Physical properties of reclaimed asphalt pavement

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Abstract. Sustainable construction is becoming an important issue in pavement engineering. The use of reclaimed asphalt pavement (RAP) for road reconstruction gives both technical and environmental benefits. Unfortunately, the properties of cold asphalt mixture using RAP is still behind of hot asphalt mixture using fresh aggregate. The objective of research is to explore the physical properties of RAP in order to understand the factors affecting the lack of cold asphalt mixture performance. The laboratory physical tests on RAP and fresh aggregate were performed to investigate particle shape, specific gravity, gradation, and bulk density. It is found that the presence of aged bitumen in the RAP affects the shape formation, specific gravity, absorption, and gradation of RAP. All those factors cause the bulk density of compacted RAP decrease. This finding opens the knowledge of why cold asphalt mixture using RAP is worse than using fresh aggregate.

Keywords: Physical Properties, Road Construction, Reclaimed Asphalt.

1. Introduction

The use of reclaimed asphalt pavement (RAP) materials for road construction become increasingly in demand due to environmental issues. It can reduce emissions gas production, decrease source of natural materials exploitation, and also solve road geometric problems. The RAP material which is the results of the damaged road milling can be reprocessed by cold mixing method to produce the new pavement. This technology can decrease the need for fresh aggregate and bitumen, reduce fuel consumption and CO2 production, and overcome the addition of road surface level when it is conducted by overlay method. It is noted that RAP materials can replace the fresh aggregate for road pavement construction up to 40%-60% with satisfied performance [1]-[2]. These benefits push the use of RAP as the prospective of road construction materials. The application of RAP in Indonesia using cold-recycling system was started in 2007 at Pantura road [3]. The indirect tensile strength and the stiffness modulus of cold asphalt mixture using RAP is found to be satisfied and meet the specification for road base course materials [3]-[4].

However the properties of asphalt mixture using RAP are still behind using fresh aggregate, the cold mix asphalt is also still behind the hot mix asphalt [5]. In the RAP cold mix, the high air void causes the low value of density [6] and stability [2]. This lack of asphalt mixture using RAP materials pushes the need to investigate intensively RAP materials. This paper reports the results of research...
exploring the physical properties of RAP. The objective of research is to open understanding factors affecting the mixture performance using RAP. This research is designed to open the knowledge of why asphalt mixture using RAP is worse than using fresh aggregate.

2. Research Method
The research method is conducted by analysis the results of physical tests on RAP, extracted RAP (RAP aggregate), and fresh aggregate. The laboratory physical tests used were aggregate identity and shape, specific gravity & absorption, sieving analysis, and loose & compacted unit weight. All test results on those materials were compared in order to get important information about factors’ affecting the lack of asphalt mixture using RAP materials. The RAP material used in this research was collected from Tegal section of Java Pantura Road in Indonesia.

3. Result and Discussion
The research method is conducted by analysis the results of physical tests on RAP, extracted RAP (RAP aggregate), and fresh aggregate. The laboratory physical tests used were aggregate identity and shape, specific gravity & absorption, sieving analysis, and loose & compacted unit weight. All test results on those materials were compared in order to get important information about factors’ affecting the lack of asphalt mixture using RAP materials. The RAP material used in this research was collected from Tegal section of Java Pantura Road in Indonesia.

3.1. Identity and Shape of RAP Materials
Figure 1 shows the RAP material used in this research that collected from Pantura road, Tegal, Indonesia. Figure 1 b and 1 c also show RAP materials collected from Cirebon [7] for comparison with RAP collected from Tegal. Color of RAP was grayish at dry condition or darker at wet condition, whereas Cirebon RAP looked browner. The color of RAP is not black because it was partially uncoated aggregates due to milling process. The RAP particles varied in size with nominal size was about 25 mm. This is an ideal size of asphalt concrete (AC) or hot rolled sheet (HRS), the popular asphalt mixture used in Indonesia. AC is a dense-graded mixture that normally used in rural road pavements, and HRS is a gap graded mixture that normally used in urban road pavements. The bitumen content of RAP was found to be about 4.16%. Bitumen content of RAP was found about 6.7% (Herman, 2004). It can be understood that the bitumen content will depend upon the type of mixture source. Normally bitumen content of AC will be lower than HRS. It is noted that RAP materials collected from stockpile can be combination of two or more mixture types. The water content of RAP was found to be about 1.3%. This water can come from trapped water in the pavement, or due to rainwater when stock in open area. Information on water content of RAP is important to understand the additional mixing water in the cold mix method. Property of aged bitumen of RAP was found to be low penetration i.e. 19.8, and it was found to be less ductile [8].

