Using Hot In-place Recycling for Rehabilitation of Asphalt Pavements Made with Coral Aggregates

S. Sheikh Sandiani, & M. Rohani
Pardad Vista Consulting Engineers Group, Tehran, Iran

M. Joharifard
Martec Recycling Corporation, Vancouver, British Columbia, Canada

ABSTRACT: Pavement rehabilitation is a major activity for all highway agencies to keep the roads in good condition. It is also of special importance to select techniques and procedures that will result in cost-effective and longer-lasting pavements to serve the nation's highway system. Hot in-place recycling (HIR), if applicable, has proven to be a viable technique for rehabilitation of pavements at low cost by using existing in-place materials. The latest environmentally friendly HIR technology that uses hot air for heating and softening the existing pavement has gained much attention recently and therefore, was used to rehabilitate the 100,000 square meters of urban roads in Kish Island in 2005. An issue about asphalt pavements in Kish Island was that the aggregates used in the mix was coral because of its availability in the region. Since the long-term performance of Hot Mix Asphalt (HMA) pavements is strongly dependent on the characteristics of the aggregate in the mix, there was a concern whether the Reclaimed Asphalt Pavement (RAP) in the final mix would perform adequately over years. This experience came out to be successful and now, after four years, the pavements rehabilitated using HIR technique are in very good condition even compared to newly constructed pavements consisted of better quality aggregates hauled from long distance. In this paper, evaluation of the aged mix, design and quality control of the final mix, and the evaluation of pavements after four years of service are discussed.

KEY WORDS: Hot in-place recycling, coral aggregate.

1 INTRODUCTION

Hot In-place Recycling (HIR) is a rehabilitation technique suitable for asphalt pavements exhibiting surficial and slight to moderate nonstructural distresses. The HIR process involves softening the existing surface with heat, scarifying the heated pavement surface, adding recycling agent (rejuvenator) and virgin aggregate or admixture (if required), mixing the material in-place, replacing it on the pavement, reprofiling, and compacting this hot mixture (Kazmierowski et al. 1999, Button et al. 1999).

HIR may be performed as either a single-pass operation or as a two-pass procedure. In the single-pass process the reclaimed asphalt mix is recombined with or without adding virgin material and then recompacted. In the two-pass process a new wearing surface will also be applied on the recompacted surface (Button et al. 1999).

The project described herein was the second use of HIR method in Iran. The first experience was the rehabilitation of a highway in Tehran, the capital city, with an older generation of hot in-place recycling equipment. This equipment used open flame burners for heating the pavement surface, thus, created smoke and particulate matters and caused opacity. That project was halted due to the opposition of residents and local tradesmen because of the health and environmental concerns.

The MARTEC Recycling Corporation's AR2000 third generation super recycler that uses a more environmentally friendly heating system, i.e. high-velocity forced hot air combined with low-level infrared, was used in this project. AR2000 is a self-propelled equipment train which contains the following components (Emery 2006):

- One or two identical preheaters that heat and soften the deteriorated old asphalt pavement;
- A heater/miller that heats pavement, mills it to controlled depths, adds rejuvenator (if required), and windrows the mix;
- A postheater/dryer/mixer that heats and dries the loosened old asphalt, adds virgin aggregate or mix (if required), thoroughly stirs the combined mix and transfers this mix to its pugmill for final mixing.

Figure 1: The AR2000 HIR Process, a Travelling Asphalt Recycling Plant (Emery 2006)

This study presents the rehabilitation of three six-lane roads, referred to as R1, R2 and R3, with the lengths of 2.4, 1.0 and 1.15 km respectively, using single-pass HIR method. These roads are located in Kish Island and have flexible pavements with asphalt mix made of coral aggregate. Coral aggregate is mostly used in asphalt pavements in Kish because of its availability in the region. Figure 2 shows HIR equipment operating in Kish Island both at night and during the day.

