SINERGI Vol. 28, No. 1, February 2024: 183-190
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2024.1.018

The usage of marginal aggregate as subbase layer

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Abstract
Aggregate holds the main role in determining the quality of pavement layers. Unfortunately, the locally available aggregates sometimes did not pass one or more requirements stated in the standard, making these aggregates technically unable to be used. These aggregates are called marginal or substandard aggregates. However, previous research projects have shown the potential of utilizing marginal aggregates as pavement layers. This research aims to analyst the techniques for utilizing marginal aggregates as pavement layers, specifically as subbases. Two techniques were evaluated herein, namely by varying the aggregate gradation and by adding cement and lime as stabilizers, and the specimens were assessed by the California Bearing Ratio (CBR) test. The research results found that varying the percentage of coarse and fine aggregates in the specimens improved the CBR value. The specimen obtained the highest CBR value with 70% coarse aggregate and 30% fine aggregate. Moreover, it was found that adding cement and lime as stabilizers at the right percentage was also able to improve the CBR value of the specimens and mixing the stabilizers beyond a certain percentage decreases the CBR value. The amount of cement and lime needed depended on the aggregate gradation used.

Keywords:
CBR Test;
Cement;
Hydrated Lime;
Marginal Aggregate;
Subbase;

Article History:
Received: August 28, 2023
Revised: October 10, 2023
Accepted: October 25, 2023
Published: February 2, 2024

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INTRODUCTION

Pavement engineers need to ensure that the pavement lasts until its designed life. In order to do that, the materials used need to be carefully selected to ensure that the material meets the specified standards. The main ingredient of the pavement is aggregates [1]. The lower part of pavement is constructed by aggregates only, and concrete and asphaltic mixtures used as surfacing layers are also mostly aggregates. Therefore, it can be concluded that the aggregate quality determines the pavement quality.

The road contractors should find aggregates and other materials from a source that is close to the project location to save on transportation costs. However, the locally available aggregates sometimes do not meet one or more of the specified requirements. Hence, the contractor needs to look for the aggregates from another quarry that might be far from the construction site, causing the cost to rise. The aggregate that does not meet one or more specified qualities is called marginal or substandard aggregate. Marginal aggregates might have high abrasion value [2], high absorption value [3], have a high swelling potential [4], or unsuitable shape and grading [5].

Indonesia, as one of the largest countries in the world, has aggregates with varying qualities that are spread across the country. Past research studies have discovered that several quarries produce natural aggregates that do not meet one or more of the requirements as stated in Indonesian standards [6][7] There is an increasing need that local road design should be able to adopt the available local material as much as possible [8]. It was suggested that where there are aggregate shortage or only marginal aggregates available locally, the road engineers should be able to adapt the road design to suit the local materials and orodify the materials by mechanical or chemical stabilization [9][10]. Incorporating marginal aggregates into road construction can also improve environmental sustainability [11].

According to [12], although marginal aggregate does not meet all the specified requirements this aggregate cane used in local roads that carry low traffic volume or to be mixed with additive substances [12]. Other researchers worldwide have also done the research projects that aimed to utilize marginal aggregate in pavements[11, 12, 13, 14, 15, 16, 17, 18]. There are a number of methodologies that have been analyzed to improve the quality of asphaltic or concrete mixtures that were prepared by using marginal aggregates, including adding chemical substances [19, 20, 21], crumb rubber [5], plastic waste [22], nano-silica [23], and by modifying the concrete mixture composition [2]. Various research projects have also shown the success of using marginal pavement aggregate or without mixing additives [24][25]. A study conducted by [16] has shown successful attempt to use coral-derived materials that have been compacted to be used as low volume roads.

Out of all methods, the two most commonly used method is to use cement and lime as stabilizer [26]. Both methods utilize the interaction between clay minerals in the marginal aggregate, water and lime. As explained in [26], the result of this chemical interaction bound the aggregate particles together strengthening the material, decreasing the plasticity index, improving the durability performance, and reducing the potential change in volume [27, 28, 29].

In Indonesia, marginal aggregate has not been widely and commonly used due to the risk of not having good performing pavements. Therefore, this paper aims to evaluate the possibility of utilizing the marginal aggregate to be used in pavement, specifically as subbase layer.

