Characteristics of masonry block that utilizes reclaimed asphalt pavement and waste cooking oil as the binder

I Nyoman Arya Thanaya[1,*], *I Nyoman* Karnata Mataram[1], and *Bayu* Setiawan[1]

[1]Department of Civil Engineering, Universitas Udayana, Bali, Indonesia

Abstract. The availability of natural aggregate is getting limited, therefore it is required new alternative materials to substitute natural aggregates. Within this experiment reclaimed asphalt pavement (RAP) was used as masonry block with waste cooking oil as the binder. The objective of this experiment was to analyze the RAP asphalt content and aggregate gradation; and the samples characteristics particularly the compressive strength of masonry block minimum of 25 kg/cm^2 that meet the Indonesian national standard SNI-03-0348-1989. The asphalt content of the RAP was initially extracted and tested for its aggregate gradation and specific gravity. The RAP was added 20% sand and a certain amount of waste cooking oil and evenly mixed. After that the mixture was compacted in a mould with a Marshall hummer, with compaction cycles for 15, 25, and 35 times where each cycle consists of 3 even blows. The size of the compacted samples were 20x10x8cm. After the samples were taken out from the mould, they were heated in an oven for 12 and 24 hours at 160°C and 200°C. It was found that the minimum waste cooking oil content required 4%. The best compressive strength was found on samples compacted at 15 compaction cycles and heated at 200°C for 24 hours. The un-soaked compressive strength was 80.5 kg/cm^2 and 68.67 kg/cm^2 for the soaked samples. In general the compressive strength well met the minimum 25 kg/cm^2. Other best characteristics was found on samples heated at 160°C for 12 hours, with lowest water absorption of 5.64% and porosity of 4.53%. The Initial Rate of Suction (IRS) was 0,25~0,45 kg/m^2.minute.

1 Introduction

In line with time, there has been less availability of natural aggregate materials. This is among other due to the population growth that requires an increase of houses as people prime need. Many walls of houses are constructed from masonry blocks produced from natural aggregates. Utilizing waste materials for masonry block with asphalt as the binder had been done by some researcher [1-4]. Masonry blocks with a binder using waste vegetable oil had also been done other researcher [5]. The samples were found to meet the

* Corresponding author: aryathanaya@unud.ac.id

minimum compressive strength required in the United Kingdom (UK), that is minimum of 2.8 MPa or 28 kg/cm^2 [6]. The sample size was 10x10x80cm.

Similar works had also been done in Indonesia with similar sample size as mentioned above with asphalt binder incorporating construction demolition waste-CDW [7]. Meanwhile, works that utilize CDW materials but with different material proportion, with a binder from waste cooking oil taken from local food seller had also been done [8, 9]. The samples that were produced with different compaction level and heat curing regime, generally the samples well met the minimum compressive strength required, i.e., 25 kg/cm^2 in line with Indonesian standard [10].

As an alternative material to substitute natural aggregate, within this experiment, material from road pavement cold milling (reclaimed asphalt pavement-RAP) was used. The nature of the waste material was commonly not homogeneous. The RAP was bound with waste cooking oil taken from local food processing activities. The size of the samples was 10x20x8cm, that is the actual minimum size in line with Indonesian standard [10]. This size was significantly larger, twice than previously produced, and therefore it requires a different method of production.

The main experiment aim was to analyze samples characteristics particularly the compressive strength of the masonry block, that should meet a minimum of 25 kg/cm^2 in line with the Indonesian National Standard [10].

2 Literature review

2.1 Masonry block aggregate gradation

Unlike asphalt-aggregate mixture, commonly there is no particular aggregate gradation on masonry block. The requirement is mostly on its minimum compressive strength. Occasionally maximum water absorption is mentioned for higher block quality [10]. Although aggregate gradation is not specifically mentioned, it is required a stable and compact shape of the block during production and handling [3]. Therefore aggregate proportion needs to be tried in line with compaction level applied. Commonly it is required aggregate gradation with sufficient fines content when relatively low compaction level to be applied [4].