Kish Island is positioned in the south of Iran and has a hot and humid climate. The average temperature in the past 6 years has been 27.5^{o}C with the maximum of 44^{o}C and minimum of 11^{o}C. The island has low precipitation and relatively high humidity due to the region’s special climactic conditions.

Figure 2: The AR2000 HIR equipment operating in Kish Island

2 MIX DESIGN

The mix design procedure consisted of sampling and evaluation of Reclaimed Asphalt Pavement (RAP), selection of type and amount of recycling agent, determination of the need for additional aggregates and/or asphalt binder and/or virgin Hot Mix Asphalt (HMA), preparation and testing of paving mixtures, and selection of optimum combination of new aggregates, asphalt binder, and recycling agent or virgin HMA.

2.1 Reclaimed Asphalt Mix

In order to design the final mix composition it was necessary to have a complete analysis of the existing pavements. This was done by sampling through cores (150mm diameter) and slabs (400 x 500 mm) and the following properties were determined using ASTM standard methods. The results of these tests are reflected in Tables 1 and 2.

- Gradation of aggregate and bitumen content of asphalt mix after extraction
- Penetration and viscosity of bitumen recovered from asphalt mix
- Marshall stability and flow of the old mix
- Physical properties of the old mix,

Table 1: Reclaimed asphalt mix and recovered bitumen properties

Properties	R1	R2	R3
Top Layer Thickness (mm)	4.7 to 6.2	4.2 to 5.1	4.7 to 6.0
AC (%)	6.47 to 8.81	6.62 to 9.05	6.56 to 7.67
Penetration @ 25^o (dmm)	12 to 17	18 to 32	23 to 34
Viscosity (mm^2/s)	1035 to 1555	945 to 1400	1070 to 1365
Density (kg/m^3)	2.02 to 2.10	2.0 to 2.07	1.98 to 2.11
Stability (kg)	1806 to 2660	1700 to 2430	1680 to 2320
Flow (0.25 mm)	16.5 to 20.8	11.6 to 16.8	10.7 to 14.5
In-Situ Air Voids (%)	13.2 to 15.5	11.3 to 14.9	10 to 14.7

Table 2: Aggregate gradation of reclaimed asphalt mix

	Percent Passing							
Sieve size (mm)	25	19	12.7	9.5	4.75	2.36	0.30	0.075
Upper Limit		100	90		44	28	5	2
Lower Limit		100	100		74	58	21	10
R1	100	99.2	95.9	89.7	68.4	53.6	16.1	5.9
R2	100	99.5	94.4		72.3	59.3	17.5	6.4
R3	100	99.3	92.9		73	62.1	14.6	3.4

Note: The average gradation for each road is given in this table.

The low penetration and high viscosity values indicated that the bitumen was aged and hardened. The stability values were high showing that the aggregate is strong enough and the interlock between rough textured and angular coral aggregate provided good load bearing capacity. However, the gradation was close to (and in some locations out of) the upper limit of the allowable range in the guidelines, meaning that the percentage of fine aggregate was almost high, and there was a concern that if the coarse particles break down during the milling, the gradation would fall out of the range. Moreover, the petrographic examination of aggregates showed that the particles were fairly cubical with 96% percent crushed (on one or more faces) and general mineral aggregate was carbonate with some fossiliferous portion.

Based on the above analysis, the decision was made to add a suitable rejuvenator and about 20% admix containing high quality rock aggregate and soft fresh bitumen to restore the runway surface condition and improve the penetration and viscosity values as required in hot climates.

2.2 Admix

The virgin aggregate selected for admix was supplied from an area in the mainland about 100 kilometers away from the construction site. The blend of aggregate was established such that while it would not exceed the maximum and minimum boundaries, it would have the potential to move the final aggregate curve closer to the mid values in the allowable range. The asphalt cement considered was AC 60-70 suitable for hot climates and medium trafficked roads according to the Iran's Guidelines. Due to the fact that a recycling agent was going to be added to the final mix to restore aged bitumen characteristics, AC 60-70 seemed a reasonable selection. The optimum asphalt content was determined using Marshall design method. Table 3 reflects the results of admix design.

