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Performance Analysis of Recycled Asphalt Material Foundation Layer and Top Foundation Layer Reviewed from Primary Displacement

Diyanti[1*], Fani Yayuk Supomo[1], Sri Indah Setiyaningsih[1]

[1] Civil Engineering Study Program, Faculty of Civil Engineering and Planning, Gunadarma University, Depok, Indonesia.

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Corresponding Author:
Diyanti
diyanti@staff.gunadarma.ac.id

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Abstract: This study aims to determine the unconfined compressive strength of recycled materials based on variations in cement content of 1%, 3%, and 5%, as well as the percentage of emulsified asphalt. This study is urgently needed because the massive development of road infrastructure drives an increase in the need for road materials. Utilization of recycled waste from existing asphalt layers and foundation layers is an alternative sustainable and environmentally friendly material. Reusing this material is more efficient if the road damage has not reached the structural stage. Testing in the study was conducted experimentally at the Road Materials Center Laboratory, Bandung, using materials from existing asphalt layers and foundations. Testing includes physical analysis of the material, compaction to determine the optimum water content and maximum dry density, and unconfined compressive strength. The results showed that the unconfined compressive strength with cement content of 1%, 3%, and 5% were 0.70 MPa, 1.70 MPa, and 2.09 MPa, respectively, with primary displacement values of 20 mm, 25.8 mm, and 24.7 mm. Meanwhile, the residual strength value decreased with increasing cement content, namely 76.3%, 66.3%, and 64.3%.

Keywords: Asphalt material; Foundation layer; Primary displacement; Recycling

Introduction

Road preservation is a very important activity in maintaining and preserving road conditions so that they can function optimally (Widyantari et al., 2018; Lombogia et al., 2024; Rohana et al., 2021). According to the Regulation of the Minister of Public Works and Public Housing Number 5 of 2023, road preservation includes several actions, namely routine maintenance, periodic maintenance, rehabilitation, and reconstruction. These activities aim to prevent further damage and ensure that the road can operate efficiently according to its planned life.

Road reconstruction is an activity to improve the structure of a road which aims to increase the capacity of sections of the road which are in a state of severe damage (Modifa et al., 2023). Reconstruction work includes repairing the entire structure, increasing the strength of the structure, regraveling, embankment excavation work, preparing the base soil, pavement structure work, repairing or creating drainage and marking (Putra et al., 2022).

Road reconstruction in Indonesia often faces challenges related to the limited availability of new materials. Therefore, the use of recycled materials is becoming an increasingly important solution in road construction activities. The use of recycled materials, such as recycled aggregates and recycled asphalt, not only helps reduce construction waste, but also saves dwindling natural resources (Himmati et al., 2023). Widayat et al. (2009) explained that several recycling technologies in Indonesia have been implemented,

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including cold mix recycling of asphalt mixtures with liquid asphalt and recycling by heating the asphalt surface layer directly in the field (in place), cement treated recycling base (CTRB), recycling by foamed bitumen (RFB), Hot mix recycling Asphalt (HMRA) (Sjahdanulirwan, 2009).

Budiarnaya et al. (2022) conducted a study using the CTRB recycling system as a foundation layer. The results showed that the cement content that met the UCS requirements was 5% with an average compressive strength of 29.48 MPa. This technology can save 45% to 60% in aggregate usage in new asphalt (Budiarnaya et al., 2022). According to Azheri (2021) in his research, the results of the study on the compressive strength of CTRB with various cement materials showed that the mixture of 30% RAP + 70% base A was 45.5 kg/cm², 58.5 kg/cm² and 45.5 kg/cm² with an average compressive strength of 49.78 kg/cm² at the age of the sample, the curing was carried out for 7 days. The increase in the compressive strength value of CTRB along with the increase in cement usage (Azheri, 2021).

Waani et al. (2014) conducted a study on the Evaluation of Mechanical Properties of CTRB Mixtures Partially Substituted with Natural Pozzolan (Tras). The results of the Compressive Strength test showed that in the CTRB mixture containing 40% RAP, the cement content that produced a strength of ≥ 35 kg/cm² was ≥ 4%, while in the mixture containing 60% RAP, the effective cement content that produced a strength of ≥ 35 Kg/cm² was 6%(Waani et al., 2014). Tran et al. (2017) conducted a study to determine the effect of RAP and RAS (recycled asphalt shingles) through testing and laboratory experiments. The results showed that recycled materials can be used in a mixture of 40% RAP and 25% RAS and 5% RAS to achieve the same construction quality, laboratory performance, and initial field performance as the control mixture of 30% RAP (Tran et al., 2017; Masri et al., 2000).

Innovations in the use of recycled materials stabilized with additives are increasingly being carried out in order to obtain and improve the performance of recycled materials (Pahrijal, 2023). This process not only helps reduce waste, but also often increases the strength and durability of the recycled material. Additives such as polymers, chemical stabilizers, or additional binders can improve the quality of the recycled material so that it is more suitable for use in road and bridge construction.