2.2 Polymerization of waste cooking oil

Waste cooking oil (WCO) is not homogeneous as it can contain various types of fats and oils. This depends on the food fried. When the waste cooking oil is used as the binder of aggregates for masonry block, it requires heat curing. During heating of the compacted masonry blocks with WCO as the binder, the WCO would undergo volatilization, oxidation, hydration and in particular polymerization [11].

Polymerization of fats and oils depends on their iodine value, which is the value of the amount of iodine in grams that is absorbed by 100 ml oil. The iodine value indicates the amount of unsaturated fatty acids. When a fatty acid that is missing any hydrogen atoms it is grouped as being unsaturated. This covers all monounsaturated and polyunsaturated fatty acids [12]. For example, the iodine value of coconut oil is 8.6, beef tallow 49.3, sunflower oil 133, and fish oil 151 [13].

Higher iodine value means a higher amount of unsaturation, where the oil will be less stable and more easily undergoes oxidation and production of free radicals. Oils with high iodine value oils are easier affected by oxidation and polymerization. Polymerization is a process that is irreversible which causes the fatty acids to become hard, insoluble, plasticlike or gum-like solids [12]. During the polymerization process, smaller molecules merge to become larger molecules. The polymerized waste cooking oils in masonry blocks would act as a binder of the aggregates [3].

2.3 Volumetric calculation

The volumetric block parameters were calculated using Eq. 1, 2 and 3. The SGmix (max theoretical density) of the mix was calculated using Eq. 1.

$$SG_{mix} = \frac{100}{\frac{\%\ a}{SG_a} + \frac{\%\ b}{SG_b} + \frac{\%\ c}{SG_c} + ... + \frac{\%\ WCO}{SG\ WCO}} \qquad (1)$$

Note: (% by weight of total mix); a, b, c, …are component of the mixtures [14].
The density was calculated using Eq. 2.

$$Density = \frac{weight\ in\ air}{volume}$$

$$Density = \frac{weight\ in\ air}{(weight\ SSD - weight\ in\ water)} \qquad (2)$$

Note: Weight SSD is the weight of sample after weighing in water then towel dried [15].
The porosity can be calculate using Eq. 3 [16].

$$Porosity\ (\%) = \frac{SG_{mix} - D}{SG_{mix}} \times 100\% = \left(1 - \frac{D}{SG_{mix}}\right) \times 100\% \qquad (3)$$

2.4 Initial Rate of Suction (IRS)

IRS test was carried out by soaking the sample in water with 3 mm depth for 60 seconds. The weight of water absorbed is divided by the area in soaked water, as shown in Equation 4 [17].

$$IRS = \frac{weight\ of\ water\ absorbed\ (kg)}{area\ of\ samples\ soaked\ in\ water\ (m^2.minute)} \qquad (4)$$

IRS indicates the effect of the unit on the sand-cement mortar. Units with high IRS require soaking of the unit in water before bonded with sand cement mortar to avoid high water absorption of the mortar [18].

3 Materials and methods

The materials used was reclaimed asphalt pavement (RAP) form cold milling of road repair works (Fig. 1a) on road section around Denpasar city of Bali, that had been stockpiled at the local authority's material base camp as shown in Fig. 1b. Added materials used was natural river sand locally available. The binder used was waste cooking oil (WCO) from local food seller as shown in Fig. 2 which were not homogeneous where fat may be settled down at the base of a container. The type of WCO used was typical as the one shown in Fig. 2 (a).

(a) (b)

Fig. 1. Cold milling work (a) and RAP stock at a base camp (b).

(a) (b)

Fig. 2. Typical waste cooking oil (WCO), without fat (a) and with fat settled down at the base container (b).

The method involves RAP asphalt content determination by extraction using reflux method [19] as shown in Fig. 3.

Fig. 3. Reflux extraction of RAP asphalt content.