Table 3: Job Mix Formula for the admix

		Sieve Size (mm) / Percent Passing							
Aggregate type:	%	19	12.7	9.5	4.75	2.36	0.3	0.15	0.075
Coarse Aggregate 1	4	100	65.9	32	15.8	8.4	0		
Coarse Aggregate 2	20	100	95.6	67	17.6	3.2	0.25		0.1
Fine Aggregate	70			100	89.7	50.5	2.2		0.2
Filler	6					100	96.3	60.8	36.2
Admix Gradation		100	97.8	91	73	42.3	7.4	3.6	2.3
Asphalt Cement	4.5								

2.3 Final Mix

The final mix was designed based on the procedure mentioned in chapters 7 and 10 of Pavement Recycling Guidelines for State and Local Governments (Kandhal and Mallick 1997). The following steps, which will be explained in the below subsections, were taken for this purpose.

1) Determining aggregate blend in the final mix
2) Determining approximate asphalt binder demand of the above aggregate blend
3) Estimating the amount of new asphalt and recycling agent in the final mix
4) Running trial mix design using Marshall method and selecting job mix formula

2.3.1 Combined aggregates in the final mix

The combined gradation was calculated using the gradation of the aggregate in the RAP and new aggregate in admix such that it would meet the desired specification requirements. Using trial and error method, the amount of new aggregate was determined to be 20 percent.

2.3.2 Approximate asphalt binder demand of the combined aggregates

The estimated asphalt demand of the abovementioned combined aggregate by weight of total mix was calculated using the empirical formula given as Equation (1).

$$P_b = 0.035a + 0.045b + Kc + F \quad (1)$$

where:

P_b = Approximate total asphalt demand of final mix, (% by weight of mix)

a = Percent of mineral aggregate retained on 2.36 mm sieve (expressed as a whole number)

b = Percent of mineral aggregate passing the 2.36 mm sieve and retained on the 75 μm sieve (expressed as a whole number)

c = percent of mineral aggregate passing the 75μm sieve

K = 0.15 for 11-15 percent passing 75 μm sieve, 0.18 for 6-10 percent passing 75μm sieve, and 0.20 for 5 percent or less passing 75 μm sieve

F = 0 to 2.0 % (based on absorption of light or heavy aggregate)

2.3.3 Estimated percent of new binder asphalt in the final mix

The quantity of new asphalt binder and/or recycling agent to be added to the trial mixes of the recycled HMA mixture, expressed as percent by weight of total mix, was calculated using Equation (2).

$$P_{nb} = \frac{(100^2 - r \cdot P_{sb}) \cdot P_b}{100 \cdot (100 - P_{sb})} - \frac{(100 - r) \cdot P_{sb}}{100 - P_{sb}} \quad (2)$$

where,

P_{sb} = Asphalt content of RAP (%),

P_{nb} = Additional asphalt and/or rejuvenator in final mix (% by weight of total mix),

r = Percent new aggregate material to total aggregate in final mix

2.3.4 Job mix formula

Using the formulas in the previous sections the approximate total asphalt demand of final mix was 6.8, 7 and 6.6 for R1, R2 and R3 respectively. The estimated percent of new binder asphalt plus rejuvenator was 1.00, 1.05 and 0.75 for R1, R2 and R3 respectively. Considering the 4.5% asphalt content determined for admix and 20% admix in the final mix, the amount of admix bitumen to total asphalt would be 0.9%. Based on the above data, the trial mixes were made using 2 to 6 percent rejuvenator by weight of RAP binder and the optimum amount of recycling agent was selected using Marshall design method. According to the results of Marshall tests the addition rate of recycling agent was selected to be 0.2 to 0.3 percent by total weight.

The recycling agent used in this project was Carbojuv supplied by a local supplier with the following properties.