The result of observation on the RAP formation can be seen in Figure 2. It can be grouped at least into 6 formations, i.e. (1) single coarse or medium particle without mastic, (2) single coarse or medium particle coated partially by mastic, (3) single coarse or medium particle with coated fully by mastic, (4) coarse particles coated fully by mastic, (5) mastic formed combination of medium and fine aggregate, filler, and bitumen, and (6) mastic formed combination of fine aggregate, filler, and bitumen. Later these RAP formations are important to open understanding of RAP mixture properties.
Figure 1. Photograph of original RAP materials collected from (a) Tegal and (b,c) Cirebon (Widiyanto, 2013). Photographs in middle and bottom row are RAP particles retained in certain sieving size.

Figure 2. The Formation of RAP

Table 1 shows the flakiness and elongation test results of coarse aggregates. Three types of aggregate were tested i.e. RAP, RAP aggregate after extraction test, and fresh aggregate. All aggregate types were found to be not flaky and elongated, and then it was classified as uniform dimension. As seen in Table 1 that RAP aggregate is more flaky and elongated than RAP. It can be understood that the presence of aged bitumen on the aggregate surface makes RAP is more rounded. This fact is supported by flakiness and elongated index in which RAP aggregate values are higher than RAP values. It is noted that the higher the index the aggregate shape is more flaky and elongated. The flakiness and elongated index of all aggregates meet the specification (max 25%).
Table 1. Flakiness and elongation test results of RAP, RAP aggregate and fresh aggregate

| Property             | RAP  | RAP Aggregate | Fresh Aggregate | Specification |
|----------------------|------|---------------|-----------------|---------------|
| Flakiness            | 0.743| 0.285         | 0.286           | 0.593         |
| Elongation           | 0.800| 0.285         | 0.067           | 0.796         |
| Classification       | Uniform dimension | Uniform dimension | Uniform dimension |
| Flakiness Index (%)  | 18.50| 20.73         | 17.89           | max 25        |
| Elongated Index (%)  | 19.92| 23.58         | 18.13           | max 25        |

3.2. Specific Gravity and Absorption of RAP Materials

Table 2 shows the results of specific gravity (SG) tests of RAP, RAP aggregate and fresh aggregate (FA) materials. RAP aggregate is aggregate resulted from extraction test. Fresh aggregate properties are included for benchmark value. Aggregate specific gravity can be defined as a weight ratio between aggregate and water at similar volume. SG value of aggregate will affect value of density. In term of RAP materials which contain aggregate and aged bitumen, the density of RAP will be affected by their both component SG and their composition. It can be understood that the presence of aged bitumen will reduce RAP density. SG test is usually followed by absorption test i.e. the aggregate ability to absorb water into their pores. The absorption value of aggregate represents ability to absorb bitumen and adhesive strength of aggregate.

There are three types of aggregate SG i.e. bulk, saturated surface dry (SSD), and apparent SG. The difference between these three types of SG is in terms of weight and volume assumption used. Bulk and apparent SG use dry weight, while SSD SG uses weight of saturated surface dry aggregate condition. Bulk and SSD SG use total aggregate volume included solid, impermeable, and permeable part, while apparent SG do not account the permeable volume part. This assumption causes bulk SG value will be lowest, whereas apparent SG value will be highest.

In Table 2 show that the values of apparent SG are highest and bulk SG is lowest for all tested materials. These results meet the described theory. It was found that the SG of RAP aggregate was higher than RAP. It can be understood that the SG of RAP is combination SG of the old aggregate and the aged bitumen, in which the SG of aged bitumen is lower than aggregate. The SG of RAP aggregate was also found to be lower than the SG of FA. This finding can be described that it may the SG of FA is originally better than RAP aggregate, or there still presence the rest of aged bitumen trapped in the inside of RAP aggregate pores. Based upon this discussion it can be concluded that the SG of RAP or RAP aggregate will be potentially lower than fresh aggregate. It is known that SG will affect to the dry weight, and then it will affect density.

SG of RAP was also found different character than fresh aggregate. It is normally SG of aggregate will increase with higher particle size, because the accretion of aggregate weight is higher than the accretion of water weight. SG of FA and RAP aggregate follow this rule as shown in Table 1. However RAP has different unique character, the highest SG values were found to be the medium size particle (5-10 mm), not coarse aggregate (10-20 mm). The SG of RAP will be affected by the RAP mastic clusters that contain combination of aged bitumen and fine aggregates. In this case, it may the RAP mastic clusters is more distributed and attached on the aggregate size of 10-20 mm.

