore the properties of the aged asphalt and to coat reclaimed or new aggregates that have been added. Hot recycling can be done in any type of hot-mix plant including the drum, batch, and continuous types. The hot-mix plant must be modified or retrofitted for recycling, if not originally equipped when new. In terms of overall plant replacement cost, the investment is relatively small. The actual hot recycling process is not complicated, and in fact not much different from the conventional process. The technology and equipment necessary to do recycling is developed and available. What makes hot recycling seem complicated sometimes is the seemingly infinite number of ways to go about it. In addition there are numerous factors unique to the highway industry and the asphalt industry in particular, that would make one recycling technique preferable in one area and not in another. These factors need to be addressed in order to meld hot recycling into the normal operating procedures of the asphalt paving industry. The concept of hot recycling has grown from one concerned with the utilization of pavement materials being disposed of in landfills to one also concerned with finding situations where pavement material removal for subsequent recycling provides an economic advantage over other pavement rehabilitation alternatives. It is the latter that is the most difficult to identify and to accomplish.

THE ROLE OF PAVEMENT MATERIAL REMOVAL AND RECYCLING IN PAVEMENT REHABILITATION

Obviously, if one is going to recycle, one must obtain pavement materials from some place. Since approximately 80 percent of all hot-mix asphalt produced is purchased by public agencies, only approximately 20 percent commercial and private, one could assume that potentially 80 percent of all recyclable materials will come from public owned pavements. Hence, the public agency is, or will be, the keystone in providing the bulk of materials for hot recycling and the manner in which they perceive and practice the concept of hot recycling is all important in determining the quantity of materials that will ultimately be made available for recycling. The estimated quantity of materials to be made available, as the hot-mix contractor interprets the agency attitude toward recycling, is all influential in motivating the necessary equipment purchases and modifications to do recycling. This in turn also has a rebound affect on the agency attitude. Hence negativism on one side will bring deeper negativism on the other side. Conversely, a positive attitude has a similar, but opposite effect.

Hot recycling has been considered by some to be a pavement rehabilitation alternative. In other words, the entire procedure of removing pavement materials and reprocessing them through the hot-mix plant to subsequent replacement in the pavement is compared against other alternatives, as for example, an asphalt overlay. Others consider that pavement material removal is the rehabilitation alternative and that hot recycling is a separate process. In other words, pavement material removal can be done independently of recycling and vice-versa, or both can be combined and planned together as above.

The National Asphalt Pavement Association and The Asphalt Institute have adopted the second

point of view and have published the following definitions associated with hot recycling.

DEFINITIONS RELATED TO RECYCLING OF PAVEMENT MATERIALS

Pavement Material Removal - A pavement rehabilitation alternative.

Methods of Material Removal

(1) ripping and crushing
(2) cold milling
(3) hot milling
(4) heater planing

Reclaimed Asphalt Pavement (RAP) - Removed and/or processed pavement materials containing asphalt and aggregate.

Reclaimed Aggregate Material (RAM) - Removed and/or processed pavement materials containing no reusable binding agent.

Recycling - The reuse, usually after some processing, of a material that has already served its first-intended purpose.

Hot-Mix Recycling - A process in which reclaimed asphalt pavement materials, reclaimed aggregate materials, or both, are combined with new asphalt, and/or recycling agents, and/or new aggregate, as necessary, in a central plant to produce hot-mix paving mixtures. The finished product meets all standard material specifications and construction requirements for the type of mixture being produced.

It is important to recognize that the two operations, pavement material removal and recycling, are separable. There will be situations where it will be advantageous to combine them as a single rehabilitation plan and there will be situations where only pavement material removal is desired, and still other situations where no pavement material removal will be done, but recycling would be permitted if other material were available.

FACTORS INFLUENCING THE DECISION TO RECYCLE

There can be instances where if the two operations are not combined and other situations where if they are combined, then no recycling will be done because there are a number of associated factors which can make recycling seem to have the lesser economic advantage. Some of these are listed below:

A. Size of project (Recycling Ratio)
B. Availability of asphalt plants modified for recycling
C. Salvage value of removed pavement materials
D. Pavement material ownership policy
E. Reclaimed asphalt material content of resultant hot mix
F. Types of asphalt plants permitted/available
G. Location of project (rural or urban)

Almost all of the above factors are interactive with one another. For example, there are almost as many different situations that one has to contend with as there are possible combinations of the above factors. For this reason it is difficult to discuss each of these factors separately as the effect of each on whether recycling will be done can be different depending on the other factors. It is essential that the ultimate decision on whether recycling should be done, however, be based upon a life cycle cost analysis.

Initial cost is sometimes used as the basis with no consideration to the future costs of the various rehabilitation alternatives. Hence it is possible that recycling will be rejected as an alternative because initial costs might be higher, yet it could be the most economic choice based on annual cost over a specified service life. Part of the difficulty in life cycle analyses is the uncertainty of pavement service life of all types of pavements, in general, future repair needs, and availability of future funds for planned maintenance or rehabilitation programs. One cannot hope, however, to make a rational selection of any pavement rehabilitation alternative without some consideration to life cycle cost analysis of all possible alternatives.