METHOD

Figure 1 shows the process by which this study was conducted. The research project was started by identifying the problem: the availability of local marginal aggregates that wanted to be utilized as a subbase layer. Then, the research project continued with the literature review process. The aggregate was tested to determine its parameters. Two methodologies were trialed in this study, which varied the aggregate gradations and used cement and lime stabilizations. The materials were tested by using California Bearing Ratio (CBR) test. Different proportions of coarse and fine aggregates are going to be tested to find the composition that meets the standard value of CBR, which is a minimum of 60%. The chosen composition would be added with cement and hydrated lime in varying percentages to increase the CBR value further.

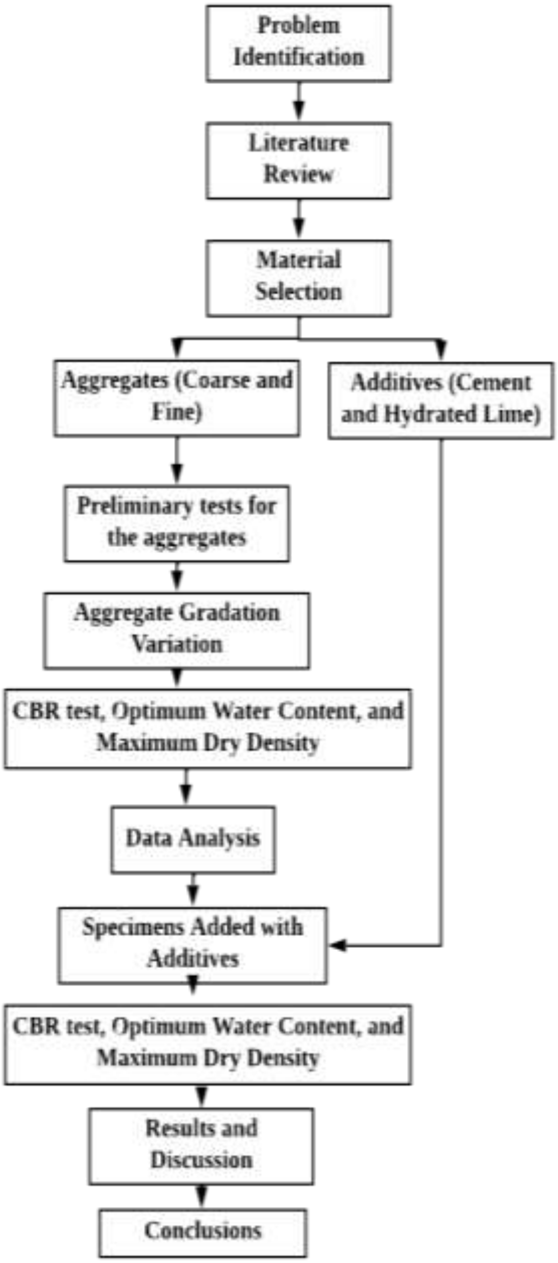

Figure 1. Research Flowchart

Materials

The aggregate used for this research was sourced from a quarry near Jakarta, Indonesia. The aggregate was to be used as a subbase layer and, hence, must satisfy several requirements. Table 1 shows the tests conducted and the requirements asked as specified in the Indonesian National Standard (SNI). The aggregates were sieved according to the grading for the subbase layer as required by the Ministry of Public Works and Housing. The proportion of coarse and fine aggregates was varied to find the composition that could produce the CBR value of at least 60%, as specified in SNI 1744:2012. Aggregates that were larger than 19 mm were removed.

Moreover, the aggregates passing sieve no. 4 were categorized as fine aggregates and the ones retained on sieve no. 4 were categorized as coarse aggregates. The proportion tested can be seen in Table 2, and the aggregate gradations curves are shown in Figure 2. The composition that has the highest CBR value would be further tested by adding some additives to improve the CBR value.

Two additives were used in this research, namely Portland Cement Type I and hydrated lime ($Ca(OH)_2$). Both cement and hydrated lime have been proven to improve the CBR value of subgrade soil [30]. The size of the hydrated lime is between 0.177 mm and 0.149 mm. The additives were added to the mixture as they were, and no pre-treatment was conducted. The additives were added separately at varying percentages, which were 3%, 6%, 9%, 12%, and 15%. The percentages were chosen to obtain as in the past research studies, the ratios used ranged from 2% to 8% [30, 31, 32], and hence, this research study aimed to see the differences in using different percentages.