Specific gravity and absorption test were conducted in one package. Values of aggregate absorption will be affected by the wide of aggregate surface. It can be understood that the finer aggregate will have wider aggregate surface. Again the RAP materials have different character compare to other aggregate. The absorption of RAP medium fraction is less than the coarse fraction. This fact can be described in similar way with the fact of RAP SG. The coarse fractions can be actually shaped as the
RAP mastic clusters that contain combination of aged bitumen and fine aggregates. These fine aggregate parts induce the coarse fraction having higher absorption value.

The absorption of RAP was also found to be lower than RAP aggregate and fresh aggregate. This fact is caused by the aged bitumen coat partially or fully aggregate surface. This aged bitumen obstructs the water absorption process to the RAP pores. The value of aggregate absorption can be used to estimate aggregate absorption to bitumen. There is a term to indicate aggregate absorption to bitumen, i.e. effective specific gravity which is calculated as average value of bulk and apparent SG. The low RAP absorption shows two aspects, i.e. (1) the need of RAP to bitumen is lower, and (2) adhesion (coating) of RAP materials is lower when compared to fresh aggregates.

### Table 2. Specific gravity test results of RAP, RAP aggregate and fresh aggregate

| Properties | 10 – 20 mm | 5 – 10 mm | < 5 mm |
|------------|------------|-----------|--------|
| Bulk SG    | 2.060      | 2.433     | 2.937  |
| SSD SG     | 2.090      | 2.277     | 3.014  |
| Apparent SG| 2.122      | 2.322     | 3.183  |
| Absorption (%) | 1.416 | 1.506 | 2.632 |

Note: RAP agg is aggregate from RAP after extracted, whereas FA is fresh aggregate

### 3.3. Gradation of RAP Materials

Gradation is particle size distribution of aggregate. In terms of RAP that having unique particle shapes, RAP gradation is very interesting material to be discussed. First, RAP is combination of two materials, i.e. aggregate and aged bitumen. It will come up with a question, “which one as a true gradation: RAP or RAP aggregate?” Second, RAP contains mastic cluster part or fine particles attached to the coarse aggregate surface. It will come up a problem that a coarse aggregate size will be greater due to the attached fine aggregate. Third, is RAP gradation used for hot and cold mix system similar? This question arises because in hot mix system, the aged bitumen will normally be dissolved, but in cold mix system, the aged bitumen will not be dissolved in early age. In the cold mix asphalt using RAP and additional fresh bitumen, there needs research to explore the process of integration between old and new bitumen.

As seen in Figure 3, the gradation of RAP was investigated in three versions, i.e. gradation produced by dry sieving and wet sieving, and RAP aggregate resulted from the extraction test. Wirtgen [9] suggested using wet sieving system for RAP materials due to the attached fine aggregates problem. It was found that the wet sieving is finer than the dry sieving. The difference between these two sieving methods looks not significant. However, the recommendation of Wirtgen [9] is true in terms of getting the real particle size distribution, not cluster size distribution.

It was also found that the RAP aggregate gradation was much finer than RAP gradation. It is noted that RAP aggregate was generated by extracting the RAP particles. This fact can be understood because the aged bitumen attached to the RAP aggregate has been dissolved. The RAP aggregate gradation curve can be utilized to understand aged bitumen or mastic fine cluster distribution on the RAP gradation. As example, it can be estimated that the aged bitumen or the mastic is approximately 10% attached to the 10mm RAP particle size and 6% on the 1mm RAP particle size. It is found that
the RAP aggregate gradation meet the AC-BC (Asphalt Concrete – Binder Course) specification envelope. However the RAP gradation is little bit coarser than the lower envelope border of AC-BC specification. It can be than understood that the source of this RAP from asphalt concrete pavement types.

There has been well understood that aggregate gradation can be grouped as dense, gap, or uniform graded. The way to determine the aggregate gradation grouped is by calculates value of Cu (Coefficient of Uniformity) and Cc (Coefficient of Curvature). It will be dense-graded if Cu>15 and 1<Cc<3, or uniform graded if Cu<15 and 1<Cc<3, gap graded if Cu>15 and Cc<1. Calculation results of these Cu and Cc values for RAP and RAP aggregate can be seen in Figure 3. It can be concluded that both RAP and RAP aggregate are dense-graded because their coefficient of uniformity is included in Cu > 15 and their coefficient of curvature is included in 1<Cc<3. This finding confirms that the source of RAP used is asphalt concrete, not hot-rolled sheet.