A. Size of the Project

This factor needs to be considered in two parts; (1) tonnage of hot mix to be removed and, (2) tonnage of hot mix to be replaced. A secondary factor that is very influential is the recycling ratio, which is the ratio of the amount of material removed to the amount of material replaced.

If this ratio is greater than 0.7 (it is assumed here that a rehabilitation plan has been selected that is adequate structurally to handle the projected traffic over the desired service life at the desired pavement serviceability level), there will in all probability be excess reclaimed asphalt pavement materials left over after the project is completed. The economic value (salvage value) of this excess material is dependent on whether there is another place to use it within a reasonable haul distance. If there is no other place to utilize the economic value of the excess material, the agency should consider increasing the tonnage replaced to lower the ratio to at least 0.7 (increase pavement thickness above projected level of need, pave shoulders, etc.). This decision should be based on the economics of life cycle cost analysis as the two resultant pavements will have different service lives, different rehabilitation needs in the future, and different annual costs (or present worth). If there were another nearby location for use of this excess material, the economic value of the excess materials could be subtracted from the initial cost of this project or if the contractor purchased the excess material from the agency, the same effect is obtained. Then the recycling ratio would not have to be lowered.

In the above example, it was assumed that a drum mixer plant was to be used. If there are no drum mixer plants available, or if the agency does not want to exclude the use of batch plants, the recycling ratio should be lowered to at least 0.5. This limitation, as well as the preceding one, is mentioned because of plant type recycling limitations which will be discussed later. Depending on the number of drum mixer plants available, this latter course of action could improve the economics of recycling by stimulating competitive bidding. However, the economics may have been worsened because more hot-mix material is being replaced than originally determined to be necessary or wanted for the desired service life. A life cycle cost analysis would help

determine whether or not this is the case.

A project designed with a recycling ratio of 0.7 in conjunction with a batch plant which has a maximum limitation on the reclaimed material content of the resultant mix of 0.5, means that excess material would be left over after project completion, whereas with a drum plant, it quite possibly would not. In instances where there is other possible use of the excess material (either on another public project or if the excess material becomes the property of the contractor it could be used on private or commercial work), it may be economically justified to still plan the project at a recycling ratio which exceeds the reclaimed material content capability of the batch plant (or even above that of the drum plant for that matter). The batch plant owner can only be competitive in this instance with the drum plant owner if he acquires ownership of the excess pavement materials rather than the agency retaining ownership, and if the former can find an economic use for the excess material on some other project either public, commercial, or private.

In instances where there is no other possible use of any excess removed materials either public, private, or commercial (no economic value) it is quite likely that the use of a drum plant will prevail and will provide the lowest cost to the agency, but this may not be guaranteed unless there are several drum plants available to provide the competitive bidding necessary for the lowest possible cost.

The industry has barely begun to gear-up for recycling. This is because recycling is not permitted on a routine basis. Of the 4,000 plus or minus batch plants and the 800 plus or minus drum plants in the United States, it is extremely doubtful if there are more than 100 plants that have been completely modified or have the recycling capability. Contractors are aware that recycling is a process that will gain momentum in the years ahead. Partial plant modifications are typically included when a new plant is purchased. The auxillary accessaries are not purchased but left until such time as a recycling opportunity becomes a reality. Therefore before a "recycling project" (remove material and reuse in same pavement) can be done, it is likely that the contractor on an average will have to expend approximately $50,000 to $75,000 to modify his plant. With no other definite prospects to recycle in the future, (no permissive statewide specification for routine reuse of removed materials) this equipment purchase will be figured into his bid. Thus, if the "recycling project" does not have sufficient tonnage to be replaced, this extra cost could negate the savings obtained from the value of the removed pavement materials. There is therefore a lessor chance, at the present, that pavement material removal and recycling on the small remotely located paving project can be economically feasible under these circumstances. In the future when more asphalt plants have been equipped for recycling, pavement material removal and recycling will be more feasible economically for the small remotely located project because the equipment modification will have been paid for or is being amortized.

We have been assuming here that the pavement materials, if removed, would have no other use but to recycle them back into the pavement structure from which they were removed and any excess material had no other use and a zero salvage value. For the small "recycling project" located within a reasonable haul distance to an asphalt plant, the same situation is evident except that the reclaimed pavement materials can be stockpiled by the contractor (thus their economic value is inventoried) for use at some later time when more modified plants become available. It is economically disadvantageous for the public agency to stockpile the excess material. The reasons for this are discussed later.

B. Availability of Asphalt Plants Modified for Recycling

As discussed previously, relatively few asphalt plants are equipped for recycling. Unless a potential "recycling project" is located near one of these, the "recycling project" will have to be sufficiently large to overcome the cost of the plant modification in order for recycling to be the most economic rehabilitation alternative and/or an immediate use seen for any excess removed pavement materials. Public agencies can stimulate the contractors to begin making the necessary modifications to do recycling by adopting a permissive specification which permits the contractor to use reclaimed pavement materials in the hot-mix asphalt he produces for them. If a contractor is permitted to do this on a routine basis and not just on a project basis the necessary capital equipment modification can be amortized over several years of work (tonnage) rather than on just one project. This approach accomplishes not only the same thing as a large single recycling project, but much more. Instead of only stimulating the modification of one plant, many contractors will be encouraged to make the modification. This would be especially true when they begin to obtain a number of projects where pavement materials are being removed as part of the pavement rehabilitation plan and they begin to develop stockpiles of these materials.