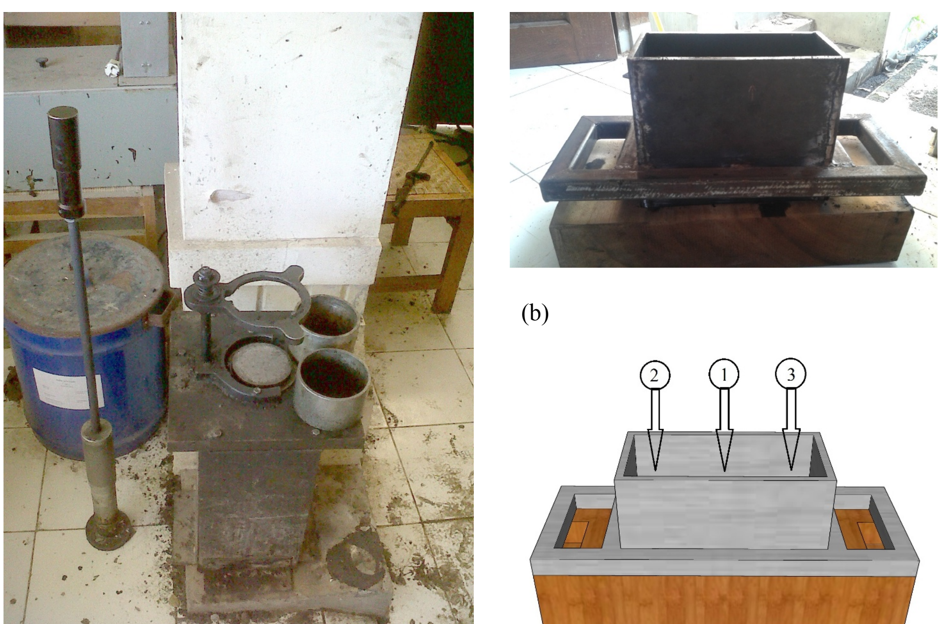
The aggregate from the extracted RAP was sieve to obtain particle size distribution data. The milled RAP was added with various percentage of natural river sand and varied waste cooking oil content. Prior used, the RAP and sand were dried out. The effort had been made to utilize material proportion where the samples have sufficient added sand content and minimum waste cooking oil content that gave the specimen with compact and stable shape during production and handling. Compactness and shape stability of the samples were affected by the level of compaction effort applied.

Table 1. Initial material proportion for 1 sample.

Waste cooking oil content (by weight of RAP) (%)	Weight of RAP (g)	Weight of waste cooking oil (g)	Total weight (g)
4	3600	144	3744
5	3600	180	3780

Table 2. Final material proportion for 1 sample.

Waste cooking oil content (by weight of agg, %)	Weight of RAP (g)	Sand (20% by RAP weight) (g)	Weight of waste cooking oil (g)	Total weight (g)
a	B	c	d=a*(b+c)	e=(b+c+d)
4	3000	600	144	3744
5	3000	600	180	3780



(a) (b) (c)

Fig. 4. The Marshall hummer (a), metal mould (b) and illustration of one cycle compaction with three blows sequence (c).

It had been experienced that when lower compaction level applied the sample should contain sufficient fines [2, 3]. Initial trial on materials proportioned is as shown in Table 1, and the final proportion is shown in Table 2, after several trials. Waste cooking oil content less than 4% by weight of RAP, was found could not hold the aggregate firmly after compaction. The material proportion on Table 2 was found suitable to obtain compact and stable sample shape during handling.

The RAP, added sand and waste cooking oil were proportioned and evenly mixed, then poured into a mold with 3 mm steel base plate and evenly tamped with a 12 mm steel rod. The base size of the mold was 10x20cm. On top of the materials was placed 5 mm steel upper plate. The materials were then compacted using a Marshall Hummer as shown in Fig. 4a. The mold was placed on a wood base during compaction. Compaction was applied in cycles. One cycle consists of three series Marshall Hummer blows with a sequence as shown in Fig. 4c. The compacted samples were de-molded using a jack as shown in Fig. 5a. After that, the samples were heat cured in the oven at 160 and 200°C for 12 and 24 hours. The number of proportioned materials was tried, so the compacted samples would have thickness 8 cm and should have a compact and stable shape (Fig. 5b).

(a) (b)

Fig. 5. The de-moulding of the samples (a), and the shape of the sample that may or may not stable during handling (b).

4 Results and discussion

4.1 The RAP data

The RAP asphalt content was tested using reflux method, was found 5.05 %. The aggregate grading of the extracted RAP is shown in Fig. 6, which shows a relatively continuous grading on the coarser side and instead in gap grading on the finer side. This is taken as data. Unlike asphalt-aggregate mixture, the masonry block has no aggregate grading requirement.

