Preliminary Study on the Use of Reclaimed Asphalt in Public Works Authority Road Projects in the State of Qatar

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Abstract

This paper describes the outcomes of a preliminary study focused on the evaluation of four full-scale pavement sections in which reclaimed asphalt (RAP) was used in partial substitution of virgin aggregates during the production of asphalt mixes. Considered mixes were produced with different RAP percentages and were thereafter laid on site for the formation of asphalt base course layers of pavements in local roads of the State of Qatar. For comparative purposes, two trials included asphalt mixes containing no RAP, and in one case use was made of a rejuvenating agent. Activities carried out for the monitoring of field trials included analysis of component materials, critical observation of production and laying operations, assessment of the most relevant characteristics of produced asphalt mixes, and evaluation of the degree of compaction achieved during construction. Experimental results were of crucial importance for the introduction of RAP-related paving technologies in the State of Qatar, providing a meaningful background to the preparation of the "Ashghal Recycling Manual" issued by Ashghal and of the draft updated version of Qatar Construction Specifications.

Keywords: Road pavements; Reclaimed asphalt; Field trials; Quality control

1 Introduction

Decades of research and field experience have shown that reclaimed asphalt (indicated as "RAP") obtained from the milling of distressed layers of flexible pavements can be used in partial substitution of virgin aggregates in asphalt mixes, thereby leading to the reduction of production costs and of the consumption of non-renewable resources (Copeland, 2011; Zaumanis & Mallick, 2015). It has also been proven that asphalt mixes containing RAP, when designed appropriately, can exhibit improved performance-related properties, especially with respect to their rutting resistance at high temperatures and under severe loading (Widyatmoko, 2008; Pradyumna

et al., 2013). In such a context, rejuvenating agents may be needed to restore the original properties of the aged binder, allowing the use of significant percentages of RAP without jeopardizing field performance of resulting asphalt mixes (Im et al., 2014; Ali et al., 2016; Moghaddam & Baaj, 2016).

The above-mentioned potential benefits of employing RAP in asphalt mixes have been considered to be of premium relevance for pavements of the road network of the State of Qatar, managed by the Public Works Authority (Ashghal). Related implementation efforts commenced in 2018 with the launch of the so-called “Ashghal Recycling Initiative” in which a significant emphasis was placed on the use of RAP not only because of the availability of such a material in Qatar, but also due to the fact that asphalt mixes exclusively rely on the import of gabbro aggregates from foreign Countries.

Since versions of Qatar Construction Specifications (QCS) issued until 2014 allowed only the use of virgin aggregates, as part of the Recycling Initiative Ashghal planned a series of activities to gradually facilitate the local implementation and fine-tuning of RAP-related paving technologies. The collaboration of Contractors was sought, and with the support of competent Ashghal Departments field trials were constructed. These entailed the production and laying of base course (BC) asphalt mixes containing RAP in field trials that were limited to secondary or residential roads characterized by low volumes of traffic, with a negligible percentage of heavy trucks.

This paper describes the outcomes of a preliminary study focused on the evaluation of four full-scale pavement sections of the type described above.

2 Field Trials

A synthetic description of the four field trials included in the study is provided in Table 1. The BC mixes produced and laid in the first three trials were, as per QCS 2014 requirements, of the “B” type, with a nominal maximum aggregate size (NMAS) of 19 mm, while BC mixes considered in the fourth field trial were slightly coarser (of the “A” type indicated in QCS 2014), with a NMAS of 25 mm. Considered mixes were produced with different RAP percentages (comprised between 15% and 40%, with respect to the weight of total aggregates in the mix). For comparative purposes, two trials included asphalt mixes containing no RAP, and in one case use was made of a rejuvenating agent.

Identification codes of the mixes listed in Table 1 are given by the combination of trial number, Contractor code, mix type, RAP percentage and, whenever used, presence of rejuvenator. Paving sections of the first three trials were located in residential streets of Al Rayyan, while the fourth trial took place on the extension of an existing access road in the Municipality of Al Wakrah.