C. Salvage Value of Reclaimed Pavement Materials

The salvage value of reclaimed asphalt pavement materials is equal to the value of the asphalt and aggregates less the costs to remove and haul these materials and any costs necessary to prepare them for the recycling process. The value of reclaimed aggregate materials or concrete are less because no binding agent is present. In the case where cold milling was used to remove the materials, they may essentially be sized enough for recycling without any other processing except perhaps for scalping of a small percentage of oversized chunks.

In the event where pavement material removal was performed because there was no other alternative available, (the base had failed and additional overlays would have been fruitless), or where the savings derived from pavement material removal resulting from not having to reposition bridges, curbs, gutters, manholes, guard rails, overhead signs, raise shoulders, etc., exceeds the cost of pavement material removal, the salvage value of the removed materials is equal to the cost of replacement materials.

This latter situation illustrates where pavement materials can be removed assuming a zero salvage value. That is, they will be removed regardless if any recycling is intended to be done. Typically, this material has been disposed of in landfills, etc. Today there are a number of contractors who have substantial quantities of these reclaimed materials stockpiled at their plant sites that have been obtained in this manner, but with little opportunity to use them.

A public agency can obtain additional benefits from those stockpiled materials (even though the contractor now possesses them) by simply permitting the contractor to use those materials in the mixes

he sells to them. Several state highway departments have taken this approach and permit the addition of reclaimed materials to base course mixes provided that conventional mix specifications are still met. The use of reclaimed materials in surface courses is still considered experimental. Although there will always be a need for the large "recycling project" where pavement removal and recycling will be tied together it is the small urban or city projects that will be done where pavement material removal and recycling are best performed as separate operations. It is the permissive specification approach which will provide the impetus for the asphalt industry to modify more plants for recycling. This in turn will eventually make possible the small rural "recycling project" which doesn't occur now because the equipment modification costs exceed material savings. Eventually, the permissive specification approach will provide competitive bidding for removed pavement materials (through lower bid prices for removal provided that the bid transfers ownership to them) among contractors until the salvage value ultimately equals the cost of new materials less removal and handling costs.

The public agencies need only consider the salvage value of removed materials that they will get in determining whether pavement material removal is to be part of the rehabilitation alternatives selected. If the material ownership is transferred to the contractor as part of the bid, then recycling need not be considered in the rehabilitation analysis. Full value for these materials will be obtained provided the project is situated in a location where any excess or surplus of removed materials could be used elsewhere. In these cases, the agency need not be concerned with the recycling ratio.

D. Pavement Material Ownership Policy

Most of the recycling done to date has been on the large "recycling project". Typically the recycling ratio on these projects have been from 0.5 to 0.7. In some instances recycling ratios have approached unity. Due to one reason or another the reclaimed material content of the resultant recycled mixture has also been made equal to the recycling ratio. The principal reason being that all pavement materials that were removed were consumed on that project so there were none left over. This can possibly be justified on the remotely located project where the economics of having left over material is not as satisfactory. However, for the project located near other potential places for reuse of any excess materials, the above practice is quite likely less cost effective.

In order to recycle at reclaimed material contents from 0.5 and greater, one must in all likelihood use a drum mixer plant. Not only has the batch plant been excluded from the bidding process in these circumstances, but even the drum plant has difficulty sometimes in recycling at these higher reclaimed contents. Depending on the nature of the materials being reprocessed, difficulty may be encountered in meeting air quality standards, particularly in regard to stack opacity. Techniques that have been used to combat this problem include lowering production rate and adding water to the reclaimed asphalt pavement materials on the cold feed belt as they are introduced into the plant. These procedures cost money to the contractor in increased hours of production and higher fuel consumption to remove the extra added water. These uncertain costs are more than likely figured in the bid price for the project.

In most recycling projects to date, the public agency has retained the ownership of removed asphalt pavement materials and has designed these projects so that the reclaimed material content was equal to the recycling ratio to eliminate excess material after the project conclusion. This is not considered good practice from an economic viewpoint and not condusive to producing quality hot-mix asphalt. For remotely located projects this plan of action may seem to be economically justified. However, the extra costs of production at high reclaimed contents may be greater than the value of some excess material after the project's completion. Where there may be other uses for the excess material on other projects in the vicinity, high reclaimed material contents are unjustified economically.

The National Asphalt Pavement Association recommends that the ownership of removed asphalt pavement materials be transferred to the contractor through the bid document and that bid items be included for the removal operation and for the salvage value of the materials. In some cases, public agencies have retained ownership of the reclaimed materials (or the excess) and have stockpiled them with the intent of using those materials in future paving contracts. Besides the expense in storing the materials (cost of land, prevention of theft, tarps to cover the materials), the agency also then assumes the responsibility (an implied warranty) that the materials in that stockpile conform to specifications when they direct a contractor to use it in his hot-mix asphalt.