Yao et al. (2022) conducted a study by adding cement and a little metakaolin as a stabilizing agent for recycled foundation layer materials. The results of the study showed that the unconfined compressive strength of the recycled aggregate mixture stabilized with cement can be significantly increased when the metakaolin dosage ranges from 1% to 3%. The addition of a little metakaolin can reduce the optimum water content of the recycled foundation aggregate mixture and increase the maximum dry density (Yao et al., 2022).

The addition of cement content to recycled materials can increase the Unconfined Compressive Strength (UDS) value so that it meets the requirements for the top foundation layer (base) applicable in Indonesia. The data and standards used in this study are as follows.

Table 1. Mixed Aggregate Gradation Requirements

Sieve Size (mm)	Passing Mass Percentage (%)
50.00 mm	100
37.50 mm	95 - 100
19.00 mm	50 - 100
2.36 mm	20 - 60
0.07 mm	0 - 15

Asphalt emulsion used in this study is asphalt emulsion CSS-1h with specifications as contained in Table 2.

Table 2. Emulsified Asphalt Specifications

Inspection	Unit	CSS-1h Min	Max
I. Test of Emulsion			
Viscosity, saybolt furol (25^{o}C)	Second	20	Viscosity, saybolt furol (25^{o}C)
24 hour storage stability	%	-	24 hour storage stability
Sieve test	%	-	Sieve test
Distillation residue	%	57	Distillation residue
Cement mixing test	%	-	Cement mixing test
II. Residue test from distillation			
Penetration 25^{o}C, 100 grams, 5 seconds	0.1 mm	40	Penetration 25^{o}C, 100 grams, 5 seconds
Ductility at 25^{o}C, cm/min	cm	40	Ductility at 25^{o}C, cm/min
Solubility inTrichloroethylene	%	97.5	Solubility inTrichloroethylene

Calculate the percentage of existing asphalt layer using the following formula:

$$d = \frac{H1 \times a}{H1 \times a + H2 \times b} \times 100(\%) \quad (3)$$

Information:
d : Percentage of existing asphalt layer (%)
H1 : The thickness of the existing asphalt layer recycled (cm)
H2 : The thickness of the top foundation layer
m1 : Wet weight of sample
m2 : Dry weight of sample

Calculate the required asphalt emulsion content based on calculations using the equation:

$$P = 0{,}04\,a + 0{,}07\,b + 0{,}12\,c - 0{,}013\,d \quad (2)$$

Information:
P : Percentage of emulsified asphalt to the total mixture (%)
a : Percentage of aggregate retained on 2.36 mm sieve (%)
b : Percentage of aggregate passing the 2.36 mm sieve but retained on 0.075 mm sieve (%)
c : Percentage of aggregate passing the sieve 0.075 mm (%)
d : Percentage of asphalt mixture (%)

The composition of the recycled material mixture is:

$$Aggregate + Cement + Emulsified\ asphalt = 100\ (\%) \quad (3)$$

Determining the weight of water to be added to obtain the target water content using the following formula:

$$W = \left\{\left(A + C + E \times \frac{R}{100}\right) \times \frac{w}{100}\right\} - \left\{\left(E \times 1 - \frac{R}{100}\right)\right\} \quad (4)$$

Information:
W : Weight of water to be added (g)
A : Aggregate volume (g)
C : Volume of cement (g)
E : Volume of asphalt emulsion (g)
ω : Target water content (%)
R : Emulsified asphalt concentration (%)

The formula used to obtain water content and dry density is as follows:

$$Water\ content = \frac{W1 - W2}{W2} \times 100\ (\%) \quad (5)$$

Information:
W1 : Wet weight of sample (g)
W2 : Dry weight of sample (g)

$$Dry\ density = \frac{m2}{h \times A}\ (g/cm^3) \quad (6)$$

Information:
h : Sample thickness (cm)
m2 : Dry weight of sample (g)
A : Mold base area (cm2)

This study aims to obtain the Unconfined Compressive Strength value based on cement content of 1%, 3%, and 5% and the percentage of asphalt emulsion from the results of sieve analysis tests of recycled materials. Based on previous studies, this study emphasizes the use of a combination of cement and asphalt emulsion as a stabilizing agent in recycled materials in road reconstruction, with a focus on the effect of variations in cement content (1%, 3%, 5%) and asphalt emulsion on Unconfined Compressive Strength. Although several studies have examined the use of recycled materials and additives, this study offers a new approach by testing a specific combination of cement and asphalt emulsion, and measuring its direct effect on the strength and density of recycled materials.