![Gradation of RAP](image)

**Figure 3. Gradation of RAP**

### 3.4. Unit Weight of RAP Materials

Unit weight can be expressed as a ratio between weight and volume. It can be used to indicate the degree of density of a material. The higher the unit weight the higher the density. In this research the unit weight was investigated using fives conditions, i.e. loose, dense by stick, dense by shake, dense using standard Proctor, and dense using modified Proctor. The loose condition means the materials are introduced into the mould without any treatment. Dense by stick means the materials is pierced using stick before measured, whereas dense by shake means the materials are shake before measured. Unit weight using standard and modified Proctor means maximum dry density value after compaction process on the wet materials. The materials used for this test are RAP, modified gradation RAP, RAP aggregate, and fresh aggregate. As seen in Table 3 unfortunately not all data is available. However the
data is enough to keep the results trend. It is supposed that the order of unit weight values for the particular material from low to high is loose, dense by stick, dense by shake, standard Proctor, and modified Proctor. It can be understood because the order represents the amount of the compaction energy given. In this case, RAP material has similar behavior with other materials. Whereas the order between those four materials from low to high is RAP, modified gradation RAP, RAP aggregate, and then fresh aggregate. RAP material has lowest value of unit weight. Modification of the RAP gradation can elevate the unit weight, but it is still lower than RAP aggregate or the aggregate.

| Property                        | RAP   | Modified Gradation RAP | RAP Aggregate | Fresh Aggregate |
|---------------------------------|-------|------------------------|---------------|-----------------|
| Loose unit weight               | 1.418 | NA                     | 1.713         | NA              |
| Dense unit weight by pierced using stick | 1.534 | NA                     | 1.854         | NA              |
| Dense unit weight by shake       | 1.568 | NA                     | 1.876         | NA              |
| Dense unit weight using standard Proctor | 1.640 | 1.701                  | NA            | 2.110           |
| Dense unit weight using standard Proctor | 1.677 | 1.770                  | 2.010         | 2.261           |

Based upon these unit weight test results, it is needed to understand the orientation of the particles during compaction for RAP materials. Understanding the effect of aged bitumen coating the surface of the particles is demanded in order to open the knowledge of compaction characteristics of RAP materials. Tests of particle orientation investigation during compaction process have been conducted. There were used two materials, i.e. RAP and extracted RAP. The material was compacted in a mould using vertical stress load. Three stone agents were put inside the material, i.e. on top, middle, and bottom of the mould. The position of stone agents before and after compaction was then monitored.

Figure 4 show the test results for RAP material (left) and extracted RAP (right). Blue point was the initial position of stone agent before the compaction process was started, whereas red point was the end position of stone agent after compaction process finish. As seen in the Figure 4 that for both materials the stone agent 3 located in the bottom of mould moved less dynamic if it is compared to agent 1 and 2. It can be understood that the effect of compaction load energy in the bottom of mould is lowest, and direction of mass movement is from the top to the bottom. It was recorded that the initial height of material was 14mm and the final height of material was 12.5mm (RAP) and 11mm (Extracted RAP). It means for RAP, the mass material on the top part go down about 1.5mm in average. The distance of mass movement decreases from top to bottom.

The discussion of aggregate orientation difference between RAP and extracted RAP is very interesting. The influence of aged bitumen will be identified from the provided difference. As seen in Figure 4, some important information can be explored. First, the orientation patterns of stone agents between RAP and extracted RAP are similar in which the stone agent 1 and 2 move more dynamic and opposite compared to stone agent 3. This fact gave evidence that the testing has been carried out correctly. Second, the movement distances of agent 1 and 2 in the extracted RAP mould were longer than in the RAP mould. Movement direction can be analyzed as horizontal, vertical, and their resultant. In this case, those three movement types of the extracted RAP were longer than the RAP.
This finding gives information that the presence of aged bitumen on the RAP material surface obstructs the particle movement. In the rule of the compaction process if the aggregate particles are difficult to move, it will cause the density of aggregate is low.

![Figure 4. RAP Particle Orientation during Compaction Process](image)

4. Conclusion

RAP is road material aggregate having combination component of old aggregate and aged bitumen with at least 6 shape formation combinations. Based upon flakiness and elongation test results the RAP material particles are classified as uniform dimensions. The presence of aged bitumen on the aggregate surface makes RAP is more rounded, but it cannot change the aggregate shape classification. The specific density and absorption value of RAP is potentially lower than fresh aggregate. The presence of aged bitumen affects the specific gravity combination between old aggregate and aged bitumen decrease. This presence of aged bitumen also obstructs water absorption process to the RAP pores. RAP can be grouped as dense-graded based upon their Cu and Cc values. RAP gradation is coarser than RAP aggregate gradation. The presence of aged bitumen does not change the RAP gradation type, but affect it coarser. The unit weight of RAP aggregate is higher than the unit weight of RAP and lower than the unit weight of fresh aggregate. The presence of aged bitumen on the RAP material causes the unit weight of RAP decrease. The unit weight of compacted RAP decrease due to 2 aspects, i.e. (1) the specific gravity of RAP is lower, and (2) the presence of aged bitumen obstructs the RAP particle movement.

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