NAPA's recommended bidding procedures are as follows:

1. The bid procedure should permit the contractor to add any percentage of reclaimed asphalt pavement to the mix he selects as long as the stated test properties of the mix are met. Specific percentages should not be a requirement of the bid. A new job mix formula should be required each time the percentage is changed.
2. If removal of asphalt pavement or other layers from the road is required, a bid item for removal should be included.
3. Where removal is required, (2 above) the contract should state that the removed material belongs to the contractor and bid items included for the salvage value of the material. The salvage value bid by the contractor will be subtracted from the total bid price if the bid price is positive, or added if the bid price is negative.
4. The bid proposal should not require reclaimed pavement that is added to the mix come from the specific job described in the bid proposal. Other reclaimed asphalt pavement should be permitted as long as the stated properties of the aggregate and the mix are met.
5. Since unnecessary crushing of reclaimed asphalt pavement produces undesirable quantities of fines, the degree of crushing should not be specified, but should be left to the contractor.

These procedures are designed to give the contractor more flexibility in recycling. Uncertainties of recycling at high reclaimed material contents are eliminated. With a permissive or alternate specification for mixes containing removed materials, in effect, excess materials from one project can be used in other agency work as well as in the private and commercial markets.

The agency must consider the recycling ratio in designing the remotely located project, but need not be concerned on any project where other uses for removed materials are close by. The contractor will establish the reclaimed material

content after the bid has been awarded in conjunction with his own capabilities and plans for excess material utilization.

E. Reclaimed Asphalt Material Content of Resultant Hot Mix

As mentioned above, if pavement material ownership is transferred to the contractor through the bid document, the reclaimed material content becomes his choice much as any other materials he chooses to utilize in the hot-mix asphalt he proposes to produce, while the recycling ratio is determined before the bid by the public agency and should logically be as compatible with the capabilities of the asphalt industry as possible.

The reclaimed material content is determined after the bid and logically so. One might ask the question, how can a proper hot mix be designed to meet quality criteria before a bid when the characteristics of the not yet removed materials are all influential in determining how much can be used?

Agency ownership of removed asphalt pavement materials has contributed to the use of high reclaimed (0.7 to 1.0) asphalt material contents. These high reclaimed material contents are counter-productive to high plant productivity and fuel conservation efforts if water is added to the process to meet air quality standards.

Contractor ownership of removed asphalt pavement materials will result in his using the reclaimed material content most profitable to him and, with adequate competiveness within the industry, will yield the greatest economic benefit to the public agencies. This does not necessarily mean that extremely low reclaimed material contents will be used, but rather a content as high as practical and profitable will be used which in all probability will be somewhat lower than used in the past. The principal factors include less wear and tear on plant equipment, greater probability of meeting air quality standards and job mix requirements, higher plant production rates, and lowered energy consumption.

The use of reclaimed asphalt material contents in excess of 0.7 (70/30) generally means that a recycling agent (or rejuvenating agent) in addition to a softer grade of asphalt cement may be required in the recycling process to reestablish asphalt cement qualities to that more compatible with conventional mixtures. At these higher reclaimed contents, the soft asphalt cement added may be insufficient in quantity to compensate for the amount of hardened asphalt in the reclaimed material. The use of recycling agents may affect the economics of high reclaimed content mixes as they are more expensive than asphalt cements. At lower reclaimed asphalt material contents, recycling agents are not generally required.

F. Types of Asphalt Plants Permitted/Available

As mentioned previously, the batch plant outnumbers the drum plant in the United States by a ratio of approximately 5 to 1. The sales of new asphalt plants finds that the ratio is almost reversed, namely five drum plants are sold for every batch plant. The principal reason for this is the lower cost associated with the operation of a drum plant. New plants are purchased when an old one wears out or when a contractor wants to increase his potential production capacity. Equipment renewal is an ongoing process for a healthy industry. The asphalt industry, in general, has been making a gradual transition from the batch to the drum type of plant. The facts above have a very profound affect on the acceptance of recycling by the asphalt contractors as has been practiced by the public agencies.

It is generally accepted that recycling in batch plants limits one to reclaimed asphalt material contents of 0.5 (50%) maximum and on a more practical basis, 0.3 and that recycling in drum plants may be as high as 0.7 (70%) maximum and on a more practical basis, 0.5. In past recycling projects, when public agencies have specified reclaimed asphalt material contents exceeding 0.5 (on projects with recycling ratios of 0.5 or greater, with agency retaining ownership of removed materials), they have essentially specified the use of a drum mixer plant. In areas of the country such as the western part of the U.S., where drum mixer plants are more prevalent, this has not created too much of a problem. However, in the more urban eastern U.S. where batch plants are more prevalent, this creates a problem if the public agency in the East tries to reapply techniques used in the West. In some eastern states where few, if any, drum plants have been accepted by the agencies, specifying recycling at reclaimed contents greater than 0.5 means that recycling cannot be done unless a drum plant is purchased. Either the agency does not want to permit drum plants or the contractors do not want to buy a new plant they don't immediately need and so recycling is not done on a mutual basis. Recycling in the eastern states is practically non-existent because of this. This of course can be easily changed.

Recycling can be done successfully in batch plants as well as drum plants. The key to accomplishing this is by, (1) transferring pavement material ownership through the bid document to the contractor, (2) permitting recycling to be done on a routine basis provided all mix quality standards are met, and (3) permitting the contractor to select the reclaimed asphalt material content he wishes and which is ultimately verified by a mix design analysis.