This research is very important to do, for the following reasons: First, Saving New Materials: The availability of new materials for road reconstruction in Indonesia is increasingly limited. By utilizing recycled materials stabilized by cement and asphalt emulsion, this research can help reduce dependence on new materials, while maintaining the sustainability of natural resources. Second, Reducing Construction Waste: Utilizing recycled materials helps reduce construction waste that has the potential to pollute the environment. This is in line with global trends in the construction industry that encourage environmentally friendly approaches and better waste management. Third, Improving Material Performance: Previous research has shown that stabilizing recycled materials with cement or other additives can increase the strength and durability of the material. This research adds new insights into how the combination of cement and asphalt emulsion can optimize the performance of recycled materials, making them more efficient and durable for road reconstruction. Fourth, Solutions for Sustainable Infrastructure: Sustainable road infrastructure is one of the main priorities in Indonesia. This research makes an important contribution by developing innovative solutions that not only save costs but also improve road quality through recycling technology.

Method

This research was conducted experimentally (Sugiyono, 2018; Ardiawan, 2022) in the laboratory of the Road Materials Center, Directorate of Road and Bridge Engineering Development, Bandung. The samples used for this study were obtained from roads in the Road and Bridge Engineering Development environment. The samples taken were 100% recycled materials in the form of existing asphalt layers and existing upper foundation layers. The number of samples used was in the ratio of 30 kg for the asphalt surface layer and 70 kg for the foundation layer. Sample excavation using a test pit by making a hole according to the condition of the road section at the test location with the depth determined by the actual in the field.

Laboratory tests conducted in this study include sieve analysis tests, water content tests, marshall compaction tests to obtain optimum water content and maximum dry unit weight, and compressive strength tests. The equipment used is a sieve, a marshall compactor, a free compressive strength tester, a marshall mold, a sample pusher (extruder) and so on. The research steps can be seen in Figure 1.

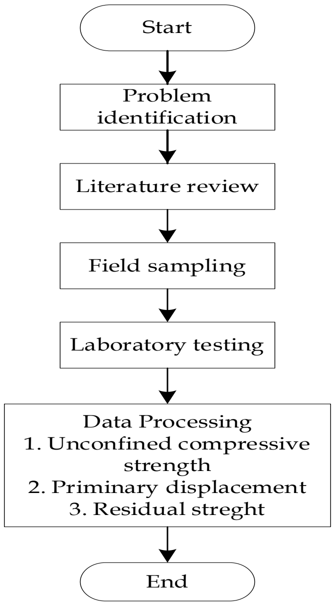

Figure 1. Research Flow Chart

Before the aggregate sieve analysis test is carried out, the samples are separated based on the size of the aggregate gradation, the aggregate size is grouped into 5 groups.Existing asphalt that is large in size with a hammer to get a size between 1.5 inches to 2 inches,The sample sieve analysis test procedure is carried out in accordance with SNI ASTM C 136-2012 (Indonesian National Standard, 2012).

Next, a combination of aggregate gradation is carried out with the percentage of the existing asphalt layer and the existing upper foundation layer.Testing of optimum water content and maximum density is done by the following steps: First, classify the aggregate by weighing the aggregate based on the calculated mixing ratio. The test specimen consists of aggregate compacted by adding additives (cement and asphalt emulsion) to the mold marshall.Mix the aggregate and cement dryly, usually 2.5% of the middle value (1- 5%) is used, then add water and stir. After that, mix the asphalt emulsion into the mixture and stir again. Get five variations of water content by changing the value that refers to the optimum water content, then make test objects with water content of 2.0%; 4.0%; 6.0%; 8.0%; and 10.0%). Second, uTo obtain the water content and dry density of each test object, testing was carried out in accordance with the SNI 1971:2011 test procedure (Indonesian National Standard, 2011).

Calculate the optimum water content obtained from the relationship curve between water content and dry density as shown in Figure 2.

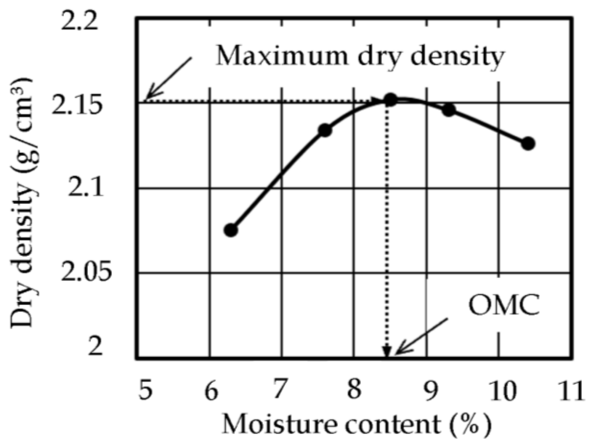

Figure 2. Relationship curve between water content and maximum dry density

The next stage is the compressive strength test of the free compressive strength test specimens made in 3 variations of cement content, namely 1.0%, 3.0% and 5.0%. Each variation is made of 3 test specimens, so that the total compressive strength test specimensfree is 9 test objects. Testing is carried out until the test object shows twice the primary displacement value. This value can be used to determine the free compressive strength value, primary displacement, and residual strength percentage.