Table 1. Aggregate Tests

Tests	Standards	Required Value
Abrasion test	SNI 2417:2008	Less than 40%
Bulk Specific Gravity Saturated-Surface-Dry (SSD) Specific Gravity Apparent Specific Gravity	SNI 1969:2008 (coarse aggregate) and SNI 1970:2008 (fine aggregate)	Min 2.5 gr/cm3
Absorption		Less than 3%

Table 2. Aggregate Proportion

Coarse Aggregate	Fine Aggregate
50%	50%
60%	40%
70%	30%
80%	20%

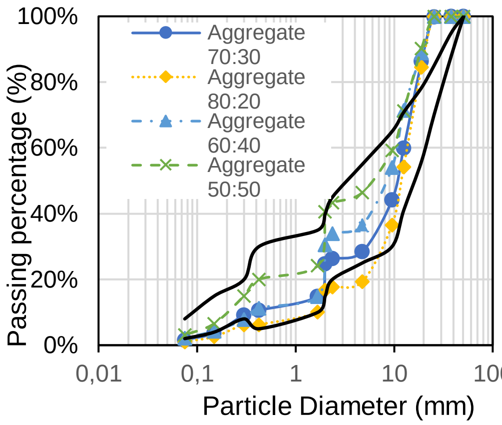

Figure 2. Aggregate Gradation Curves

CBR Test

CBR test is a commonly used test worldwide to evaluate the quality of soil and rock materials used for pavements and has been used as the basis to design road pavement [33][34]. In this research, the CBR test was conducted according to SNI 1744:2012 and the specimens were soaked for four days before the CBR test was performed; hence, soaked CBR values were used herein. The standard was also followed to determine the Optimum water content (OWC) and the maximum dry density of the specimen.

During the specimen preparation process, to ensure that the specimens had the same compaction, the aggregates were divided into three equal portions and compacted per layer.

RESULTS AND DISCUSSION

Aggregate Test Results

Table 3 shows the results for both coarse and fine aggregates. It can be seen from the results that both coarse and fine aggregates had a bulk density lower than 2.5 gr/cm^3 and absorption values higher than 3%. Therefore, this aggregate can be categorized as marginal aggregate, although the abrasion, SSD specific gravity, and apparent specific gravity values of both coarse and fine aggregates met the specifications.

Table 3. Aggregate Test Results

Tests	Aggregates		Required Values
	Coarse	Fine	
Abrasion	22.77%		Less than 40%
Bulk Specific Gravity	**2.40 gr/cm^3**	**2.14 gr/cm^3**	Minimum of 2.5 gr/cm^3
SSD Specific Gravity	2.51 gr/cm^3	2.84 gr/cm^3	
Apparent Specific Gravity	2.70 gr/cm^3	2.62 gr/cm^3	
Absorption	**4.51%**	**8.52%**	Less than 3%

Aggregate Gradation Test Results

Figure 3 shows the results of OWC for each gradation variation. It can be seen that as the proportion of coarse aggregate increases and fine aggregate decreases, the percentage of water content decreases. This shows that the amount of water needed for the CBR test decreases, which could be caused by the specimen's lower percentage of fine aggregate. The fine aggregate, as shown in Table 3, has a higher absorption percentage than the coarse aggregate, and thus, the less fine aggregate is present, the less water is absorbed and needed.

Each gradation variation was also tested for their maximum dry density values. The results in Figure 4 show that as the proportion of coarse aggregate increases from 50% to 70%, the dry density increases from 2.16 to 2.21. However, when more coarse aggregate was added to 80%, the dry density value decreased to 2.18. This could be caused by the imbalance in the proportion of coarse and fine aggregates, resulting in the aggregates being less dense.

Figure 5 shows the CBR test results for each gradation variation. As the percentage of coarse aggregate increased from 50% to 70%, there was an increase in CBR value from 41% to 60%.