The idea that one needs a drum plant to recycle is erroneous and may in fact, have been inadvertently promulgated by asphalt plant sales literature that stresses the higher asphalt reclaimed material content potential of drum plants. The economics of recycling are separate and completely distinct from the economics of drum mixer versus batch plant operation. This fact has been clouded by unnecessary attempts to maximize the reclaimed asphalt material content in recycled mixes.

G. Location of Project (rural or urban)

Several aspects of this factor have already been discussed. The distinction between rural and urban for the purposes of this paper is more related to the salvage value of excess removed pavement materials. If one is not able to recycle them on a particular project from which they are removed or if there is no other possible use of the materials within a reasonable haul distance then the salvage value is essentially zero or possibly less. If the above is the case, one is essentially "rural," whereas if there is a positive salvage value, then one is "urban."

On "rural" projects, the agencies have in the past typically retained the ownership of removed pavement materials and have designed the rehabilitation project at very high recycling ratios, and subsequently, very high reclaimed

asphalt material contents in the resultant mix (the same in most cases) to minimize the purchase of new materials and to eliminate excess reclaimed materials at the project's conclusion.

In most recycling projects, the above is actually "false economy." While agencies may have claimed savings on these projects in the past, it has only been because of a permissive attitude by the environmental control agencies who had typically given variances for many of these projects which were also designated experimental. In a number of cases air quality standards were not met during any part of the recycling operation. Variances will not be given in the future, and consequently the uncertainty of the plant operations being shut down and resultant fines (penalties) due to uncontrollable emissions at high reclaimed contents will certainly be figured in future bid costs.

In "urban" areas the forced use of high reclaimed asphalt material contents as a result of projects designed at high recycling ratios by agencies that retain pavement material ownership in particular, is even more uneconomical because these areas will also be the more populated, industrialized sections of the country. In "rural" areas there may be more time to bring the recycling process under control through plant and mix adjustments to meet emission standards; however, in "urban" areas, this practice will not generally be permitted or possible. These unknowns result in higher bid prices which can negate the "savings" an agency thought it could get by requiring high reclaimed asphalt material contents in the resultant mix.

RECYCLING TECHNOLOGY

The technology associated with pavement material removal is described as follows:

A. Pavement Material Removal & Processing

Some reclaimed asphalt pavement (RAP) will come from removal of the full thickness of asphalt on roads or streets being rehabilitated. The pavement can be broken up with ripper teeth on a dozer enough that it can be loaded into trucks with front-end loaders. In some cases it is necessary to further break the pavement into smaller size by grid rollers or equipment tracks before it is transported to the crusher site.

Contamination of the RAP with underlying base course causes no problem, but if the underlying untreated base course and subbase are to be reclaimed and used as the aggregate in the resultant mix, it is imperative that the underlying base not be contaminated with RAP or unacceptable smoke will be emitted from the dryer.

Crushing existing asphalt pavements has not created problems if the pavement pieces are first broken to a size which can be accepted by the various crushing components. Crushing in hot weather has not created any special problems to date. Experience has shown that crushing RAP does not require a heavy duty unit. Most crushing to date has been done by jaw and roll crushers; however, manufacturers are now working on units designed especially for this purpose. The size to which reclaimed asphalt pavement chunks should be crushed is determined primarily by the plant recycling process. It is important that the chunks are remelted and mixed thoroughly with the added new materials. However, if the maximum size of the aggregate particles in the reclaimed asphalt pavement chunks exceeds the maximum size permitted by the mix specifications, crushing must be done to reduce the maximum particle size to the specification limits. Unnecessary crushing of reclaimed asphalt pavement chunks only increases the amount of dust-sized particles and will have an uneconomic effect on how much reclaimed material can be used in the resultant mixture.

A substantial amount of RAP is expected from milling operations, either hot or cold, made to restore a given pavement to grade or to a lower grade. In this process a rotating drum equipped with special teeth cuts the pavement to a predetermined depth and reduces it in size in the process. Milling (cold planing) is primarily done to correct a pavement surface distress or to remove overlays. The material by-product resulting from milling is already reduced in size, and suitable for use in hot recycling without further reduction, except possible scalping off of oversized chunks.

Two features govern the storing of RAP. One is that RAP tends to stick together if stockpiles are high. The lowest stockpile height that space will permit should be used. The other is that the uncrushed RAP will absorb moisture in the stockpile. In the road, the pavement will have less than about one percent moisture, but the moisture can increase a percent or so in storage. If the pavement is crushed before stockpiling it will absorb a much higher percentage of moisture. More energy is needed to evaporate this moisture. The energy must come from the heated uncoated aggregate and since there is a limit on how hot the aggregate can be heated, particularly in batch plants, higher moisture contents means that less RAP can be added to the mix. Methods of minimizing moisture buildup should be considered. If scheduling permits, storing small quantities of crushed RAP would minimize moisture buildup. Protected stockpiles may be cost effective.

Crushed or milled RAP can pick up considerably more water than uncrushed RAP if exposed to rain. Moisture contents in excess of five percent have been measured in stored crushed RAP. Ingenuity is needed to prevent moisture buildup to conserve energy and permit using as much RAP as desired. If the crushing plant has the capacity, the stockpile of crushed RAP should be kept to the minimum needed to provide surge capacity.

