Mixture design consideration for foamed asphalt using RAP materials

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Abstract. The use of reclaimed asphalt pavement (RAP) in cold foamed asphalt mixture can decrease the need of fresh aggregate and bitumen, reduce fuel consumption and CO2 production. A cold foamed asphalt using RAP material is a unique asphalt mixture. Performance of these materials will be affected by mix design process. This paper discusses about mix design consideration for these mixture especially to set the aggregate and foamed bitumen properties properly. The method used to propose mix design consideration in this paper is by analyzing results of the long research work about foamed asphalt and RAP materials in laboratory. It is found that the optimum value of foamed bitumen properties is affected by bitumen grade, foam characteristic, water content at foaming, and temperature of bitumen. The best aggregate properties should consider the plasticity index, aggregate gradation, and the percentage of RAP proportion. The percentage of RAP proportion influence specific gravity, mixture density, volumetric characteristic, and mixture performance.

1. Introduction
The Report of TRL611 [1] published a classification for cold recycled materials. There are three families of cold recycled materials. Materials mixed with hydraulic are called as fully hydraulically bound. Materials mixed with visco-elastic binder are named as fully visco-elastically bound. Recycled materials mixed without binder are mentioned as unbound materials. Cold recycled mixture with different binder types and curing behavior can be categorized by areas within these three families. Four material types i.e. quick hydraulic (e.g. using cement), slow hydraulic (e.g. using lime), quick viscoelastic (e.g. using bitumen and cement), and slow viscoelastic (e.g. using bitumen and lime) fall into these three material families. Based on this TRL classification, asphalt using foamed bitumen and reclaimed asphalt pavement (RAP) materials will be closer to the viscoelastic behavior either slow or quick viscoelastic families.

The use of RAP in cold foamed asphalt mixture can decrease the need of 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 replaced the fresh aggregate for road pavement construction with satisfied performance [2]. However, the properties of foamed asphalt mixture using RAP is unique. This mixture is superior in environment issues but inferior in properties issues. This mixture should be designed as properly as possible, included in the mix design process. This paper reports the results of research exploring the main consideration used
for mix design of foamed asphalt using RAP. The objective of research is to open understanding factors affecting the mixture performance using RAP.

The laboratory mix design for bituminous materials is conducted to achieve the optimum proportions of material components that fulfill the mixture specification. The amount and properties of all mixture components should be combined economically to yield optimum mixture properties. According to the Asphalt Institute (1988) the important things to consider in the asphalt mix design are:

- The bitumen content to maintain durability and fatigue cracking resistance of mixture,
- The stability and stiffness modulus of mixture to withstand deformation caused by traffic loads.
- The void percentage to maintain the mixture from flushing, bleeding, or loss of stability during secondary compaction under traffic loading.
- Mix workability during mixing, laying and compaction process.

2. Research method

The method used to propose mix design consideration in this paper is by analyzing results of the long research work about foamed asphalt and RAP materials. There are two main researches with topics of the effect of foamed bitumen properties to cold mix asphalt performance, and study of mixture density and stability of cold mix asphalt using RAP materials.

This research focus on mix design consideration in term of two aspects namely determines the optimum foamed bitumen properties and aggregate properties considerations. First aspect was conducted by produce foamed bitumen using laboratory equipment i.e. Wirtgen WLB 10, and investigated the foamed bitumen properties e.g. the maximum expansion ration and half-life. Second aspect by investigated the properties of RAP materials using related testing, e.g. specific gravity, sieving analysis, compaction, Marshall test, and Pavement Facility Testing. The resulted data tests were then analyzed to explore the main consideration of mix design process for asphalt using foamed bitumen and RAP.

The considerations used in this mix design refer to these following procedures:

- CSIR procedure [3]. This procedure is widely implemented in many cold recycling projects in South Africa.
- Lee and Kim procedure [4]. This procedure developed specifically for cold-in-place rehabilitation (CIPR) using foamed bitumen.
- Wirtgen procedure [5]. This procedure developed the method to select the optimum properties of foamed bitumen in order to produce the best foamed asphalt mix performance.