Table 1: Description of Field Trials

Trial	Contractor	Mix type	RAP (%)	Mix code
1	A	BC Class B	20	1A-B-20
2	A	BC Class B	40 40* 0	2A-B-40 2A-B-40R 2A-B-0
3	A	BC Class B	15	3A-B-15
4	B	BC Class A	15 0	4B-A-15 4B-A-0

* with rejuvenating agent

3 Job Mix Formulas and Preliminary Tests

Given the preliminary character of the trials, Job Mix Formulas (JMFs) of asphalt mixes containing RAP did not stem from specific mix design activities. Rather, Contractors referred to existing Conformity Certificates issued for asphalt mixes containing gabbro aggregates, designed according to the Marshall procedure. Thus, approved JMFs were adjusted to obtain the target binder content and size distribution of the aggregates of reference mixes. For mixes containing a limited quantity of RAP such an approach is standard practice in many Countries which already employ hot recycling of RAP on a routinely basis. Although use of higher RAP percentages was scheduled in the first two field trials, this simplified approach was maintained throughout the study.

In conformity with QCS (2014), bituminous binders employed for the production of asphalt mixes were all of the neat (unmodified) type and of 60/70 penetration grade. This generally corresponds to a PG64S-22 grade defined as per AASHTO M 332-14.

In most of the trials, asphalt mixes containing RAP were produced with no use of rejuvenating agents. However, in field trial #2 one of the mixes was produced with 40% RAP and 1.5% (by weight of RAP) of a commercial rejuvenator (Iterlene ACF 2000, supplied by Iterchimica, Italy). No preliminary study was carried out to verify to what extent such a dosage, which was suggested by the supplier, would affect the rheological and chemical characteristics of the aged bitumen contained in RAP. In such a context it should be mentioned that previous studies showed that the degree of field ageing of bitumen in Qatar is extremely high, thereby suggesting that the residual bitumen contained in RAP may be very close to the so-called "black rock" condition (Sirin et al., 2017).

In the case, of the first three trials, employed RAP was a 0-20 mm material available in a single fraction that did not derive from any granulation and/or separation process. On the contrary, in the case of the trial #4, available RAP was preliminarily processed with the consequent formation of three fractions (0-5 mm, 5-14 mm and 14-20 mm) that were thereafter recombined in pre-defined proportions to obtain a single fraction. Such an operation, which is in line with international best practice, was deemed necessary to better control the grading, composition and volumetrics of the final asphalt mix (Al-Qadi et al., 2012).

RAP was sampled during the planning phase of the first three field trials and on the day of production of trials #1 and #4. Samples were then subjected to analysis for the determination of particle size distribution before binder extraction (as per ASTM C136-14), binder content (as per ASTM D2172-17) and particle size distribution after binder extraction (as per ASTM D5444-15). Results of these tests are synthesized in Table 2 and in Figs. 1 and 2.

When considering the single-fraction RAP material employed in the first three trials, non-negligible differences were found, in terms of both bitumen content (Table 2) and particle size distribution (Fig. 1), between the results of analyses performed on samples taken in the planning and production phases. This was most likely due to the non-homogeneity of the stockpiled RAP, which was not subjected to any preparatory processing, with the possible presence of agglomerations and clusters. Such a hypothesis was confirmed by the size distributions of extracted aggregates (Fig. 2), that were found to be quite constant.

With respect to the results obtained on the reconstituted RAP employed in the fourth field trial, it was observed that extracted aggregates exhibited a particle size distribution which was similar to that of the aggregates contained in the single fraction used in the first three trials. Binder content (equal to 3.4%) was intermediate between the previously obtained values and in line with the percentages normally adopted in base course and wearing course mixtures complying to QCS 2014.