Both rubber-tired and crawler-type loaders have been used with success in rehandling RAP. At times some reconsolidation may occur in which case the use of loader buckets with teeth is recommended. Driving on the stockpile should be avoided.

B. Plant Recycling Processes

Recycling can be done in either a batch type, drum mixer type, or continuous mixer type asphalt plant.

Batch Plant.

Hot recycling can be done in a batch-type asphalt plant by what can best be described as the "mixer heat transfer method." This method was first developed in Maplewood, Minnesota, and is also known as the "Minnesota Method."

In this method the reclaimed asphalt pavement (RAP) is fed to the plant weigh box at stockpile-ambient temperature by a handling system consisting of stockpiles, feeding bin, feeder and conveying mechanism while the required uncoated aggregate is processed through the regular plant feeding

system, dryer, elevator and tower. This uncoated aggregate is superheated in the dryer and transfers its heat to the cold RAP in the plant mixer. Additional asphalt and/or softening agent is added there.

This process avoids both smoke pollution and material buildup problems by not passing the RAP through the plant dryer, elevator and screen.

The amount of RAP which can be used is determined (in order of importance):

1. The moisture content of the RAP.
2. The required temperature of the resultant mix.
3. The temperature to which the aggregate is heated.
4. The stockpile temperature of the RAP.

Present experience and calculations indicate that the amount of RAP which can be used in this method may be as high as 50 % of the total mix if the moisture content of the RAP is minimal and is fed to the plant at normal stockpile temperatures. A more practical amount is 30 to 40 percent.

Hot recycling of RAP by the mixer heat transfer method is being done satisfactorily in many sections of the country and modifications to permit recycling can now be installed on any conventional batch-type plant. There are, however, many points in the process which must be understood to assure good operation. These points will be emphasized in the following detailed description of the various parts of the process.

For a batch plant, the crushed RAP is fed to the plant with a conventional cold feeder except the bin should have a relatively small capacity with steep sides and a wide and long bottom opening to allow for easy discharge and minimal sticking problems. When RAP is fed into the feeder bin, it should be dribbled in as much as possible. It should not be fed to the bin as a unit drop since this causes compaction of the RAP with resultant bridging, sticking and discharge problems. Vibrators should not be used on this bin since they would only encourage compaction of the RAP. Both belt and slat type feeders have been successfully used. They should be fairly wide and should have sufficient horsepower to be used in a startstop operation as necessary. Vibrating type feeders are not recommended as they could also encourage the tendency of the RAP to consolidate and stick.

Basically two methods are used to transport the crushed RAP to the weigh hopper. One method uses a belt or other type conveyor to move the crushed RAP from the feeder bin directly into the weigh hopper. The conveyor width and speed should be such that the desired amount of RAP per batch can be discharged into the weigh box in sequence with the superheated aggregates from the plant hot bins without delaying the cycle. In other words, the RAP and the aggregates must be placed in the weigh hopper within the 40 to 60 seconds it takes the previous batch to be mixed, otherwise the cycle will be delayed.

The conveyor will be starting and stopping as directed by the plant weighing controls. The conveyor will require a backstop or anti-rollback device if it is fed by a feed bin unit equipped with feeder. The backstop may not be necessary if the feeding bin discharges directly onto the conveyor belt as the friction of the RAP on the belt would keep it from moving backward. A special-duty type motor might be necessary because of the start-stop operation. In lieu of this, a hydraulic or clutch-type mechanical drive might be used to permit continuous running of the conveyor power unit. The conveying device to the tower must be operated by the asphalt plant weighing control system as an additional material. The conveying device should be interlocked with the feed bin feeder so that both stop simultaneously.

The other method uses a special bin adjacent to the weigh box. The crushed RAP is fed into this bin by a belt conveyor or in limited space installations by a vertical or inclined elevator. If the bin does not discharge directly into the weigh box, a high-speed conveyor is necessary. The bin should have steep side slopes to avoid binding of the RAP.

The RAP should enter the weigh box as close to its center as possible to prevent material buildup on the weigh box sides. The RAP material <u>should not</u> be first in the weighing sequence for the same reason.

The area surrounding an asphalt plant weigh box and mixer is covered by a metal enclosure to prevent dust from escaping to the atmosphere. Pipes from the plant fugitive air system connect to the enclosure to aid in dust suppression. The amount of air that these pipes withdraw from the enclosure is sufficient for regular plant operations. It is also normally sufficient for the recycling process when RAP with low moisture content is fed to the weigh box.

When RAP with high moisture content is used, the heat transfer process in the plant mixer liberates large amounts of water vapor and the amount of vapor generated may be in excess of the exhausting ability of the fugitive air system.

To minimize dust entrainment in the escaping water vapor, the dry mix time should be minimized, and the asphalt discharge should commence immediately after the weigh hopper gates are opened. Water vapor and particulate emissions can be minimized by keeping the moisture contents of the reclaimed material as low as possible and/or reducing the proportion of RAP in the hot-asphalt mixture. If the volume of water vapor cannot be kept within the capacity of the fugitive air system, then the capacity of the system must be increased.