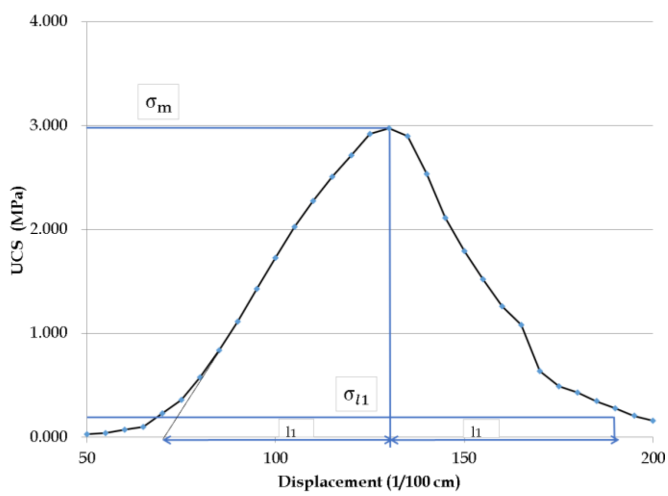

Figure 3. Unconfined compressive strength test graph

The next stage is a thickness test to determine the volume of each test object and then calculate the dry density value. The last stage is to determine the optimum cement content. The optimum cement content is determined based on the middle value in the tolerance range of cement content values that meet the standards for Free Compressive Strength (KTB), Primary Displacement, Residual Strength (Pranata & Setiyaningsih, 2024). Unconfined compressive strength (UCS) is the strength of the material against pressure without a limiter. The higher the UCS value, the better the stability of the material. Primary Displacement is the main displacement of the material during testing which indicates the material's ability to withstand deformation. While residual strength is the remaining strength that indicates the material's ability to maintain its strength after receiving a certain load or pressure. The optimum cement content is determined based on the middle value in the tolerance range of the test results that meet the three standards above. This range is obtained by testing various cement content and then selecting the most appropriate value to achieve optimal performance.

Overall, this testing stage involves several systematic steps to determine the quality of recycled materials stabilized with cement and asphalt emulsion. The first stage is thickness testing to determine volume. In this initial stage, the thickness of the test object is measured to calculate the volume accurately. This thickness measurement is very important because volume is a key variable in calculating the dry density of the material. Volume is obtained by measuring the dimensions of the test object using a precision measuring instrument.

The second stage of calculating dry density. At this stage after the volume of the test object is determined, the next step is to calculate the dry density value. Dry density is calculated by dividing the dry weight of the test object by the volume previously obtained. Dry density is an important indicator to determine how dense and strong the material is after the compaction and drying process.

The third stage is determining the optimum cement content. In this final stage, testing is carried out to determine the optimum cement content. The optimum cement content is the amount of cement that provides the best performance on recycled materials. This content is determined by conducting several tests for various cement content and selecting the content that meets three main criteria:

Results and Discussion

Sieve Analysis Testing

Testing was carried out on recycled aggregates, Sieve analysis test samples of 5-7 kgquartering methodor sample splitter (Olusola, 2016; Campos-M & Campos-C, 2017) then the aggregate sieve analysis test was carried out. The sieve analysis test was carried out to determine the gradation of the recycled sample. Samplecrushed using a hammer until the size is between 1.5 inches to 2 inches. The results of the sieve analysis test are shown in Figure 4.

Sieve analysis testing using sieves measuring 53 mm, 37.5 mm, 31.5 mm, 26.5 mm, 19 mm, 13.2 mm, 4.75 mm, 2.36 mm, 0.075 mm. To meet the maximum grain size of 2 inches, the material retained on sieve No.26.5 was discarded. The graph of the results of the sieve analysis test is shown in Figure 5.

	Sieve size (mm)	Grading of existing base course aggregate		Grading of existing asphalt mixture		Combined grading	Reference grading	Desirable grading
Weight of passing sieves (%)	53	100.0	(Removing larger than 26.5 mm)	100.0	(Removing larger than 26.5 mm)	100.0	(Removing larger than 26.5 mm)	100
	37.5	100.0		100.0		100.0		95 - 100
	31.5	100.0		85.0		95.1		-
	26.5	93.4	100.0	75.0	100.0	87.3	100.0	-
	19	78.5	84.1	65.0	86.7	74.0	84.8	50 - 100
	13.2	69.5	74.5	50.0	66.7	63.1	72.3	-
	4.75	47.8	51.2	25.0	33.3	40.3	46.2	-
	2.36	31.3	33.5	15.0	20.0	25.9	29.7	20 - 60
	0.075	1.9	2.0	0.0	0.0	1.3	1.5	0 - 15

Figure 4. Sieve Analysis test results

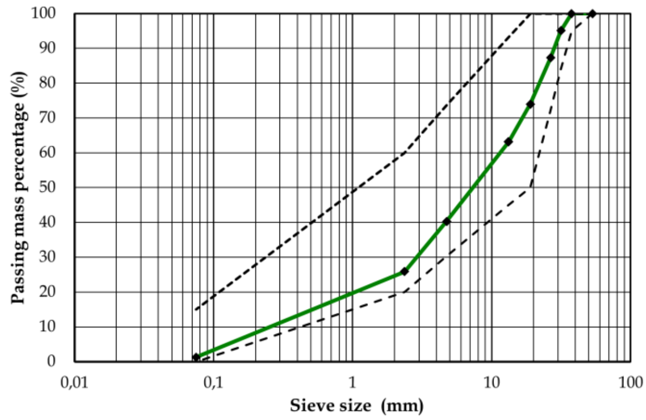

Figure 5. Aggregate gradation test results

Based on the results of the recycled aggregate gradation analysis test, the percentage of those passing the sieve was within the upper and lower limits so that the aggregate could be used.

