DENVER'S METHOD OF URBAN HOT RECYCLING

William E. Smith, Denver Department of Public Works

The street system of the City and County of Denver consists of approximately 1,700 miles of paved and unpaved streets. About 1,640 miles are paved including curb and gutter. Approximately 98% of this mileage consists of asphaltic concrete surfacing. The base course for these streets may include cobblestone, a crushed granite rock, or graded sand and gravel or some deep strength asphalt. The base course is usually related to the type in use during the era in which it was constructed. The streets have various crowns and may slope from 0.5% to 14%; widths may vary from 30 feet to 36 feet (the usual standard). Originally there were streetcar tracks in many of the arterial streets, and these tracks were overlaid over the years. The combination of asphaltic concrete surfacing has varied through the years, but generally consists of a medium soft rock mined from gravel pits along the South Platte River with a Los Angeles Abrasion Test of between 35 and 40. The temperature extremes in Denver range from -20°F. to 110°F., and rainfall is 12 to 14 inches per year. Low level surface oxidation does occur in Denver.

Chip sealing was a common practice until 1973 and almost all residential and collector streets received chip seal treatment every seven to ten years. The chip seal consisted of a Platte River gravel and a RC-800 asphaltic material. Arterial streets did not receive chip seal and were, almost without exception, overlaid with asphaltic concrete. Overlays were conducted every four to five years. Thickness varied from one to two inches. The material generally consisted of a Platte River gravel and, of course, the bitumen equivalent to an AC-10 or 20. Most of the City's streets have a concrete curb and gutter, and in the older areas this has been overlaid many times until there is often only one to three inches of curb remaining. Most of these streets also have high crowns.

Streets to be recycled require more than a cursory review in that quite often the overlays that have occured are a result of subbase failure due to increased loads and volumes of traffic. If this is the case and a determination is made to recycle the pavement, it is essential that an exact or greater pavement section than existed be maintained. On two occasions excess pavement was removed. We found that subbase failure had occured where traffic volumes and weights were high. With these increased volumes and weights it has been necessary for the traffic engineer to remove parking on arterial streets and add traffic lanes adjacent to the curb in order to handle the increased number of vehicles. Failures occured on this curb lane due to water in the flow line, construction, and maintenance that has occured over the years. A joint existed when the Portland cement concrete curb abutted the asphaltic concrete pavement, and this has always been a problem of base failure. As the street was overlaid, the thickness on these edges was tapered to the joint. As a result the pavement thickness is less along the edges. As the surface planing starts it is usually the intent to remove one and a half or two inches adjacent to this curb in order to achieve maximum flow line capacity. This one and a half or two inch removal can be disasterous since the pavement section in the weakest part of the street is reduced. It is, therefore, suggested that if you are looking at a recycling program, pay close attention to the needed pavement section for present day traffic since many of these older streets have been upgraded (overlaid) as failure occured.

In 1979 during the months of March and April, we decided to remove the surface of a major arterial which had extensive patches, numerous chuckholes, and some reflective cracking. Needless to say, this had been a problem all winter so it would have been a very little loss to experiment with the removal and then attempt to overlay when weather permitted. The removal of the top two inches of surface progressed without difficulty, and the rideability of the surface was improved, although the texture of the dry surface created a driver problem in that the rideability of the street was comparable to a cobblestone surface. There were several complaints about the noise and the inability of the drivers to maintain control of their vehicles. The public and media called it a chicken wire texture. The surface was used by the public for approximately two months before the overlay occured, and we had very little difficulty after the first week of complaints. When the overlay started in June, we had trouble with slippage on a high volume bus lane, and it was necessary to change the mix and add some additional tack coat to that particular lane to alleviate the slippage problem.

The previous method for correcting street failures has been to overlay the surface. This has resulted in steep crowns, better pavement sections and a greater cost to replace the street when it was necessary to remove all the curb, gutter and pavement. With limited budgets it is nearly prohibitive to even consider starting at subgrade for rebuilding. We, therefore, have searched for an economical method to maintain a given street in its present condition. With accelerated costs occuring, it was not difficult to set a policy whereby the City would remove one, two or three inches of asphalt and replace the same amount, thereby creating a new surface which offered equal life and better rideability than the surface prior to cold planing. Considering the investment and cost of acquiring the necessary equipment, the cost benefits are very advantageous to recycling, and these will be discussed later.

The City of Denver has a Barber-Greene batch plant rated at 250 tons per hour. There is a bag house for air pollution control and we find that this is very adaptable to hot mix recycling. The recycled material is injected behind the bag house. Thus the quality of mix produced is equal to or better than the virgin mix. One of the problems encountered with the virgin mix was inadequate fines (passing a #200 sieve). By adding the recycled material more fines are introduced. The greater concentration of fines is a result of the grinding procedures which occur during removal. The following gradation depicts the difference between our virgin rock and that of recycled material (See Tables I, II and III).