3. Discussion

3.1. Consideration to select the optimum properties of foamed bitumen

Three important stages in order to select the optimum properties of foamed bitumen can be described as follows. Firstly, exploring the characteristic of foamed bitumen, i.e. maximum expansion ratio (ERm) and half-life (HL) values at some temperatures and water contents variations for several selected bitumen penetration grades; Secondly, determining the best bitumen penetration and temperature at foaming process using the ERm vs HL curve; Thirdly, determining the best foaming water content (FWC) using ER-HL vs FWC curve and selected foamed bitumen specification. It can use either CSIR [3], Lee and Kim [4], or Wirtgen procedures [5].

It has been widely understood that foamed bitumen with higher maximum expansion ratio and longer half-life will have better quality, and asphalt mix properties using it will have better performance. Unfortunately, maximum expansion ratio and half-life have inverse values, and this makes it difficult to determine the optimum properties of foamed bitumen. Based on the experiences, foamed bitumen which has good properties and can function effectively usually has ERm values
between 10 and 15, which may be resulted by using foaming water content between 1 and 3 percent. Table 1 shows various guidance of minimum application of ERm and HL limit based on empirical experiences.

Table 1. The Guidance of ERm and HL values.

| Method                  | Minimum ERm | Minimum HL |
|-------------------------|-------------|------------|
| CSIR [3]                | 10          | 12 seconds |
| TRL Report 386 [6]      | 10          | 10 seconds |
| Wirtgen [5]             | 8           | 6 seconds  |
| Chiu and Huang [7]      | 8           | 8 seconds  |

Wirtgen [5] has proposed an easy method to determine the optimum properties of foamed bitumen. This method is not very rigorous but very suitable for field applications that require speed in making decisions. Wirtgen method use values data of ERm and HL in various FWC, and the optimum FWC is selected based on the minimum application of ERm and HL limit. Figure 1 shows the results of foaming characterization under laboratory foaming plant investigation using bitumen grade pen 50/70. The ERm and HL have been investigated at a range of temperature and foaming water content values. The foamed bitumen properties produced using bitumen pen 50/70 is investigated at temperature of 140°C, 160°C and 180°C and at FWC of 1%, 2%, 3%, 4%, and 5%. As shown in the figure 1, Foamed bitumen produced at a temperature of 160°C are determined as the best properties because the ERm values at temperature of 160°C for those 5 variation of FWC are higher than other temperatures, although the values of HL are not the highest. After determining the best temperature then the next step is to determine the optimum value of foaming water content at the best temperature as shown in figure 2.

Jenkins [8] therefore introduced the Foam Index (FI) concept as a function of ERm and HL in order to find the optimum FWC. Values of FI will increase when values of ERm and HL increase. Optimum FWC could therefore be determined using this FI parameter. Foamed bitumen with high foam index value is indicated to have good properties. The optimum properties of foamed bitumen could therefore
be determined from the full range of foaming water content variation at one temperature. However, as shown in figure 2, the relationship between FI and FWC has no optimum value, FI values rises continually with the increase of FWC values. In this case therefore the optimum FWC was selected using Wirtgen method. The optimum foaming water content is decided to be around 1.9% as shown in figure 2.

![Graph showing relationship between FI and FWC](image)

**Figure 2.** Selecting the optimum value of FWC.

The considerations in determining the bitumen grade for foamed asphalt is actually no different for hot mix asphalt. Both types of mixture are very concerned to the aspect of traffic load type (heavy or light traffic) and regional climate (hot or cold region). It is widely understood that for roads with high traffic load or roads in a hot climate requires bitumen with low penetration. It should be noted that in foamed asphalt mixture, the bitumen grade type will also significantly influence the binder distribution in the mixture during the mixing process, which affect to the stiffness value of foamed asphalt mixture. Thus, in selecting the usage of bitumen grade type of foamed asphalt must consider together the influence of bitumen penetration on the bitumen distribution and on the mixture performance in the field.