Emulsion Asphalt Content

The percentage value of the existing asphalt layer is used to determine the content of emulsified asphalt used in making test specimen samples for optimum water content testing (Wirahaji, 2012; Maizuar et al., 2023). The optimal asphalt emulsion content of the recycled base layer is calculated using the following equation:

Thickness of existing asphalt layer: D1 = 6.0 cm

Design thickness of foundation layer D = 20.0 cm

Density of existing asphalt layer = 2.4 g/cm^3

Density of existing base course

B = 2.1 g/cm^3

The calculation of the percentage of the existing asphalt layer (d) is as follows.

$$d = \frac{D_1 \times a}{D_1 \times a + (D - D_1) \times b} \times 100$$

$$d = \frac{6 \times 2.4}{6 \times 2.4 + (20 - 6) \times 2.1} \times 100$$

$d = 32.9$ %

Optimal asphalt emulsion content:

$P = (0.04 \times a) + (0.07 \times b) + (0.12 \times c) - (0.013 \times d)$

$P = (0.04 \times 80.4) + (0.07 \times 18.6) + (0.1 \times 1) - (0.013 \times 32.9)$

$P = 4.4$ %

Based on the calculation results, the optimal asphalt emulsion content value is 4.4%.

Optimum Water Content

Accuracy in measuring the mass of aggregate and water in the manufacture of cement concrete and asphalt concrete (especially cold mix asphalt concrete with emulsified asphalt) greatly affects the quality of the concrete produced (Kushartomo et al., 2020). However, often the aggregates available are in wet conditions, so it is necessary to make corrections to the aggregate mass and water so it is important to do water content testing. The results of the water content test can be seen in Table 3.

Table 3. Water Content Test Results

Target Moisture Content (%)	Volume (cm³)	Wet Weight (g)	Dry Weight (g)	Moisture Content (%)	Dry density (g/cm³)
4	578.2	1251.3	1186.4	5.5	2,052
5	583.8	1251.3	1189.6	5.2	2,038
6	574.1	1273.3	1189.7	7	2,072
8	584.6	1286.4	1181.6	8.9	2.021
10	589.5	1266.7	1174.1	7.9	1,992

The water content test object consists of 5 samples based on the water content target which refers to the optimum water content value, five water content samples, namely water content samples with water content percentages of 4%, 5%, 6%, 8%, and 10%. Each sample is printed inmarshall compaction mold and pounded 50 times. From this test, the maximum dry density data was obtained which was used as a reference to determine the optimum water content value. The maximum dry density was produced by a sample with a target water content of 6%, which was 2,072 (g/cm³).

Next, the maximum dry density value is*plotting*into theThe relationship curve between water content and maximum dry density to determine the optimum water content value, the optimum water content value is shown in Figure 6.

Based on Figure 6, the relationship curve between water content and maximum dry density, it can be seen that the optimum water content value produced under maximum dry density conditions is 6.3%.

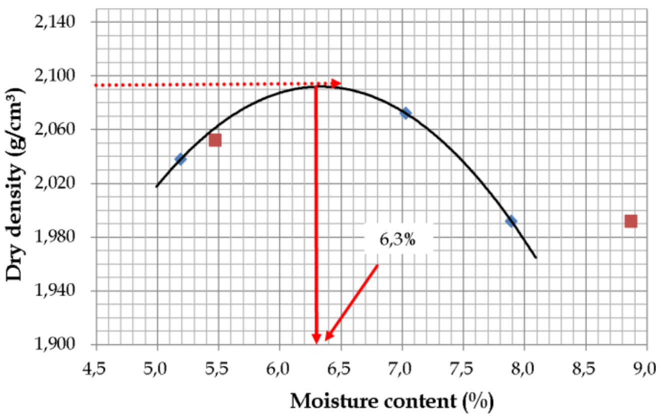

Figure 6. Relationship curve between water content and maximum dry density

Unconfined Compressive Strength (UNC)

In concrete compressive strength testing, displacement refers to the change in length that occurs in the test specimen in response to the applied load Rofiq et al. (2019). Compressive strength testing is carried out until the measuring instrument shows more than twice the displacement value (primary displacement) obtained at the maximum free compressive strength level (Rofiq et al., 2019).

Unconfined compressive strength test specimens were made as many as 9 test specimens with 3 variations of cement content, namely 1%, 3%, and 5% and emulsified asphalt content of 4.4%, the determination of emulsified asphalt content was obtained based on the results of the sieve analysis test. From the unconfined compressive strength test, three parameters will be obtained as the determination of the optimum cement content. The parameters in question are unconfined compressive strength, primary displacement, and residual strength. The results of the unconfined compressive strength test are shown in Table 4 and Figure 7 as follows.

