



Assessment of RAP Refining Duration Based on Bitumen Mastic Removal Efficiency and Preservation of Aggregate Surface Texture to Increase RAP Content in New Asphalt Mixtures

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Abstract. The use of Reclaimed Asphalt Pavement (RAP) in new asphalt mixtures is often limited due to the presence of aged binder, which can compromise the mechanical performance of the road pavements. However, from a sustainability perspective, it is crucial to develop effective strategies for the recovery and reuse of RAP aggregate. One potential approach involves the mechanical treatment of the material to remove the binder coating on the aggregates, producing a refined product suitable for large-scale reuse in new asphalt mixtures. This study investigated the performance of a plant for the mechanical refining of RAP aggregate with the aim of identifying the optimal refining duration and maximizing bitumen mastic removal without causing excessive polishing of the aggregates. RAP was subjected to different processing times in the plant: one with direct flow, and others with 2, 3, and 5 min of refining loop duration, evaluating both residual bitumen content and skid resistance. The results showed that a refining loop duration of 2 min provided the best balance between efficient bitumen mastic removal and preservation of aggregate surface texture.

Keywords: RAP · mechanical refining · direct flow · refining loop duration · bitumen mastic removal · skid resistance

1 Introduction

The road infrastructure sector is continuously committed to ensuring a high level of service across transportation networks. To preserve adequate functional and structural performance, both routine and extraordinary maintenance interventions are required. These operations often involve the partial or complete removal of deteriorated asphalt layers, which are subsequently replaced with new asphalt mixtures. The removal process is typically carried out using a milling machine, capable of removing the desired

layers and producing a bituminous granular material known as Reclaimed Asphalt Pavement (RAP). Originally RAP is classified as waste and destined for landfill; however, through appropriate processing and selection procedures it can lose its waste status and be valorised as secondary raw material for the production of new asphalt mixtures [1]. Nevertheless, the incorporation of RAP aggregate into new mixtures is subjected to limitations. The bituminous binder contained in RAP is aged and oxidized; as a result, the inclusion of high RAP aggregate contents leads to mixtures with increased stiffness, greater brittleness, and higher susceptibility to cracking phenomena. In particular, under cyclic traffic loading, characteristic alligator cracking may develop, which is associated with fatigue failure [2]. To address this issue, strategies such as additives or highly modified asphalt binders are often adopted in the design of new mixture containing RAP aggregate. Another approach involves processing RAP through specific mechanical refining systems. These systems employ impact and abrasion mechanisms that, on one hand, enable the removal of a significant portion of the binder mastic from the aggregate surface, while on the other hand, may induce aggregate polishing, thereby altering its surface characteristics [3]. The aim of the present study is to identify the optimal refining duration for RAP aggregate within the refining plant, in order to achieve the effective balance between bitumen mastic removal and the preservation of aggregate surface properties. The intention is to obtain refined RAP aggregate whose characteristics are as similar as possible to those of the original virgin aggregate.

2 Materials and Methods

2.1 RAP Refining Plant

The scheme of the RAP refining plant is shown in Fig. 1. It is designed to separate and recover the different components of the RAP aggregate, with the aim of making them suitable for use in the production of new asphalt mixtures. The RAP is initially poured into a loading hopper, which collects the material and conveys it via conveyor belt to a vibrating flip-flow screen. The latter, thanks to its vibrating action and the presence of metal meshes, allows the separation of the RAP in two particle size fractions:

- a RAP fine aggregate fraction, which passes through the 4 mm-meshes and is stockpiled;
- a RAP coarse aggregate fraction, retained by the 4 mm-meshes, and conveyed to an accumulation hopper.

Subsequently, the RAP coarse aggregate is discharged onto another conveyor belt that carries it to a first Rotary Asphalt Refiner (RAR). This unit consists of an upper loading part and a series of internal rotating cylinders placed below. Once introduced, the RAP coarse fraction undergoes a combination of impacts and friction, both against the metallic parts of the unit and among the aggregate particles themselves. This combined action results in the partial removal of the bituminous binder mastic from the surface of the RAP aggregate. At the outlet of the RAR, two components are obtained:

- a RAP fine aggregate fraction with a high bitumen content;

- a RAP coarse aggregate fraction with a lower bitumen content compared to the incoming material.

Both the fractions are conveyed to a secondary RAR, which further increases the degree of bitumen mastic removal from the RAP coarse aggregate. The outgoing materials are then separated by a secondary vibrating flip-flow screen: the bitumen-rich RAP fine aggregate that passes through the 4 mm-meshes is conveyed directly to the stockpile already formed by the fine aggregate collected in the initial phase, while the retained material follows a path that depends on the operating plant settings.