Hot mix containing reclaimed materials and made by the mixer heat transfer method can use up to 50% maximum of RAP. The remaining material will be new or reclaimed aggregates. These aggregates are processed through the conventional parts of the asphalt plant starting in the cold feed system. This system operates normally and no alterations are required. When the aggregate is processed through the dryer, it must be heated enough to provide the heat needed to bring the RAP up to the desired temperature during the heat-transfer process in the plant mixer. Aggregates have been heated to 500° F. (260° C) in recycling to date without serious problems, but even this may be too high for safe operation of a baghouse. If aggregate temperatures much higher than 500° F. (260° C) are used, caution is necessary in operating and cooling down the dryer.

These high temperatures require reasonable attention to the condition and arrangements of dryer flights to prevent excessive temperature of the dryer gases which exit into the dryer air system. It is particularly important that an adequate veil of aggregate be maintained. In recycling to date, excessive dryer gas temperature in the air system has not been common and can be prevented. The higher dried material temperature may result in a somewhat shorter than normal life for the discharge end flights of the dryer and also for the burner system refractories. This increased maintenance, however, should not be excessive.

At the end of each production cycle, the dryer drum should be allowed to run empty for a reasonable

cooling period after production shutdown. This cooling period will protect against possible warping of the dryer shell and its internal parts. Because of the superheating of the aggregate in the dryer, the dryer exhaust gas temperatures may be higher than normal. Extreme exhaust gas temperatures can be prevented by proper arrangement and maintenance of the dryer flights. For plants with wet wash air pollution systems, the high exhaust gas temperatures present no particular problems.

For asphalt batch plants equipped with a baghouse, extremely high exhaust temperatures could damage the bags. Most baghouses use Nomex bags. If the gases entering the baghouse are continuously above 400°F. (204°C), the bag life will be shortened. At exhaust gas temperatures over 450°F. (232° C), the deterioration of the bag material would be greatly accelerated. Steps should be taken to keep the temperature of the exhaust gas entering the baghouse below 400°F. (204°C).

Upon discharge from the dryer, the superheated aggregate is carried up to the top of the batch plant tower by the hot elevator system. The only problems noted to date have been produced by excessive elongation of the elevator chains during operation and subsequent shrinkage on cooling. The elongation creates slack which may exceed the capacity of the take-up device. If the elevator has no take-up device and the shaft is moved to accomodate the elongation, the shaft must be moved back during cool-down or the shrinkage of the chain may break the shaft.

The superheated aggregate passes from the hot elevator over the batch plant screens. No problems should be encountered during the screening operation unless the screen bearings are located inside the dust housing. If so, excessive temperature buildup could occur in these bearings. Lubricants designed for higher than normal temperatures should then be used.

To prevent excessive temperature drop of the superheated aggregate consideration should be given, depending on the size of the bins and the material storage time, to insulating the outside of the hot bins.

No changes are needed to the asphalt cement delivery system unless a softening or reclaiming agent is to be added. The point of discharge of the softening agent, either into the asphalt weigh bucket or directly into the pugmill, depends on the requirements for each individual agent.

Drum Mixer Plant.

In this method reclaimed asphalt pavement is processed directly through the drum mixer together with uncoated aggregate. Additional new asphalt cement and/or softening agent is added in the drum mixer, and the discharged product is a recycled hot mix. The main problems in this type of recycling originally were smoke emissions from the asphalt cement portion of the reclaimed asphalt pavement (residual asphalt), and a material buildup inside the drum.

During the past years drum mixers have been modified so that the smoke emission problems have been virtually eliminated. This has been done by continuing to feed uncoated aggregate into the burner end of the drum mixer while the reclaimed asphalt pavement is now fed into the process at a point either partway down the drum or from the discharge end. This late introduction of reclaimed asphalt pavement is done by several different proprietary methods.

This type of operation uses uncoated aggregate to absorb the more intense heat of the burner flame, so that the reclaimed asphalt pavement receives heat from lower gas temperatures, and from the heat content of the uncoated aggregate. This results in no smoke emissions or very minimal emissions.

This process seems to require approximately a minimum thirty percent of uncoated aggregate to effectively cool the burner flame, resulting in the maximum use of approximately seventy percent of reclaimed asphalt pavement if the moisture content of the RAP is minimal and is fed to the plant at normal stockpile temperatures. The reason that the drum mixer can produce mixes using a slightly higher reclaimed asphalt material content, if desired, is because the mixture (after all ingredients have been combined) is subjected to additional heating during mixing from the exiting dryer gases.

Another method feeds both uncoated aggregate and salvaged asphalt pavement together into the feed end of the drum after first adding water to the dryer feed to moisten and help agglomerate the small residual asphalt particles in the reclaimed pavement. Atmospheric air intake which is increased, together with a special combustion tube-internal cone assembly, is then used to lower the temperature of the burner gases and prevent the burner flame from touching the cascading combined feed in the dryer. Reclaimed asphalt material contents higher than seventy percent are possible with this method when air standards can be met, but at a significant loss of plant productivity, mix discharge temperature, and increased fuel consumption per ton processed to evaporate the added moisture. These are the economic trade offs to utilizing all RAP when any excess would have no economic salvage value.

Material buildup has occurred in some drum mixers processing high reclaimed asphalt pavement contents. The buildup is a combination of some of the residual asphalt and minus 200 mesh portion of the material being processed. It can also be caused by the asphalt cement content in the original pavement, by sealing agents and/or special additives which were used to treat the pavement during its lifetime. It may also be caused by softening agents added in the drum mixer.