Table 4. Unconfined Compressive Strength Test Results

	Cement Content		
	1%	3%	5%
Dry Density (%)	1.98	2.05	2.59
Unconfined Compressive Strength (MPa)	0.70	1.70	2.09
Primary Displacement	20.00	25.80	24.70
R, strength (%)	76.30	66.30	64.30
Water Absorption (%)	3.03	2.01	2.32

Based on the compressive strength test, the average compressive strength value of each sample with cement content variations of 1%, 3%, and 5% is 0.70 MPa, 1.70 MPa, and 2.09 MPa. The compressive strength value increases according to the increase in the amount of cement content used, this occurs because cement functions as the main binding material in concrete, so the addition of cement will increase the strength of the test object.

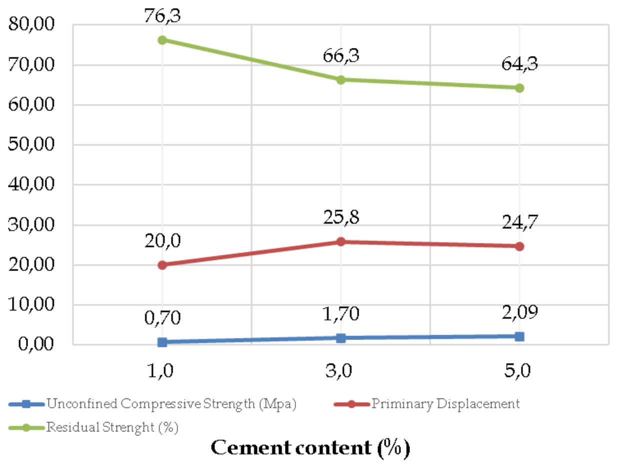

Figure 7. Graph of unconfined compressive strength, primary deisplacement, and residual strength (%) based on cement content variations

Average value of primary displacement (Zebua, 2023; Kurniawan et al., 2023) from 3 variations of cement content in sequence, namely 20.0, 25.8 and 24.7, the more cement added, the greater the primary displacement value. Residual strength is the strength or load that can still be held by an object or material that has been damaged without failure. Structures with higher residual strength values are safer because they can withstand loads without failure. In this study, the residual strength values obtained from 3 variations of cement content in sequence were 76.3%, 66.3%, and 64.3%.

Sieve analysis testing is carried out to determine the gradation of recycled aggregates (Taher et al., 2020; Marthasari, 2021). The samples were crushed to a size between 1.5 inches to 2 inches, and the test was carried out using sieves ranging in size from 53 mm to 0.075 mm. The results showed that the percentage of aggregate passing the sieve was within the specified limits, so that the recycled aggregate was qualified for use. The calculation of the optimal asphalt emulsion content was based on the thickness of the existing asphalt layer and the foundation layer. Calculated using a formula that takes into account the density of the layer, the optimal asphalt emulsion content value was obtained at 4.4%.

Water content testing was conducted on five samples with target water content of 4%, 5%, 6%, 8%, and 10%. The results showed that the maximum dry density was achieved in samples with a water content of 6%, with a dry density value of 2.072 g/cm³. The relationship curve between water content and maximum dry density showed that the optimum water content was 6.3%. Unconfined compressive strength testing was conducted on nine (9) test specimens with variations in cement content of 1%, 3%, and 5%, and emulsified asphalt content of 4.4%. The test results showed that the unconfined compressive strength value increased with the addition of cement content: 0.70 MPa for 1%, 1.70 MPa for 3%, and 2.09 MPa for 5%. The primary displacement value also increased in the addition of 1% and 3% cement, namely 20 and 25.8. Then it decreased in value when adding 5% cement content, namely 24.7. Meanwhile, the residual strength value decreases with increasing cement content, namely 76.3% for 1%, 66.3% for 3%, and 64.3% for 5% cement content.

Conclusion

This study shows that increasing cement content in the stabilization of recycled materials in asphalt layers and foundations has a significant effect on the strength and displacement of the material. Unconfined Compressive Strength increases with increasing cement content, with results of 0.70 MPa (1%), 1.70 MPa (3%), and 2.09 MPa (5%), respectively. However, increasing cement content also affects the primary displacement, which tends to decrease at 5% cement content, from 25.8 mm (3%) to 24.7 mm (5%). The residual strength of the material decreases with increasing cement content, indicating that the material's ability to withstand loads without failure is slightly reduced at higher cement content, namely 76.3% (1%), 66.3% (3%), and 64.3% (5%). Overall, although increasing cement content strengthens the material, there is a trade-off in terms of residual and displacement capabilities, which need to be considered in field applications.