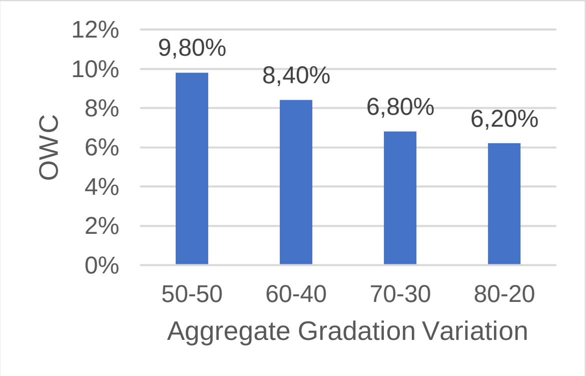

Figure 3. OWC test results for each gradation

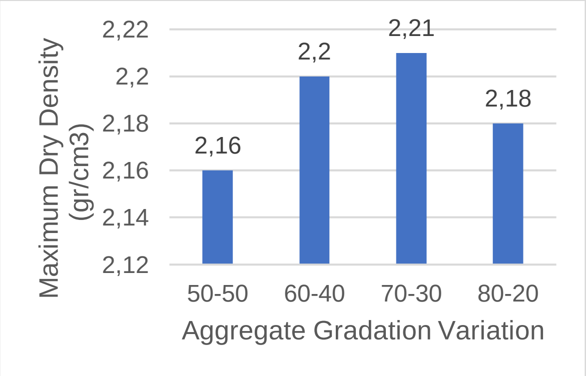

Figure 4. Dry Density test results for each gradation

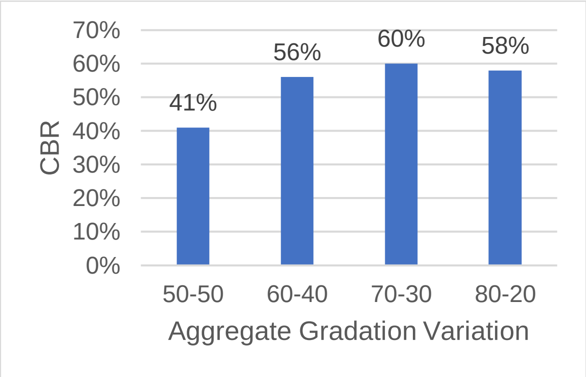

Figure 5. CBR test results for each gradation

However, when coarse fine aggregate was further increased to 80%, the CBR value slightly decreased to 58%. The CBR value is related to the maximum dry density value (Figure 2); hence, a decrease in dry density value leads to a decrease in CBR value. Thus, it can be concluded that the composition with 70% coarse aggregate and 30% fine aggregate is the one that can achieve the minimum requirement of CBR value. This finding suggests that it is possible to achieve the desirable CBR value by using marginal aggregate by selecting the right aggregate gradation.

The Effect of Additives on CBR Test Results

The next step was to analyses the effect of mixing cement and hydrated lime onto the specimens. Two compositions were analyzed: the 60-40 and 70-30. The 70-30 variation was chosen to see if the CBR value can be increased further. The 60-40 variation was chosen as it did not reach enough CBR value, and hence, it is necessary to evaluate if additives could improve the CBR value to meet the specifications.

Figure 6 shows the OWC values for 60-40 and 70-30 aggregate gradations mixed with various percentages of hydrated lime and cement. As the percentage of additives increases, the OWC values increase for both variations and for both additives. Generally, the OWC values for 60-40 aggregate gradation were higher than the 70-30 aggregate gradation. This is similar to when the aggregates have not been mixed with additives, as seen in Figure 1. For the 60-40 aggregate gradation, adding hydrated lime and cement increased the OWC from 8.4% to 10.8% and to 11.8%, respectively. Additionally, for the 70-30 aggregate gradation, adding hydrated lime and cement raised the OWC from 6.8% to 10.2% and to 10.8%, respectively. This was caused by the ability of both hydrated lime and cement to absorb water and, hence, increased OWC values.