It should also be highlighted that bitumen grade types affect the values of viscosity and stiffness modulus. Bitumen with low penetration values will generally have high viscosity and stiffness modulus. Thus, a foamed asphalt generated using hard bitumen (low penetration) will have two sides different consequences. First, it will have negatively consequence because hard bitumen (high viscosity) will reduces workability during mixing. Second, it will have positive consequence because hard bitumen (high stiffness) will enhance layer stability in pavement structure. A foamed asphalt generated using soft bitumen (high penetration) will have opposite situation. Therefore, in the determination of bitumen grade type for foamed asphalt mixture must also consider two important things, i.e. the capability of mixer and the climate in where the road is located. A foamed asphalt produced using hard bitumen is recommended to use a high speed mixer so that the bitumen distribution is good and evenly distributed; but if there is no high speed mixer, it is recommended to use a soft bitumen grade. On the other hand, if a foamed asphalt mixture is to be implemented in a cold region, it is recommended to use higher bitumen penetration because the distribution of bitumen will be more significant to develop stiffness modulus value at low temperature; however, in the non-cold region, a harder bitumen grade type will more suitable because the stiffness modulus of mixture will more significant to develop the stability of foamed asphalt mixture at high temperature.
It should also be noted that consideration to determine the usage of bitumen grade type in the mixing process can be seen using different angles. In order to generate foamed bitumen with high ERm, it is recommended to implement high temperature foaming (160°C - 180°C) for hard bitumen (Pen 50/70) and to implement low temperature foaming (140°C - 160°C) for soft bitumen (Pen 160/220). In this case the influence of bitumen temperature foaming on the bitumen or foamed bitumen viscosity should also be considered properly.

3.2. Aggregate properties consideration

There are at least four steps to prepare aggregate in the mix design process. First, ensure that plasticity index of aggregate is low. Second, ensure that aggregate gradation meet the specification for foamed asphalt e.g. as developed by [9], and filler content should not be less than five percent. Third, the maximum dry density (MDD) and optimum water content (OWC) is determined using Proctor procedure both standard and modified type. Fourth, aggregate sample for about 3-5 batches is prepared carefully, check initial water content of RAP aggregate, and the usage of cement or lime (if needed) should replace the equivalent percentage of mineral filler.

It can be seen that The RAP gradation exhibits coarser according to the recommendation of ideal grading specification for foamed asphalt mixture [9]. The proportion of filler is approached to be 0.3% (using dry method sieving) or 2.1% (using washing method sieving). It is noted that minimum need of filler for foamed asphalt mixture is about 4.5%. As shown in the figure 3 the gradation of RAP was investigated using dry sieving and wet sieving method. 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 is true in terms of getting the real particle size distribution, not cluster size distribution.

The percentage of RAP proportion should be properly considered. First, the specific gravity of RAP is lower than fresh aggregate. Second, the density of RAP is lower than fresh aggregate. Third, the volumetric characteristic of asphalt mixture using RAP is worse than using fresh aggregate. Fourth, the performance of asphalt mixture using RAP is worse than using fresh aggregate.

Table 2 shows the specific gravity (SG) test of RAP, RAP aggregate and fresh aggregate (FA) materials. RAP aggregate is aggregate resulted from extraction test. 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. Absorption value of aggregate represents ability to absorb bitumen and adhesive strength of aggregate.

Table 3 shows density test results of several materials using standard and modified Proctor. The materials used for this test are RAP, modified gradation RAP, RAP aggregate, and fresh aggregate. It is supposed that the order of density values 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 density. Modification of the RAP gradation can elevate the density, but it is still lower than RAP aggregate or fresh aggregate.