Continuous Mixer Plant.

The continuous mixer has not been utilized to any great extent for recycling primarily because there are so few of this type. Some recycling has been done, however, both in the United States and Canada with the continuous plant. The process would be quite analogous to the Maplewood concept for batch type plants and would have generally the same maximum limitations on reclaimed material content. An additional feeder is needed to input RAP into the foot of the hot elevator feeding the continuous pugmill. Reclaimed aggregate would be processed through the dryer in conventional fashion.

C. Spreading and Compaction

Conventional pavers and rollers have been used and no special equipment has been required to date in either spreading or compacting mixes containing reclaimed pavement materials. Work done shows laying temperatures ranging from 225° to 300°F.

D. Mix Design and Quality Control

Mix designs are developed using regular mix design test procedures and the results have been satisfactory in most instances. It is quite apparent that a very important part of recycling will

be a thorough laboratory design and control of the recycled mix with particular emphasis on the aggregate gradation and asphalt characteristics of the reclaimed asphalt pavement. Quality control during recycling is equally important as in conventional hot-mix processing.

The goal of recycling is to produce a final product meeting the specified quality mix requirements of conventional mixes in all respects. In order to achieve the desired mix design, it is necessary to understand the material quality aspects of reclaimed pavement.

As an asphalt pavement ages in service, some changes which may have taken place during aging needs to be corrected. These changes can be summarized as follows:

1. Mineral aggregates: Degradation of aggregate particles sometimes occurs through wear and time resulting in changes in gradation from the original mix. The process of reclaiming, whether crushing or cold milling, can create further and more substantial degradation. If the reclaimed asphalt pavement contains an excess of fine material, additional coarser sized aggregate, which in turn may require more asphalt cement, will have to be added. The surplus of fines could be a combined result of those in the original mix, plus those caused by the size reduction of the pavement in the crushing or milling process.

2. Asphalt cement: By processes of oxidation, volatilization, aggregate absorption, and other chemical changes, the asphalt cement hardens and loses ductility. This hardening renders the pavement more susceptible to cracking and raveling as it ages. The aging is most severe at the surface due to environmental exposure and less severe within the pavement.

An analysis of the gradation in the reclaimed material can permit the contractor to add new aggregates of the required gradation to meet the final gradations specified in the mix design. Analysis of the properties of the reclaimed asphalt cement can permit the decision as to the amounts and specifications of new asphalt required to meet the properties specified in the designed final mix.

The reclaimed material content must be determined by mix design procedures with plant recycling limitations and the project recycling ratio in mind. In the past, reclaimed asphalt material content of the resultant mix was set equal to the recycling ratio (which was often maximized and above plant recycling limitations) with lesser regard for mix quality standards.

If mixes containing reclaimed materials are designed to meet the same criteria as conventional mixes, the structural design coefficients of recycled mixes should be the same as given to conventional mixes. If recycled mixes are to be designed on the basis of project recycling ratio requirements without consideration to established mix design procedures and mix design criteria, then the durability and structural relationship between recycled mixes and conventional mixes is a debatable one. RAP materials with more variable gradations and asphalt contents are best used at lower reclaimed asphalt material contents rather than loosening up specifications or quality design criteria. This enables the use of standard structural design coefficients for mixes containing recycled materials.

E. The Economics of Pavement Material Removal and Recycling

The economics of pavement material removal are dependent on the following:

1. The salvage value of the reclaimed pavement materials which is equal to the cost of an equal quantity of new aggregates and asphalt cement less the cost of pavement material removal, hauling, and processing.

2. The life cycle cost of the various pavement rehabilitation alternatives available as a result of pavement material removal. The recycling ratio is considered in these analyses.

3. The savings realized from not having to reposition manholes, guardrails, overhead signs, bridges, curbs, gutters, raising shoulders, etc.

The salvage value is further affected by (a) the nature of the reclaimed materials (gradation variability, type of aggregate, hardness of asphalt, etc.), (b) whether there is a market for use of the reclaimed material either on the particular project from which they are removed or on other projects (if there is a market, the recycling ratio is unimportant; if there is no market, the recycling ratio is a significant factor), (c) whether there is a permissive recycling specification in force, (d) the availability of asphalt plants equipped for recycling which is affected by many factors discussed earlier, and (e) the reclaimed material ownership policy in effect which determines whether the agency or the contractor sets the reclaimed asphalt material content in the resultant mixes, the level of which affects recycling economics.

The economics of recycling are dependent on the following:

1. The reclaimed asphalt material content of the resultant mix as it affects plant production rate, emissions control measures (such as adding water to cold feed), and the need for specialized rejuvenating agents.

2. The moisture content of the reclaimed pavement materials as it affects fuel consumption in the drying of aggregates and plant production rate.

3. The relatively small cost of plant modifications when computed on a tonnage basis.

The future for recycling is dependent on developing the economics of recycling above. It is estimated that in 1980, perhaps as much as 10 million tons of hot-mix asphalt contained some amount of reclaimed pavement matrials. The amount of reclaimed materials may have been as much as 4 million tons. As more persons understand and utilize the techniques of pavement material removal and recycling, the tonnages will undoubtedly get larger.

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