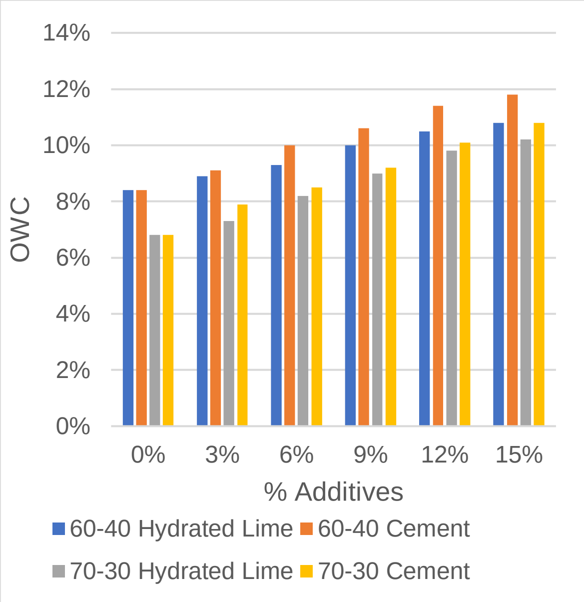

Figure 6. OWC test results for 60-40 and 70-30 aggregate gradations

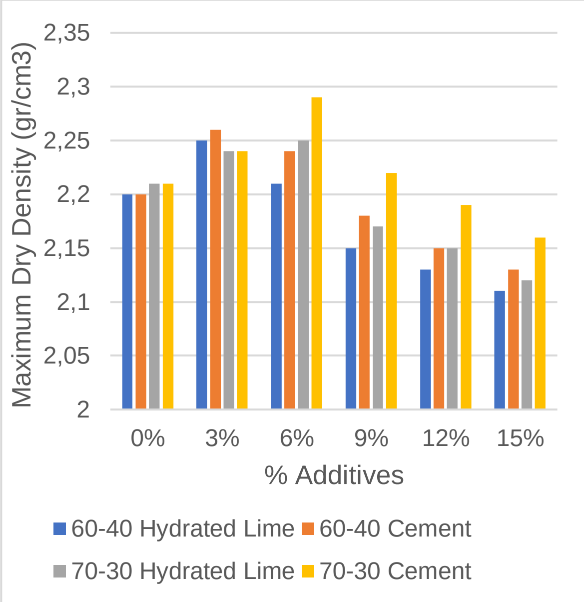

Figure 7. Dry density test results for 60-40 and 70-30 aggregate gradations

Looking at the data, it can also be seen that the aggregates that have been mixed with cement have higher OWC values than the ones that have been mixed with hydrated lime. This is caused by the hydration process in cement that requires water. Cement contains some materials that react with water, such as silica, iron sand, and gypsum.

The maximum dry density values for all variations that have been mixed with hydrated lime and cement are presented in Figure 7. For the 60-40 aggregate gradation, the highest maximum dry density was obtained when it was added with 3% of hydrated lime and cement, while for the 70-30 aggregate mix, the dry density value peaked when it was added with 6% of hydrated lime and cement. However, adding more additives after that resulted in decreasing dry density values, and the values starting from adding 9% additives were lower than the dry density of the control specimen or the one that had no additives, except for the 70-30 aggregate gradation, where the dry density values started to decrease when 12% of cement was added.

The increase in maximum dry density value was caused by the cement binding the coarse and fine aggregates together, resulting in a denser mixture. However, putting too much cement or hydrated lime causes the mixture not to bind well as there was excess material at fine size, which the decreasing values can show of maximum dry density.

Figure 8 shows the results of the CBR test for specimens with 60% coarse aggregate and 40% fine aggregate that have been mixed with hydrated lime and cement.

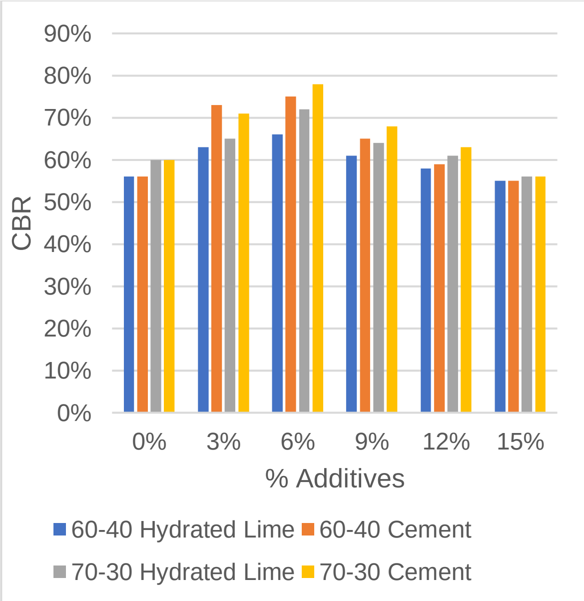

Figure 8. CBR test results for 60-40 and 70-30 aggregate gradations

Generally, the specimens that have been mixed with cement have higher CBR values than the ones that have been mixed with hydrated lime. It can also be seen that adding certain amounts of additives increased the CBR values. When the specimen was mixed with 3% and 6% hydrated lime, the CBR values increased from 56% to 63% and 66%, respectively, making the CBR values meet the specified requirement of 60%. However, the CBR values gradually decreased when 9%, 12%, and 15% of hydrated lime was added onto the mixture. Similar patterns can also be observed with the specimens that were mixed with cement. Adding cement up to 6% improved the CBR values even better than using the hydrated lime, but adding cement at higher percentages caused the CBR values to decrease. Adding 3% and 6% cement improved the CBR values from 56% to 73% and 75%, respectively. This, again, makes the aggregate mixtures meet the specified requirement. Adding 9% cement also increases the CBR value from 56% to 65%, which is lower than the values stated before. The decline in CBR values could be due to the fine size of both hydrated lime and cement that was present at an excessive amount in the mixture, which resulted in a drier mixture, as can be seen from the dry density results in Figure 7. The lower the dry density value, the lower the CBR would be.