Table I. A comparison of virgin vs. reclaimed material size.

	% Passing Reclaimed Material	% Passing Virgin Material
1/2"	100.0	100.0
3/8"	93.3	94.5
#4	78.2	77.8
10	58.4	54.0
40	26.9	18.9
80	15.4	7.6
200	9.5	3.9

Table II. Physical characteristics of reclaimed materials.

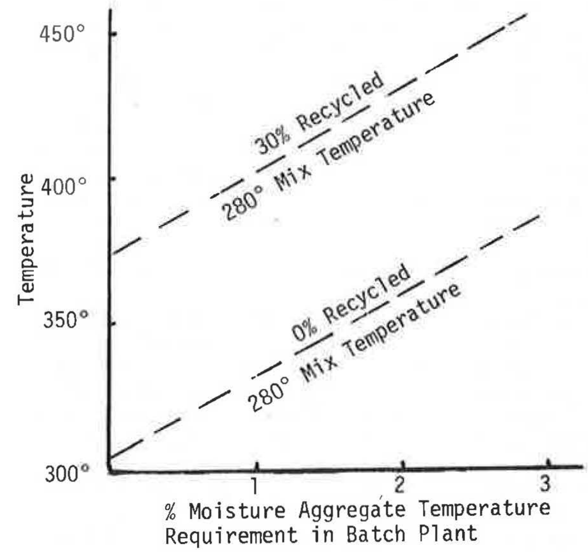
	Reclaimed Material Marshall Method
Lab Density	2.311
Lab Weight	144.1#/cu. ft.
Stability	2,735
Flow	10
Air Voids	3.14%

Table III. Physical characteristics of virgin materials.

	Virgin Mix Marshall Method
Lab Density	2.257
Lab Weight	140.8#/cu. ft.
Stability	1,625
Flow	6
Air Voids	7.50%

It is required that the virgin rock be heated approximately 50°F. to 60°F. above what would be required for non-recycled material, but the resulting temperature at the laydown machine is adequate. The following graph (Figure 1) shows the temperature required for a 280°F. mixture with virgin rock versus 30% recycled mix.

Figure 1. Temperature requirements for reclaimed vs. virgin mixes.



The batch plant is operated by natural gas, which at this point is still the cheapest source of fuel available. We find the stationery batch plant is advantageous from the standpoint of being located in a central point of the City, and since all of the work occurs in Denver, there is no need for a mobile plant.

The first attempt at recycling resulted in the bag house plugging. This was caused by the attempt to place the asphalt to be recycled into the virgin rock before heating and, of course, the heat releasing the cutbacks in the asphalt as well as from evaporation of the bitumen created the problem of particulates which blocked the bag house. We then reverted to placing the recycled material into the drum of heated rock and this resulted in no visible pollution emitting from the exhaust. This, however, limits the amount of material that can be recycled. We heat the rock to approximately 345°F. and then when we add the recycled material it decreases this temperature to about 290°F. It still results in a job site temperature of around 280°F. which is adequate for this mix. There are several things involved in this environmental evaluation, but probably the strongest item is the conservation of both gravel and bitumen. The 30% recycle gives a direct savings on both of these items and results in less mining operations necessary for gravel as well as less processing of oil products. Our addition of 30% recycled material has resulted in a higher bitumen content. We were running as high as 7% on the mixture, and while this exceeds recommended standards, we found that on many local streets where light weight vehicles as well as light volumes of traffic occured this was very advantageous in the life expectancy of the street surface. During this summer's operation, we normally added 5% AC-10 or 20 to the virgin rock, and this has resulted in a six to six and a half percent bitumen content. This will fluctuate, however, depending on the asphaltic content of the recycled material.

Energy savings are closely related to the environment in that we do save the 30% of materials which are recycled. However, there are additional savings from energy which are in the form of transportation. We are able to haul the materials from the planing machine to the batch plant on the return trip of trucks which have delivered hot mix asphalt to areas cold planed the previous day. During this season we have found that it is more beneficial to separate the operation of paving and planing into two separate operations in that breakdowns, delays because of traffic, etc. created more problems and delayed both operations to such an extent that it was more beneficial to run separate operations. This results in an energy tradeoff of removing the material to be recycled against what would be required to mine gravel, crush gravel and deliver gravel to the batch plant. Needless to say, the energy required to remove the material to be recycled is much less.

The cost for cold planing two inches of material from Denver's existing streets was 88¢ per square yard in 1979. The estimated value of the material removed was $1.60 per square yard. With the increase in cost of bitumen, gravel and transportation, it is obvious to me that we must do more recycling. It is simply a matter of what type of recycling is most beneficial from both the cost standpoint and final product achieved. One must examine this from the needs of their particular entity. If this need is for overlay, then I feel strongly that hot mix recycling is most advantageous. If it is for the base course, then perhaps cold mixing is more beneficial. Whatever the results are, recycling is certainly necessary in our limited budget and rising costs.