In fact, at the beginning of the RAP refining operations, it is decided whether the material should:

- undergo a single refining cycle, with a duration of less than one minute, i.e. the RAP aggregate is treated by the two RARs and the two RAP aggregate fractions are stockpiled (indicated hereafter as “direct flow”); or
- be conveyed again to the accumulation hooper before the first RAR. The RAP coarse aggregate is then treated in this closed loop for a certain amount of time and stockpiled at the end of the process (this procedure is indicated as “refining loop”).

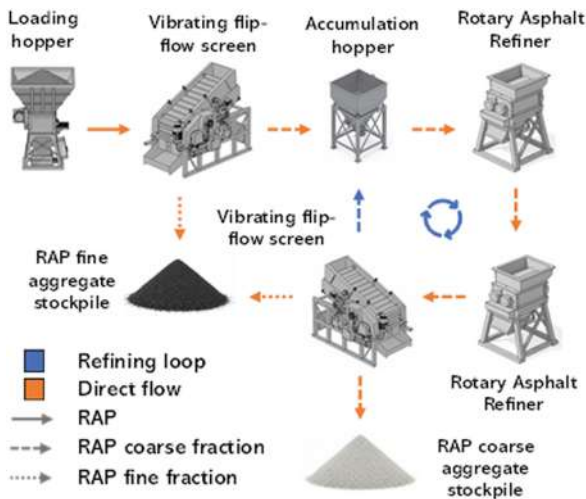


Fig. 1. RAP refining plant diagram.

2.2 Materials

In this study, the treated material consisted of RAP aggregate obtained from the milling of an Open Graded Friction Course (OGFC) from a highway pavement (RAP_REF). The material was introduced into the refining plant, and the RAP coarse aggregate was sampled by the primary vibrating flip-flow screen, representing the material before the actual refining process (RAP_C). Subsequently, depending on the operating mode of the plant, additional samples were collected from the RAP coarse aggregate stockpile. Table 1 summarizes the investigated materials and the treatment they underwent.

Table 1. Studied materials.

Material	Treatment type	Sampling location (Fig. 1)	Refining loop duration
RAP_REF	none	Loading Hopper	N/A
RAP_C	Primary screening	Accumulation Hopper	N/A
RAP_C0	Direct flow	RAP coarse aggregate stockpile	0 min
RAP_C2	Refining loop		2 min
RAP_C3			3 min
RAP_C5			5 min

2.3 Experimental Program

The experimental program included the determination of the bitumen content for all materials according to the EN 12697–1. Subsequently, the surface friction properties were established by the determination of the Pendulum Test Value (PTV), as specified by EN 13036–4. Specimens were prepared in accordance with EN 1097–8. As the norm provides that the test is carried out on particles between 7.2 and 10 mm, only one set of specimens was tested for RAP_REF and RAP_C aggregates. The specimens were subjected to the pendulum friction test in order to evaluate the surface properties and assess how the refining process affects the surface texture of the RAP aggregates. Figure 2 shows the number of tests carried out in the experimental program.

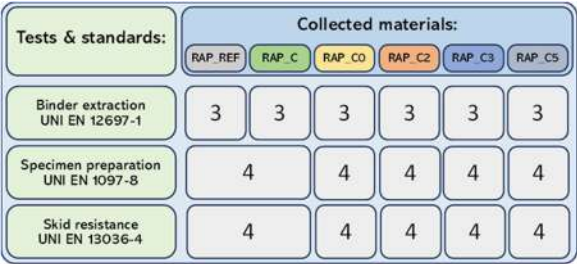


Fig. 2. Experimental program.

3 Results

The analysis of the graph reported in Fig. 3 shows that the initial RAP source (RAP_REF) had an average residual bitumen content of 4.4% by RAP weight. However, a significant reduction in binder content was observed with the first sieving operation, before any refining action. During this stage, the material passing through the 4 mm-sieve, characterized by a higher specific surface area and consequently a higher binder content, was separated. The coarse material retained at the 4 mm-mesh (RAP_C) exhibited an average residual bitumen content of 3.6%. Figure 3 reports the binder content as a function of

the refining loop duration, highlighting how the treatment process progressively reduced the residual binder. When the refining process was performed in direct flow mode, i.e. with no refining loop, the final product (RAP_C0) showed a residual binder content of 1.9%, corresponding to an overall reduction of 57% compared to RAP_REF. However, when the plant operated in refining loop mode, the material refined for approximately two minutes (RAP_C2) showed a further residual bitumen reduction, with the bitumen content decreasing to 0.9%. The increase of the refining loop duration did not lead to significant variations: after 3 and 5 min of refining loop (RAP_C3 and RAP_C5, respectively), the residual bitumen content did not significantly vary compared to the 2-min refining loop result. The slight increase in bitumen content related to the 5 min refining loop duration can be attributed to sampling variability. Overall, the process enabled the removal of up to approximately 80% of the original residual bitumen (RAP_REF). For the optimal 2-min refining loop configuration, the initial 4 mm screening of the original RAP_REF led to approximately 25% by mass of RAP fine aggregate fraction and 75% of RAP coarse aggregate fraction subjected to the refining process (RAP_C). During refining, about 30% by mass of the RAP_C was removed as bituminous mastic and fine particles, resulting in a total amount of approximately 50% of refined coarse aggregate with respect to the original material (RAP_REF).