Table 2: Binder Content of RAP

	Trials #1-3	Trial #4
Planning	3.7	-
Production	3.0	3.4

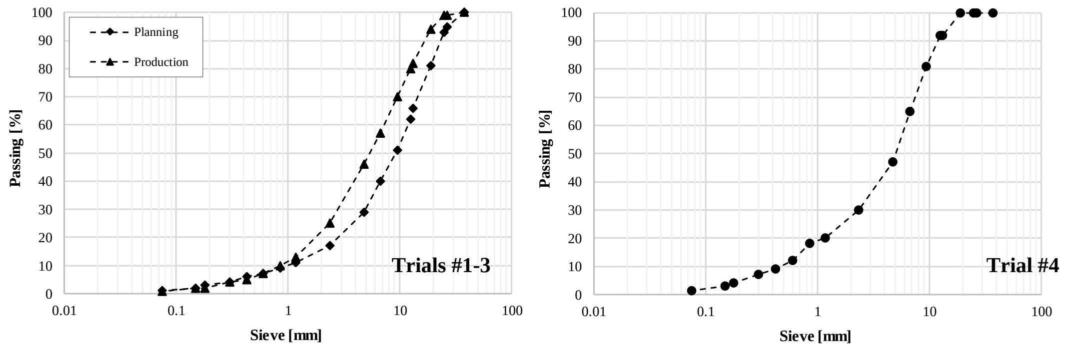

Fig. 1: Particle size distribution of RAP particles

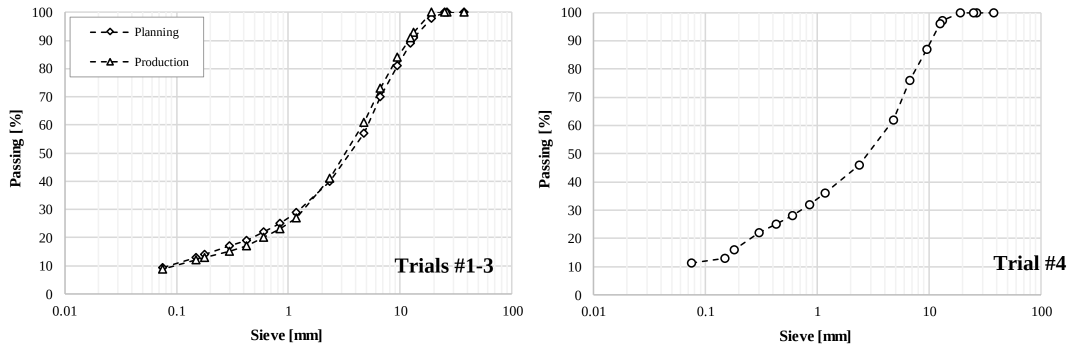

Fig. 2: Particle size distribution of aggregates extracted from RAP

4 Production and Laying

During production of the BC asphalt mixes, the RAP fraction was cold-fed directly to the pug mill. At the moment of mix discharge in hauling trucks, mix temperature was of the order of 170°C. Paving sites were prepared the day before the trials by applying a prime coat on the surface of the existing granular sub-bases. Asphalt mixes arrived on site with a temperature of approximately 155°C and in all cases environmental conditions at the time of laying were favourable, with air temperatures in the range of 20-30°C.Laying was carried out by employing two pavers operated in echelon in order to guarantee the formation of hot-on-hot longitudinal construction joints. Breakdown rolling was carried out by means of tandem steel rollers, while pneumatic tire rollers were used for completion of the densification process.

During the first three trials, due to the lack of RAP processing, agglomerates of fine RAP were visible in the asphalt mixes. Conversely, the appearance of the mix laid in trial #4, containing 15% of pre-processed RAP, was more homogeneous. The use of 40% RAP in trial #2 proved to be challenging from the viewpoint of laying. In particular, segregation phenomena were observed at the paver's screed and it was observed that breakdown rolling needed to be carried out in an extremely timely manner to overcome the stiff response of the mixes under compaction.

5 Experimental Investigation

5.1 Characteristics of Asphalt Mixes

Test results obtained on loose samples of the asphalt mixes for the assessment of composition are synthesized in Tables 3 and 4 and in Fig. 3. Results of tests carried out on Marshall-compacted specimens are provided in Tables 5 and 6. Symbols adopted in the tables are: B for percent binder content, f/B for filler-bitumen ratio, v for void content, S for Marshall Stability, F for Marshall flow, S/F for Marshall quotient, S_{t1} for indirect tensile strength evaluated in dry conditions, S_{t2} for indirect tensile strength evaluated after conditioning in water, TSR for tensile strength ratio.

Composition of the mixes was assessed by referring to binder content (determined as per ASTM D2172-17) and to the particle size distribution of extracted aggregates (determined as per ASTM D5444-15). Corresponding results, synthesized in Fig. 3 and in Tables 3 and 4, highlighted non-negligible deviations from the JMFs and in some cases led to violations of QCS 2014 limits.