The aggregate extracted from the RAP was tested for its specific gravity as shown in Table 3. This data is needed for determining the specific gravity of the mixture, to enable the calculation of porosity.

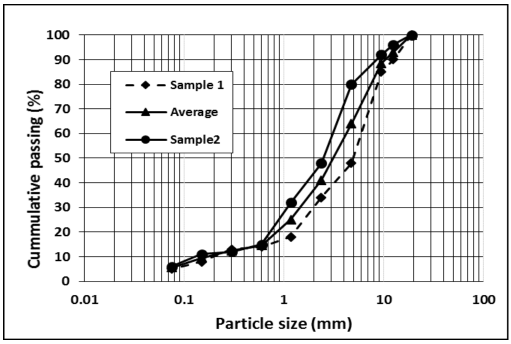


Fig. 6. The reclaimed asphalt pavement (RAP) particle size distribution.

Table 3. Specific gravity of aggregate extracted from the RAP.

Aggregate	Specific gravity (SG)			Effective SG= SG.Bulk+SG.App)/2
	Bulk	SSD	App	
Coarse aggregate from RAP	2.215	2.275	2.357	2.286
Fine aggregate from RAP	2.185	2.246	2.327	2.256
River sand	2.172	2.218	2.277	2.225

4.2 Results of the initial trial

On the initial trial, the RAP only used different waste cooking oil (WCO) content. At WCO content less than 4%, the shape of the samples were found less stable and less compact, although the compressive strength was satisfactory far above minimum 25 kg/cm^2 targeted, as shown in Table 4.

Table 4. Compressive strength of aggregate from initial trial.

Heating temp (°C)	Heating duration (hours)	Waste cooking oil content (%)	Compressive strength (kg/cm^2)
200	12	4	54.17
		5	42.50
200	24	4	61.93
		5	53.83

4.3 Results of the next trial

Results from the next trial where the RAP materials were added with 20% river sand with final material proportion as shown in Table 2.

4.3.1 The compressive strength

The samples compressive strength is the main property of the masonry block. Compressive strength at various compaction cycle and heat curing regime are shown in Fig. 7 for the un-soaked sample, and on Fig. 8 for the soaked specimens (soaked in water for 24 hours). The un-soaked specimens gave higher strength in a range between 30-70 kg/cm^2 that well above minimum 25 kg/cm^2. This is comparable to low-cost fly ash brick [20]. It is logical that the samples with higher compaction level (that cause the specimens denser), and more intense heat curing gave higher value (the WCO binder and the asphalt within the RAP became harder).

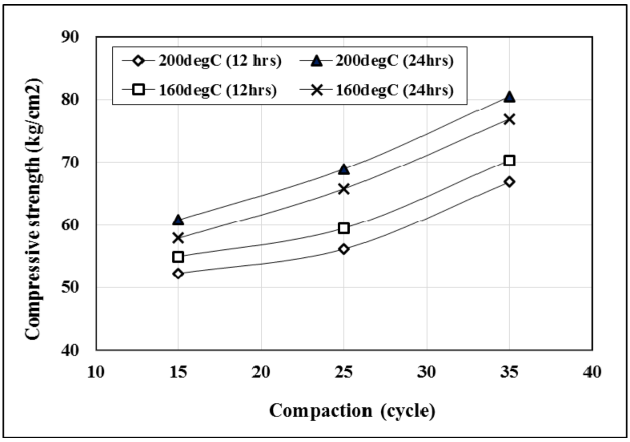


Fig. 7. Un-soaked compressive strength vs. compaction cycle.

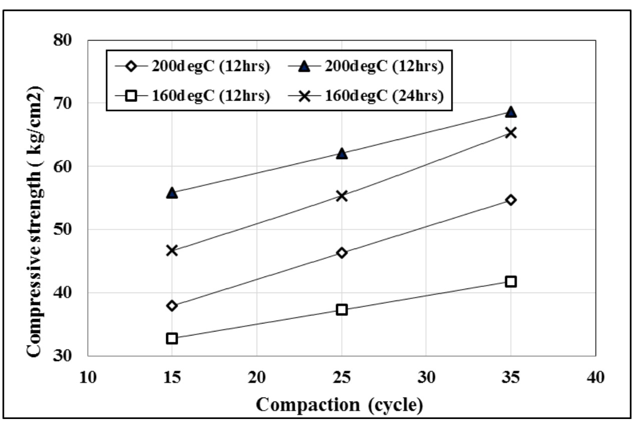


Fig. 8. Soaked compressive strength vs. compaction cycle.