Table 4: Properties of the recycling agent

Asphaltenes, wt%	1.5
Maltenes, wt%	98.5
Kinematic Viscosity, cst	210

3 QUALITY CONTROL

The quality control plan included testing on samples taken from

- Admix from asphalt plant
- Recycled asphalt mix, i.e. the combination of RAP, new admix and rejuvenator. (Samples of the recycled asphalt mix were taken immediately after the screed)
- Cores of compacted recycled asphalt mix.

Samples were tested in the laboratory to determine the aggregate gradation, bitumen content, maximum theoretical density, Marshall stability and flow. Five core samples were taken after completion of compaction each day, analyzed for density and compared to maximum theoretical density. Places where loose recycled asphalt mix samples had been taken were marked so that the core samples of the compacted mat were taken from the same strip where the loose samples had been taken. The results of testing indicated the following:

1) Aggregate gradation for the field samples of all the three roads agreed very closely with the gradation considered for design and fell in the allowable range with only a few points slightly exceeding the boundaries (Figures 3 to 5).
2) The asphalt content was variable with ranges from 5.4 to 8.2 for R1, 6.1 to 7.8 for R2 and 6 to 8.7 for R3.

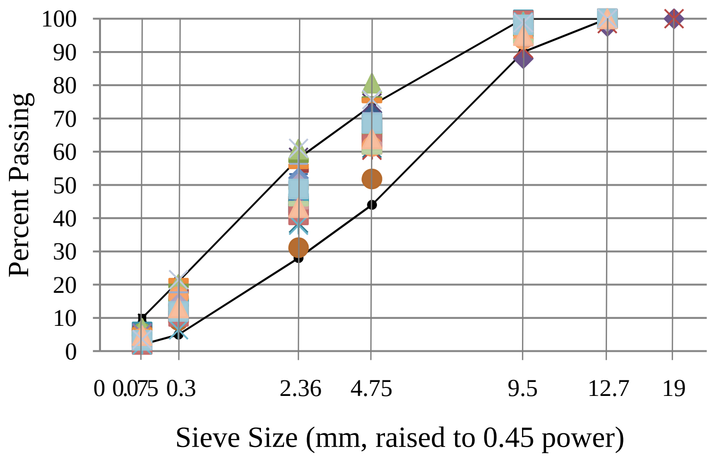

Figure 3: Aggregate gradation of field samples taken from recycled pavement of R1

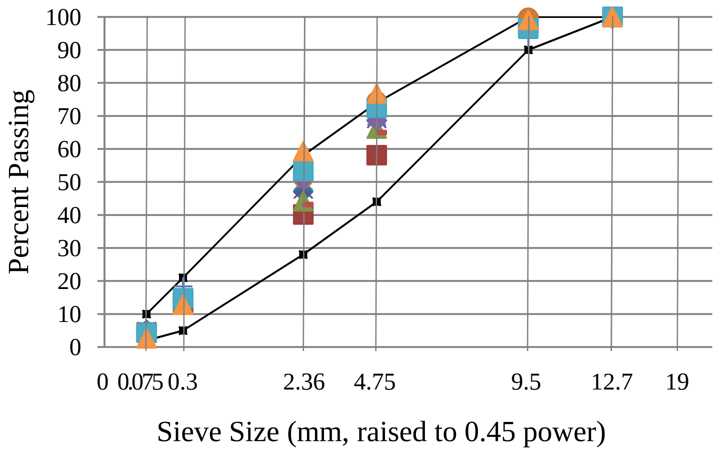

Figure 4: Aggregate gradation of field samples taken from recycled pavement of R2