Use of lower RAP dosages (equal to 15% and 20% in trials #1, #3 and #4) led to a coarser grading of the fine fraction (passing the 4.75 mm sieve), whereas a finer grading in the entire range of particle sizes was found for the mixes containing 40% RAP (laid in trial #2). Such an outcome was explained by referring to the composition of RAP fractions, which did not replicate the combination of virgin fractions of the JMFs. Furthermore, it was postulated that when employing non-processed RAP, the presence of clusters led to an increase of the percentage of fines and filler in an unpredictable manner. As expected, particle size distribution of mixes containing no RAP was in line with JMFs.

Binder content of asphalt mixes significantly deviated from target, being in most cases lower, and higher only for the mixes laid in the second field trial. These results were presumably due to the variable contribution coming from RAP, especially in the case of the non-processed material employed in the first three trials. It should be also mentioned that the setting adjustments made by the Contractors during the production of mixes containing RAP had negative effects on the production of the reference mixes with no RAP, which were unfortunately characterized by binder over dosage (mix 2A-B-0) or under dosage (mix 4B-A-0).

Table 3: Binder content and Filler/Bitumen Ratio of asphalt mixes (BC Class B)

	1A-B-20	**2A-B-40**	**2A-B-40R**	**2A-B-0**	**3A-B-15**	**Target JMF**	**QCS limits**
B (%)	3.5	4.6	4.6	4.2	3.7	3.8	3.6 - 4.0
f/B	1.4	1.6	1.5	0.9	1.1	1.05	0.8 - 1.5

Table 4: Binder content and Filler/Bitumen Ratio of asphalt mixes (BC Class A)

	4B-A-15	**4B-A-0**	**Target JMF**	**QCS limits**
B (%)	3.1	3.4	3.6	3.3 - 3.9
f/B	1.2	0.9	1.19	0.8 - 1.5