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Author Contributions

Conceptualization; D. FYS. SIS.; methodology.; D. FYS. SIS.; validation; D.; formal analysis; FYS.; investigation.; D. FYS. SIS.; resources; D. FYS. SIS.; data curation: D. FYS. SIS.; original draft writing: SIS.; review and editing: SIS.; visualization: D. FYS. SIS. All authors have read and approved the published version of the manuscript.

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Conflict of Interest

Researchers in this study were given a mandate by the institution to improve the competence and capacity of lecturers, with the hope that the results of this study can provide a positive contribution to the development of human resources in the academic environment.

References

Ardiawan, K. N., Sari, M. E., Abdullah, K., Jannah, M., Aiman, U., & Hasda, S. (2022). *Metodologi Penelitian Kuantitatif*. Yayasan Penerbit Muhammad Zaini.

Azheri, R. (2021). *Kajian Metode Mix Design CTRB (Cement Treated Recycling Base) Studi Kasus: Jalan Hr. Subrantas, Panam Kota Pekanbaru*. Universitas Islam Riau. Retrieved from http://repository.uir.ac.id/id/eprint/8490

Budiarnaya, P., Ariawan, P., & Swasdita, I. G. (2022). Perencanaan Mix Desain Cemen Treated Recycling Base (CTRB) Untuk Lapis Pondasi Atas Dengan Menggunakan Material Recycle Hasil Garukan Dari Aspal Hot Mix. *Reinforcement Review in Civil Engineering Studies and Management*, *1*(2), 73–81. https://doi.org/10.38043/reinforcement.v1i2.4100

Campos-M, M., & Campos-C, R. (2017). Applications of quartering method in soils and foods. *International Journal of Engineering Research and Applications*, *7*(1), 35–39. https://doi.org/10.9790/9622-0701023539

Himmati, I., Prawesti, I. P., & Brahmantya, A. A. (2023). Roadect: Deteksi Persoalan Infrastruktur Jalan Sebagai Solusi Strategi Digital Dalam Penyampaian Aspirasi Masyarakat Berkelanjutan. *Jurnal HPJI*, *9*(1), 9–16. https://doi.org/10.26593/jhpji.v9i1.6435.9-16

Kurniawan, Ricky, Abrar, A., & Halimatusadiyah. (2023). Perhitungan Struktur Bawah Gedung Baru Sekolah Tinggi Teknologi Dumai. *Jurnal Teknik Sipil*, *1*(2), 28–44. https://doi.org/10.52072/slumptes.v1i2.404

Kushartomo, W., Sutandi, A., & Linggasari, D. (2020). Memperkirakan Perbandingan Kadar Air Semen Pada Beton Keras. *Jurnal Muara Sains, Teknologi, Kedokteran Dan Ilmu Kesehatan*, *4*(1), 177. https://doi.org/10.24912/jmstkik.v4i1.7416

Lombogia, R., Dundu, A. K. T., & Malingkas, G. Y. (2024). Metode Pelaksanaan Pekerjaan Preservasi Jalan Ruas Kaiya-Kotamobagu. *Tekno*, *22*(87), 85–92. https://doi.org/10.35793/jts.v22i87.53822

Maizuar, Said Jalalul, A., & Wirda, A. (2023). Karakteristik Marshall Campuran AC-BC Menggunakan Ethylene Vinyl Acetate Sebagai Asphalt Modifier. *Jurnal Teknologi Terapan & Sains 4.0*, *4*(1), 891–902. https://doi.org/10.29103/tts.v4i1.11054

Masri, Y., Siahaya, V. T. C., & Istia, P. T. (2023). Pengaruh Penambahan Aspal Terhadap Stabilitas Marshall Pada Material Reclaimed Asphalt Pavement (RAP) Di Ruas Jalan Jenderal Sudirmal–Rijali Kota Ambon. *Jurnal Indonesia Sosial Teknologi*, *4*(5), 543-555. https://doi.org/10.59141/jist.v4i5.614

Modifa, I., Harahap, M. A. K., Saragih, D. S., Nizar, A., & Sipayung, R. (2023). Peningkatan Jalan Menggunakan Perkerasan Kaku (Rigid Pavement) Pada Ruas Jalan Provinsi Parsoburan–BTS Labuhan Batu Utara Kabupaten Toba. *Jurnal Santeksipil*, *4*(1), 21-34. https://doi.org/10.36985/jsl.v4i1.886

Olushola, B. (2016). An Assessment of Laboratory Sample Splitting Techniques. *International Journal of Engineering and Technology*, *6*(10), 358–364. https://doi.org/0000-0002-5776-3063

Pahrijal, R. (2023). Mengubah Sampah Menjadi Harta Karun: Inovasi Daur Ulang yang Menguntungkan Lingkungan dan Ekonomi (Studi Literature). *Jurnal Multidisiplin West Science*, *2*(06), 483–492. https://doi.org/10.58812/jmws.v2i6.430

Pranata, A. A., & Setiyaningsih, S. I. (2024). Perencanaan Lapis Fondasi Daur Ulang Menggunakan Lapis Fondasi Atas dan Lapis Aspal Eksisting. *Prosiding Seminar Nasional Ilmu Teknik*, *1*(1), 116–130. https://doi.org/10.61132/prosemnasproit.v1i1.8