For the specimens with 70% coarse aggregate and 30% fine aggregate, adding hydrated lime up to 12% improved the CBR values at varying values above 60%. Adding 3% and 6% hydrated lime increased the CBR values from 60% to 65% and 72%, respectively. Even though adding 9% and 12% hydrated lime increased the CBR values compared to the control sample (from 60% to 64% and 61%), the increase in CBR was not as much as 3% and 6%. Moreover, a similar trend was observed when adding cement to the mixture. Adding 3% and 6% cement improved the CBR values from 60% to 71% and 78%, respectively. Adding 9% and 12% also increased the CBR values, but not as much as 3% and 6%. The CBR values increase from 60% to 68% and 63% for 9% and 12% of cement, respectively. When more cement was added (15%), the CBR value decreased from 60% to 56%.

From the data, it can be observed that different percentages of additives can be mixed into the mixture to get satisfactory results. For the 60-40 mixture, adding either hydrated lime and cement at 3% or 6% was able to make the aggregate mixture meet the specifications. For the 70-30 mixture, adding up to 12% of either hydrated lime or cement increased the CBR values, as the control sample already has a CBR value of 60%. However, adding more than 6% of either of the additives only improves the CBR values by less than adding 3% or 6% of additives. Additionally, it can also be seen that adding cement to the mixture increased the CBR value more than adding hydrated lime.

Previous studies conducted by [32, 35, 36, 37] have shown that marginal aggregates stabilized with cement could be used as a subbase layer, and the CBR value was improved. This is similar to the finding of this research project, where it is possible to improve the CBR value of the specimens constructed from marginal aggregates by adding stabilizer, such as cement.

CONCLUSIONS

The objective of this research project was to find a technique to utilize local aggregate that does not meet the standard or marginal aggregate. The marginal aggregate used herein had lower bulk density and higher absorption values than those required in the Indonesian standards. Two methods were analyzed in this study, which varied the aggregate gradations and added lime and cement as stabilizers onto the specimens.

From the CBR test results, it was found that aggregate gradation affects the CBR values, and it can be concluded that a specimen that consisted of 70% coarse aggregate and 30% fine aggregate had the highest CBR value of 60%, which met the requirement to be used as pavement subbase layer. It was also found that the higher the percentages of fine aggregates used in the specimen, the higher the OWC would be, which was caused by the aggregates having high absorption values. The aggregate gradation also affected the maximum dry density due to the compactness of the specimen.

Furthermore, two selected aggregate gradations, which were 60-40 and 70-30 aggregate gradations, were mixed with lime and cement as stabilizers. The data found that adding lime and cement as stabilizers at the right amount improved the CBR values. For the 60-40 aggregate gradation, adding up to 6% of either lime or cement improved the CBR from below 60%, which did not meet the requirement, to above 60%. However, different percentages were required for 70-30 aggregate gradation. For 70-30 aggregate gradation, adding up to 6% of either lime or cement was also able to improve the CBR values and adding more than that up to 12% was also able to increase the CBR value but a decreasing rate. Additionally, the specimens that have been mixed with cement have higher CBR values than the ones that have been mixed with lime.

The research results have shown that the marginal aggregate can be used as a pavement layer. The CBR value was improved by choosing the correct gradation and using cement and hydrated lime as stabilizers at the right amount. For further research, it is recommended to apply these techniques to other types of marginal aggregates, to analyst other parameters, such as liquid limit and plasticity index, as stated in the 2018 General Specification for Road and Bridge construction work and to apply the modified marginal aggregates in-field.

ACKNOWLEDGEMENTS

This work is supported by the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology, Republic of Indonesia with contract number 179/E5/PG.02.00.PL/2023; 1402/LL3/AL.04/2023; 149/VR.RTT/VII/2023.

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