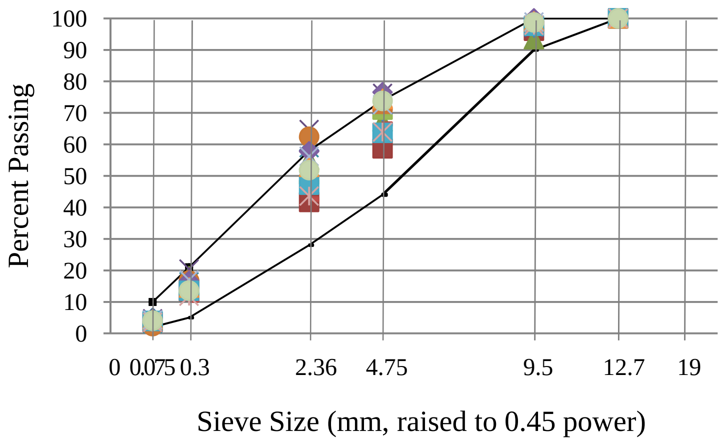

Figure 5: Aggregate gradation of field samples taken from recycled pavement of R3

3) Air voids were generally high with the maximum range of 1 to 11 percent. However, the majority of the air voids (about 50% of the samples) were less than 6%. Kandhal and Mallick (1997) declared that air voids in hot in-place recycled mix can be higher than 4 percent. They indicated that higher design air voids of up to 6 percent have been used successfully in Canada. In the case of coral aggregate higher air voids should not be an issue.
4) Stability values were much higher than the minimum required by the specifications and ranged from 1045 to 3308 kg for R1, 1684 to 2476 kg for R2 and 1122 to 2669 kg for R3. Flow values were generally good ranging from 10 to 14 for R1, 6.2 to 11.2 for R2 and 8.6 to 13.2 for R3. The majority of flow values met the specifications requirements. The only exceptions were a few samples from R2 that had flow values below 8.
5) Density of the recycled hot mix asphalt was generally higher than 90% of Marshall density and in almost half of the samples it was higher than 95%.

4 EVALUATION OF RECYCLED PAVEMENTS

The roads recycled in this project had distresses in the slight to moderate severity category before rehabilitation. R1 pavement had fairly rough surface texture with cracks on the surface. R2 and R3 had smooth to slightly rough texture with cracks on their surface. Some loss of asphalt cement from the surface of a few aggregates particles were evident in all samples indicating low severity raveling/weathering. Moreover, all the cores taken from these roads had dry mix appearance with visible voids. Figure 6 shows the surface condition of the roads before rehabilitation.

All the roads were evaluated four years after the rehabilitation and Pavement Condition Index (PCI) was calculated for each using a simplified method defined by Wolters et al. (2002). The PCI values for R1, R2, and R3 were 93.5, 91.5 and 89.5 respectively, indicating that these roads are in an excellent condition. Although some construction problems were encountered in the beginning, these pavements have performed very well during the last four years.

One of the construction issues was compaction problems resulting from low temperature of asphalt mix in the back of the HIR train (about 80% lower than what is indicated in the guidelines) and the high paving speed of these equipment. This problem was resolved by adding a second rubber wheel roller to the compacting process and lowering the speed of preheaters to provide more heat. By lowering the speed of preheaters, the actual mat temperature behind the HIR paving screed was raised from values close to 95^{o}C to values between 110^{o}C and 125^{o}C. In addition to the compaction issue, it was found that the HIR equipment was not calibrated in the beginning, thus the amount of rejuvenator added to the mix was about 30% more than those determined in the design. This problem was also solved by calibrating the device.

Figure 6: Surface condition of the roads before rehabilitation

In general, low severity cracks and raveling, in some locations, have appeared on the pavement surfaces that can normally happen for any pavement under service. Figure 7 depicts road surface conditions four years after HIR.

It is noteworthy to mention that the performance of recycled pavements, to this date, has been comparable to that of conventionally rehabilitated and even newly constructed pavements in the Island.

5 CONCLUSIONS

This paper described the use of HIR technique for rehabilitation of old asphalt pavements made with coral aggregate in Kish Island with hot climate. HIR has shown promise for the rehabilitation of such pavements under medium traffic. This project demonstrated the mix design, monitoring of construction and quality control testing, and evaluation of rehabilitated pavements. The results of quality control tests indicate acceptable properties for the final recycled mix.

Figure 7: Surface condition of the roads four years after rehabilitation

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