Table 4 shows the comparison between volumetric performance of foamed asphalt specimens using RAP and fresh aggregate. It can be seen that the specimens using fresh aggregate have a lower void volume. It means that fresh aggregate makes the specimen more compactable than RAP aggregate. The excellence of fresh aggregate can be observed at both VMA and VIM values and at three compaction levels i.e. 15, 30, and 45 passes.

Figure 4 shows rutting performance of foamed asphalt using RAP under Pavement Facility Test. In this case, two different mixture types are compared, namely foamed asphalt using 50% of RAP (50% using fresh aggregate) and using 75% of RAP (25% using fresh aggregate). The surface rutting of the 7 point locations in average along the wheel path of the trial pavement sections has function to the
load applications. Rutting was developed to varying degrees in these two types of section. It is found that in terms of the amount of rutting, the mixtures using 50% of RAP is better than using 75%.

![Figure 3](image-url). Gradation of RAP sieved using dry and wash method.

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

| Properties       | Particle size | 10-20 mm | 5-10 mm | < 5mm |
|------------------|---------------|----------|---------|-------|
|                  | RAP | RAP | FA | RAP | RAP | FA | RAP | RAP | FA |
|                  | Agg  | Agg  |    | Agg  | Agg  |    | Agg  | Agg  |    |
| Bulk SG          | 2.060 | 2.243 | 2.937 | 2.109 | 2.192 | 2.762 | 1.937 | 1.968 | 2.565 |
| SSD SG           | 2.090 | 2.277 | 3.014 | 2.133 | 2.227 | 2.841 | 1.976 | 2.016 | 2.688 |
| Apparent SG      | 2.122 | 2.322 | 3.183 | 2.170 | 2.272 | 3.000 | 2.016 | 2.068 | 2.926 |
| Absorption (%)   | 1.416 | 1.506 | 2.632 | 1.117 | 1.611 | 2.878 | 2.041 | 2.459 | 4.822 |

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

### Table 3. Density of RAP using Standard and Modified Proctor.

| No. | Method      | Density (gr/cm³) |
|-----|-------------|------------------|
|     |             | RAP | Mod grad RAP | RAP Agg | Fresh Agg |
| 1   | Standard Proctor | 1.640 | 1.701 | NA | 2.110 |
| 2   | Modified Proctor | 1.677 | 1.770 | 2.010 | 2.261 |
Table 4. Values of VIM, VMA, and VFA for Foamed Asphalt Specimen using RAP and Fresh Aggregate

| Pass | RAP | Fresh Agg |
|------|-----|-----------|
|      | VIM (%) | VMA (%) | VFA (%) | VIM (%) | VMA (%) | VFA (%) |
| 15   | 14.24 | 19.13 | 25.56 | 12.8 | 17.83 | 28.21 |
| 30   | 13.53 | 18.45 | 26.67 | 12.04 | 17.01 | 29.22 |
| 45   | 12.58 | 17.56 | 28.36 | 10.74 | 15.92 | 32.54 |

Figure 4. Rutting performance of Foamed Asphalt Using RAP in Longitudinal profiles.

4. Conclusions
The optimum foamed bitumen properties are affected by bitumen grade, maximum expansion ratio and half-life, foaming water content, and bitumen temperature when foaming. The best aggregate properties should consider the plasticity index, aggregate gradation, and the percentage of RAP proportion. The percentage of RAP proportion influence specific gravity, mixture density, volumetric characteristic, and mixture performance.

Acknowledgments
This project is financially supported by the Direktorat Riset dan Pengabdian Masyarakat Direktorat Jenderal Penguatan Riset dan Pengembangan Kementerian Riset, Teknologi, dan Pendidikan Tinggi (Indonesian Government) with contract number: 211.4/A.3-III/LPPM/V/2017, and the facilities support of Universitas Muhammadiyah Surakarta.
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