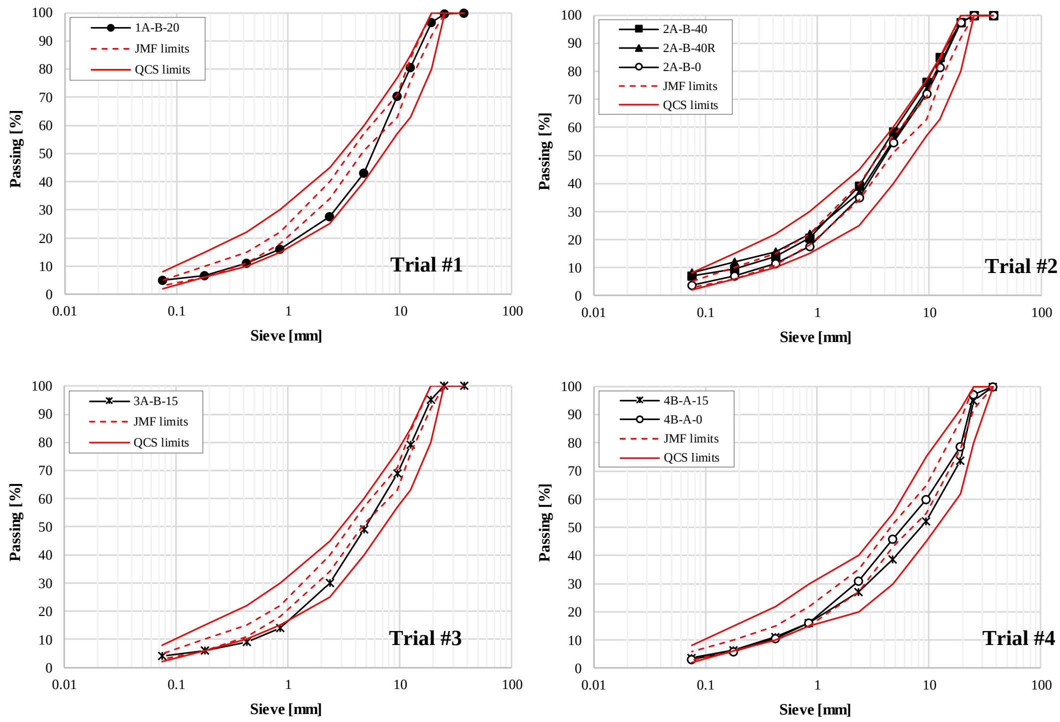

Fig. 3: Particle size distribution of aggregates extracted from asphalt mixes

Marshall-compacted specimens were prepared in the laboratory by following the procedure indicated in ASTM D6926-16 (75 blows per face). Specimens were thereafter characterized in terms of their volumetric properties and subjected to the Marshall stability test (as per ASTM D6927-15) as per (QCS, 2014). Further tests were performed to evaluate the tensile strength ratio (TSR) after water immersion (as per ASTM D4867-14). Although such a measurement was not mandatory in QCS 2014, it was considered to be a useful to assess asphalt mix durability. Finally, as required by QCS 2014, additional Marshall specimens were compacted with 400 blows per face in order to verify their void content (v_{400}) which in such extreme conditions can provide an indication of the resistance to bleeding. Results of the above-mentioned tests, synthesized in Tables 5 and 6, highlighted non-negligible deviations from the JMFs and in some cases led to violations of (QCS, 2014) limits.

In most cases the volumetrics of specimens compacted both with 75 and 400 blows per face deviated from target. In particular, very low void contents were found for the mixes with 40% RAP, possibly as a result of the very high content of bitumen, fines and filler. On the contrary, mixes containing lower RAP percentage (equal to 15-20%) with a coarse grading of the fine fraction, yielded void content values, which were higher than the target. As a result of the previously mentioned adjustments of production settings, mixes containing no RAP did not reach acceptable densification levels after standard compaction with 75 blows per face, with void content values that were above target both for the class B mix (2A-B-0) and for the class A mix (4B-A-0). Finally, use of the rejuvenating agent for the mix containing 40% RAP led to a void content reduction, thus suggesting that the employed additive may have softened the aged bitumen of the recycled fraction.

Assessment of the effects of RAP on the results of Marshall Stability tests was complicated by the variability of RAP composition and of added binder dosage. Nevertheless, use of 40% RAP was found to cause a significant increase of stability, while minor effects were recorded with respect to Marshall Flow. In the case of trial #4, the effect of RAP was highlighted more clearly, possibly as a result of the better control of RAP composition.

TSR results were mainly controlled by void contents, reaching values above 85% for highly compacted mixes (with 40% RAP), while lower values were achieved for the less compacted mix with 15% RAP (4B-A-15). In such a context, it should be mentioned that the threshold value normally referred to for acceptance purposes in standard technical specifications is equal to 80%.

Table 5: Results of tests carried out on Marshall Specimens (BC Class B)

	1A-B-20	2A-B-40	2A-B-40R	2A-B-0	3A-B-15	Target JMF	QCS limits
v (%)	7.5	3.3	2.5	7.0	6.5	6.6	4.5 - 8.0
S (kN)	16.3	21.5	33.8	19.4	18.4	13.2	≥ 9.5
F (mm)	2.5	2.7	2.3	2.2	2.7	2.6	2 - 4
S/F (kN/mm)	6.5	7.8	15.0	8.6	6.7	5.1	≥ 4.75
v_{400} (%)	5.9	2.1	1.5	4.8	4.8	5.1	≥ 3.4
S_{t1} (kPa)	-	1316	1017	-	-	-	-
S_{t2} (kPa)	-	1126	898	-	-	-	-
TSR (%)	-	86	88	-	-	-	-

Table 6: Results of tests carried out on Marshall Specimens (BC Class A)

	4B-A-15	4B-A-0	Target JMF	QCS limits
v (%)	7.6	9.0	6.8	4.0 - 8.0
S (kN)	17.4	14.8	14.4	≥ 9.5
F (mm)	2.4	2.5	2.7	2 - 4
S/F (kN/mm)	7.2	5.9	5.3	≥ 4.75
v_{400} (%)	5.6	6.1	5.0	≥ 3.2
S_{t1} (kPa)	1122	1159	-	-
S_{t2} (kPa)	808	793	-	-
TSR (%)	72	68	-	-

5.2 Field Compaction

The effectiveness of field compaction of asphalt mixes was evaluated by determining the void content of sets of 8 cores extracted from compacted layers and by thereafter calculating the degree of compaction with respect to corresponding Marshall specimens (see Tables 5 and 6). Average results obtained from the above-mentioned tests are given in Table 7, which also lists minimum and maximum values or measured void contents. Symbols adopted in the table are v for void content and %RD for percent relative density (referred to Marshall specimens). Cores were not available in the case of mix 4B-A-0, laid in trial #4 and containing no RAP.