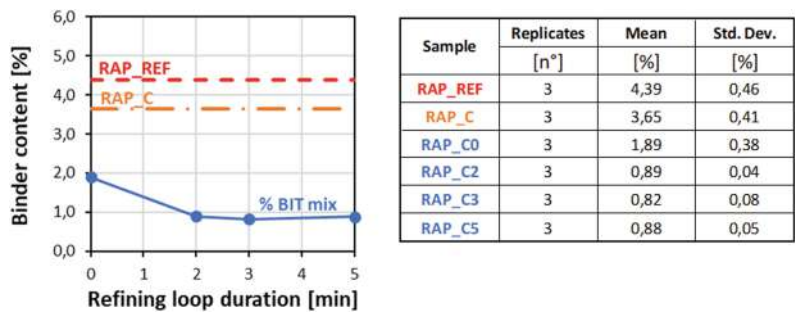


Fig. 3. Binder content of the RAP fractions as a function of refining loop duration.

Following the evaluation of the residual binder content, the skid resistance was measured to assess the effect of the refining process on the surface texture of the RAP aggregate particles. Skid resistance was expressed in terms of Pendulum Test Value (PTV), calculated as the average of five measurements performed on four specimens for each material. In the asphalt pavement engineering literature, the measured PTV is often reported as the British Pendulum Number (BPN), and both are used as equivalent indicators of skid resistance related to surface microtexture [4]. These results confirm that the PTV values obtained in this study are in line with those commonly reported in literature [5]. Results are shown in Fig. 4. The reference material (RAP_REF) exhibited a PTV value of 69. The material processed through the direct flow (RAP_C0) showed a slightly higher PTV, indicating that the abrasive action exerted by the refining system contributed to the partial removal of the binder film coating the aggregates, thereby exposing the mineral surface and increasing friction. As shown in Fig. 4, for refining loop duration up to two minutes, the dominant effect was the binder removal rather than

the aggregate polishing. In fact, the material RAP_C2 exhibited a PTV similar to that of the reference material, suggesting a balance between binder removal and aggregate polishing. When the refining loop was increased to three minutes, a higher reduction in PTV was observed (from 69 to 65), indicating that the polishing action became predominant over binder removal. This interpretation was consistent with the results shown in Fig. 3, where the residual binder content remained nearly constant between 2 and 3 min of refining loop, confirming that beyond the 2-min threshold the refining process primarily affected the aggregate texture rather than removing the bituminous film. For the material RAP_C5 the PTV further decreased to 64. Although this reduction was relatively small, it indicated that after approximately three minutes of refining loop the aggregate surface reached a stable condition, where the texture was polished and no further significant changes occurred in either bitumen removal or surface texture. In summary, increasing the refining loop duration beyond two minutes led to a progressive polishing of the aggregate surface, while the residual binder content remained essentially unchanged.

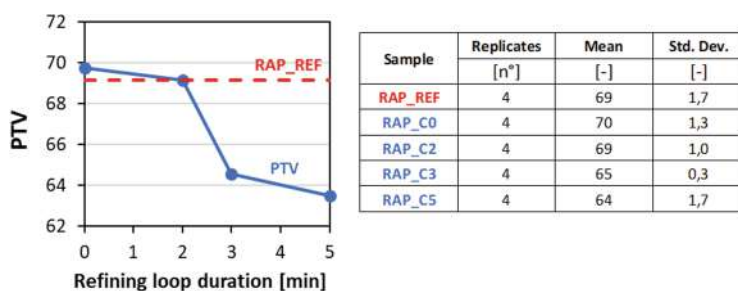


Fig. 4. Pendulum Test Value as a function of refining loop duration.

4 Conclusions

The goal of this study was to establish how the RAP refining plant operating conditions could affect both the residual bitumen content and the surface microtexture. Such aspects were evaluated by two main operating conditions: direct flow and refining loop. The combined analysis of binder content and skid resistance results indicated that the optimal refining loop time within the refining plant was 2 min. Shorter times, such as in direct flow, led to a RAP aggregate material characterized by a high PTV value but with still a significant amount of residual binder. Conversely, extending the refining loop time beyond 2 min did not provide additional benefits: the residual binder content remained nearly constant while the PTV decreased. In perspective, the effect of treated RAP coarse fraction in hot asphalt mixtures recycling needs to be studied to significantly increase the percentage of RAP incorporated into new asphalt mixtures, although only a single RAP source was used in this study, representing a limitation of the experimental scope. Moreover, the lower bitumen content offers potential benefits in terms of reduced gas emissions during the production process. Finally, further developments will focus on identifying effective applications for the RAP fine fraction, ensuring that this material can also be fully recycled.

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