Putra, B. H. R., Yogi, M. R. A., Elianora, E., & Prakasa, R. R. (2022). Penentuan Pekerjaan Preservasi Jalan Nasional Pematang Reba-Rengat Berdasarkan Umur Sisa Perkerasan. *Konstruksia*, *14*(1), 8. https://doi.org/10.24853/jk.14.1.8-17

Rofiq, M. A., Alrasyid, H., Iranata, D., & Irawan, D. (2019). Prediksi Perilaku Lentur Kolom Beton Bertulang Mutu Tinggi Terhadap Kombinasi Beban Perpindahan Monotonik dan Aksial Rendah. *Jurnal Aplikasi Teknik Sipil*, *17*(1), 43-50. https://doi.org/10.12962/j2579-891X.v17i1.4899

Rohana, N. S., & Hudori, M. (2021). Preservasi Perkerasan Lentur Berdasarkan Nilai Kondisi Jalan Menggunakan Metode Pci Di Jalan Srikandi Kota Pekanbaru. *Jurnal Rab Contruction Research*, *6*(2), 101–111. https://doi.org/10.36341/racic.v8i2.2922

Romadhon, E. S., & Marthasari, D. Y. (2021). Analisis Kekuatan Tekan Beton Dengan Aggregate Kasar Dari Beton Daur Ulang. *Jurnal Teknik Sipil-Arsitektur*, *20*(1), 17-22. https://doi.org/10.54564/jtsa.v20i1.60

Sjahdanulirwan, M. (2009). Kinerja Daur Ulang Campuran Dingin Dengan Aspal Busa Pada Lalu Lintas Berat. *Jurnal Jalan-Jembatan*, *26*(3), 256–265. Retrieved from https://uilis.usk.ac.id/serial/index.php?p=show_detail&id=18117

Standar Nasional Indonesia. (2011). *SNI 1971:2011 "Cara*

Uji Kadar Air Total Agregat dengan Pengeringan." Badan Standarisasi Nasional.

Standar Nasional Indonesia. (2012). *SNI ASTM C136:2012. Metode Uji untuk Analisis Saringan Agregat Halus dan Agregat Kasa*r. *B*adan Standardisasi Nasional.

Sugiyono. (2018). *Metode penelitian kuantitatif, kualitatif dan kombinasi (mixed methods)* (Cet 10). Alfabeta.

Taher, T., Suharwanto, & Komarudin. (2020). Agregat Beton Daur Ulang Dari Limbah Bata Ringan Sebagai Subsitusi Agregat Natural Pada Beton Normal. *Jurnal Rekayasa Infrastruktur*, *6*(2), 19–27. https://doi.org/10.31943/jri.v6i2.173

Tran, N., Xie, Z., Julian, G., Taylor, A., Willis, R., Robbins, M., & Buchanan, S. (2017). Effect of a recycling agent on the performance of high-RAP and high-RAS mixtures: Field and lab experiments. *Journal of Materials in Civil Engineering*, *29*(1), 1–8. https://doi.org/10.1061/(ASCE)MT.1943-5533.0001697

Waani, J. E., Prabandiyani, S., & Setiadji, B. H. (2014). Evaluasi Sifat-Sifat Mekanik Campuran CTRB yang Disubstitusi Parsial dengan Pozolan Alam (Tras). *Jurnal Teknik Sipil ITB*, *21*(3), 229–240. https://doi.org/10.5614/jts.2014.21.3.6

Widyantari, I. G. A., Agustawijaya, D. S., & Murtiadi, S. (2018). Analisis Risiko Preservasi Jalan Sp . Tohpati – Tampak Siring – Istana Presiden, Kabupaten Gianyar, Provinsi Bali Risk Analysis on Road Preservation Tohpati-Tampak Siring-Istana Presiden Intersection, Gianyar Regency, Bali Province. *Jurnal Spektran*, *6*(1), 86–94. https://doi.org/10.29303/spektrum.v5i2.124

Wirahaji, I. (2012). Analisis Kadar Aspal Optimum Laston Lapis Aus Pada Ruas Jalan Simpang Sakah-Simpang Blahbatuh (Studi Kasus Paket Pemeliharaan Berkala Jalan Tahun Anggaran 2011). *Jurnal Ilmiah Teknik Sipil*, *16*(2), 117–131. Retrieved from https://jurnal.harianregional.com/jits/full-7503

Yao, J., Wang, W., & Song, X. (2022). Performance of cement stabilized recycled aggregate base course added with metakaolin. *In E3S Web of Conferences*, *34*(1), 1009. https://doi.org/10.1051/e3sconf/202234101009

Zebua, D. (2023). Analisis Displacement Struktur Beton Bertulang Pada Gedung Rumah Sakit. *Jurnal Penelitian Jalan Dan Jembatan*, *3*(1), 20–25. https://doi.org/10.59900/ptrkjj.v3i1.133