As expected, average void content values of the laid asphalt mixes were consistent with those of the corresponding Marshall specimens, with QCS requirements that were not satisfied for three of the considered mixes. Although variability of test results was relatively high, it was observed to be lower for mixes containing 15% RAP and in particular, for the mix containing processed RAP, which during compaction operations was also observed to be the most homogeneous. Percent relative density was in all cases within the QCS acceptance range, thus indicating that regardless of the deviations from the JMFs, considered mixes could be efficiently compacted in the field.

Even though high in-place void content may be detrimental for long-term durability, given that the asphalt mixes were placed on roads characterized by low traffic levels and negligible percentage of heavy trucks, they were not removed and left to withstand the actions of vehicle loading.

Table 7: Volumetrics of cores extracted from compacted layers

	1A-B-20	2A-B-40	2A-B-40R	2A-B-0	3A-B-15	4B-A-15	QCS limits
v (%)	9.2	4.3	5.4	8.2	7.1	5.9	5.0 - 8.0
v_{min} (%)	7.4	2.8	3.3	7.0	5.5	4.8	-
v_{max} (%)	11.0	6.1	6.7	9.4	8.5	7.5	-
%RD (%)	98.2	99.0	97.0	98.7	99.4	101.8	97.0 - 101.8

6 Conclusions

Results obtained in the preliminary study described in this paper were of crucial importance for the introduction of RAP-related paving technologies in the State of Qatar, constituting a valuable reference for the preparation of the "Ashghal Recycling Manual" issued by Ashghal (Elhussein et al., 2021) and for the update of Qatar Construction Specifications (QCS, 2018).

Regardless of the fact that experimental results highlighted deviations from target JMFs and partial violation of requirements set in (QCS, 2014), it was proven that the production and laying of base course asphalt mixes containing RAP was feasible and compatible with the technical capabilities, plants and equipment of local Contractors. It was also confirmed that in order to fully exploit RAP as a valuable component of asphalt mixes, such a material needs to be subjected to preliminary processing, which consists in granulation followed by separation into size fractions, and to appropriate laboratory tests for the assessment of its composition.

Since it was envisioned that Engineers, Supervision Consultants and Contractors in Qatar would need some time to gradually gain confidence in the use of RAP, in the first phase of its widespread implementation it was decided, by setting proper constraints in (QCS, 2018), to limit its percentage to 15% in base course asphalt mixes laid exclusively on infrastructures characterized by low traffic volumes (up to 3 million Equivalent Single Axle Loads, ESALs) and on roads made for temporary use (for less than 20 years). However, plans were made to progressively increase (up to 30%) the maximum allowable RAP percentage in asphalt base courses and to extend the applicability of related technologies to the entire road network of the State of Qatar. Such a goal was made explicit in the "Ashghal Recycling Manual," where it was stated that for RAP contents comprised between 15% and 30% specific mix design studies, including additional performance-related tests, should be carried out for approval.

Further research activities related to the use of RAP in asphalt mixes are currently in development, focusing on the optimization of mix designs and on the assessment of performance-related properties. Additional activities are being planned for the monitoring of pilot and full-scale projects. It is envisioned that obtained results will lead to further refinements of specifications and guidelines, thereby contributing to the construction of more sustainable and durable road pavements in the State of Qatar.

Acknowledgements

Experimental activities documented in this paper were performed with the involvement of the laboratory of the Ashghal Center for Research & Development (ACRD) and of the Road Materials Laboratory of the Politecnico di Torino, Italy.

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Cite as: Santagata E., Yeganeh S., Sebaaly H., Elhussein O. & Al Marri A., "Preliminary Study on the Use of Reclaimed Asphalt in Public Works Authority Road Projects in the State of Qatar", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0116