The effect of water soaking was found significant to reduce the compressive strength between 14-28% of the un-soaked samples. The samples with less intense heat curing were more significantly affected by water soaking. Nonetheless, the samples still meet a minimum compressive strength of 25kg/cm^2 [10].

4.3.2 Porosity, water absorption, and initial rate of suction (IRS)

The porosity of the samples was found in line with the compressive strength as shown in Fig. 9. At lower compaction level the density of the samples was lower hence gave higher porosity. The situation is also revealed and with a similar trend on water absorption as presented in Fig. 10 and an initial rate of suction (IRS) shown in Fig. 11. The IRS value was typically similar with common values on masonry blocks, i.e., 0.25-2.0 kg/m^2.minute [18]. On lower quality masonry block, there is no requirement of porosity, water absorption, and IRS. These data are additional data, where samples with higher water absorption and IRS, should be soaked in water before they are used and bonded with sand cement mortar, as they may absorb water content of the mortar that can reduce the bonding ability and durability of the mortar.

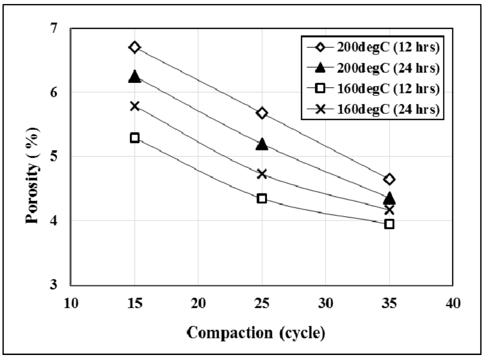


Fig. 9. Porosity vs. compaction cycle.

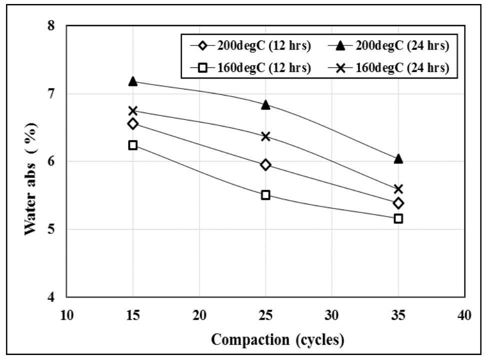


Fig. 10. Water absorption vs. compaction cycle.

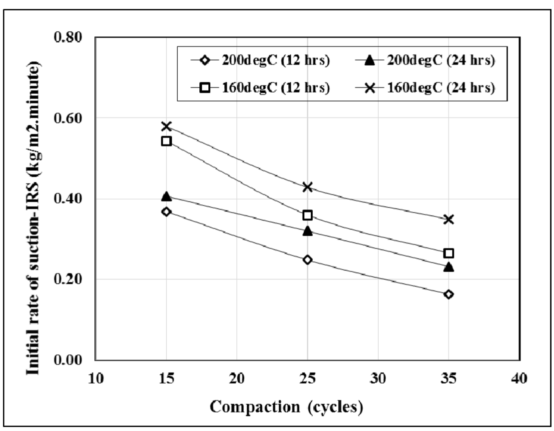


Fig. 11. Initial rate of suction vs. compaction cycle.

5 Conclusions

From the results and analysis, it can be concluded several points as follows. Waste cooking oil can be used as masonry block binder with main aggregate from RAP, with minimum waste cooking oil content required 4% by weight of aggregate. Best masonry block characteristic was found on samples heated at 160°C for 12 hours, with the lowest water absorption of 5.64% and porosity of 4.53%. The Initial Rate of Suction (IRS) was 0.25~0.45 kg/m^2.minute Higher compaction level and more intense curing regime gave higher compressive strength up to 80 kg/cm^2 that well above minimum 25 kg/cm^2.

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