|  |  |
| --- | --- |
| THE USAGE OF MARGINAL AGGREGATE AS SUBBASE LAYER |  |

**Adelia Dwidarma Nataadmadja1\*, Eduardi Prahara1, and Andreas Bennardi1**

1Department of Civil Engineering, Faculty of Engineering, Binus University, Indonesia

|  |  |
| --- | --- |
| ***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, which 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 analyze the techniques to utilize marginal aggregates, so that they can be used as pavement layer, specifically as subbase. There were two techniques evaluated herein, namely by varying the aggregate gradation and by adding cement and lime as stabilizers, and the specimens were assessed by California Bearing Ratio (CBR) test. From the research results, it was found that varying the percentage of coarse and fine aggregates in the specimens was able to improve the CBR value. The highest CBR value was obtained by the specimen 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 certain percentage decreases the CBR value. The amount of cement and lime needed depended on the aggregate gradation used.*  *This is an open access article under the* [*CC BY-SA*](http://creativecommons.org/licenses/by-sa/4.0/) *license* | ***Keywords:***  *Marginal Aggregate, CBR Test, Subbase, Cement, Hydrated Lime*  ***Article History:***  *Received: May 2, 2019*  *Revised: May 29, 2019*  *Accepted: June 2, 2019*  *Published: June 2, 2019*  ***Corresponding Author:***  *Adelia Dwidarma Nataadmadja*  *Civil Engineering Department, Faculty of Engineering, Bina Nusantara University, Indonesia*  *Email: adelia.nataadmadja001@binus.ac.id* |

**INTRODUCTION**

It is important for pavement engineers 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 for both concrete and asphaltic mixtures that are used as surfacing layer are also consisted of mostly aggregates. Therefore, it can be concluded that the aggregate quality determines the pavement quality.

It is desirable for the road contractors to find aggregates and other materials from a source that is close to the project location to save on transportation costs. However, sometimes, the locally available aggregates do not meet the one or more of the specified requirements, and hence, the contractor need to look for the aggregates from another quarry that might be far from the construction site, which causing the cost to rise. The aggregate that does not meet one or more of the 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 there are several quarries that produce natural aggregates that do not meet one or more of the requirements as stated in Indonesian standards [6]–[8]. There is an increasing need that local road design should be able to adopt the available local material as much as possible [9]. It was suggested that where there are aggregates shortage or only marginal aggregates that are available locally, the road engineers should be able to adapt the road design to suit the local materials or to modify the materials by mechanical or chemical stabilization [10]. Incorporating marginal aggregates into the road construction can also improve the environmental sustainability [11].

According to [12], although marginal aggregate does not meet all the specified requirements, but this aggregate has the potential to be used in local roads that carry low traffic volume or to be mixed with additive substances [12]. The research projects that aimed to utilize marginal aggregate in pavements have also been done by other researchers worldwide [6], [12]–[19]. 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 [20], [21], crumb rubber [5], nano-silica [22], and by modifying the concrete mixture composition [2]. Various research projects have also shown the success in using marginal aggregate in pavement with or without mixing additives [6], [7], [14]. A study conducted by [13] has shown successful attempt to use limestone, slag, and unspecified substandard aggregates can be used as asphalt mixtures for surfacing layer.

Out of all methods, the two most commonly used method is to use cement and lime as stabilizer [23]. Both methods utilize the interaction between clay minerals in the marginal aggregate, water and lime. As explained in [23], the result of this chemical interaction bound the aggregate particles together, which able to strengthen the material, decrease the plasticity index, improve the durability performance, and reduce the potential change in volume [24]–[26]. Additionally, a study by [7] has shown a successful attempt to use marginal aggregate in North Sulawesi, Indonesia, to be used as base course layer by stabilizing it with cement.

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. There were two methodologies trialed in this study, which are varying the aggregate gradations and using 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 with varying percentages as an attempt to further increase the CBR value.

**EXPERIMENTAL DESIGN**

## **Aggregates**

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, needed to satisfy several requirements. Table 1 shows the tests conducted and the requirements asked.

Table 1. Aggregate Tests

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

The aggregates were sieved according to the grading for subbase layer, as stated in [27]. The proportion of coarse and fine aggregates were varied to find the composition that could produce the CBR value of at least 60%, as specified in SNI 1744:2012 [28]. 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 by sieve no. 4 were categorized as coarse aggregates. The proportion tested can be seen in Table 2. The composition that has the highest CBR value would be further tested by adding some additives to improve the CBR value.

Table 2. Aggregate Proportion

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

## **Additives**

There were two additives used in this research, namely Portland Cement Type I and Calcium Hydroxide (Ca(OH)2) or hydrated lime. Both cement and hydrated lime have been proved to be able to improve the CBR value of subgrade soil [29]. The size of the hydrated lime is between 0.177 mm and 0.149 mm. The additives were added separately at the same ratio, which were 3%, 6%, 9%, 12%, and 15%.

## **CBR Tests**

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 [30]. In this research, the CBR test was conducted according to SNI 1744:2012 [28]. 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 they were 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/cm3 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/cm3** | **2.14 gr/cm3** | Minimum of 2.5 gr/cm3 |
| SSD Specific Gravity | 2.51 gr/cm3 | 2.84 gr/cm3 |
| Apparent Specific Gravity | 2.70 gr/cm3 | 2.62 gr/cm3 |
| Absorption | **4.51%** | **8.52%** | Less than 3% |

## **Aggregate Gradation Test Results**

Figure 1 shows the results of Optimum Water Content (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, and this could be caused by the lower percentage of fine aggregate in the specimen. The fine aggregate, as shown in Table 3, has a higher absorption percentage than the coarse aggregate, and thus, the less fine aggregate present, the less water absorbed and needed.

Figure 1. OWC test results for each gradation

Each gradation variation was also tested for their maximum dry density values. The results in Figure 2 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 which resulted in the aggregates being less dense.

Figure 2. Dry Density test results for each gradation

Figure 3 shows the CBR test results for each gradation variation. It can be seen that as the percentage of coarse aggregate increased from 50% to 70%, there was an increase in CBR value from 41% to 60%. 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), and 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.

Figure 3. CBR test results for each gradation

## **The Effect of Additives on CBR Test Results**

The next step was to analyze the effect of mixing cement and hydrated lime onto the specimens. There were two compositions analyzed, which were the 60-40 and 70-30 compositions. 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 would be able to improve the CBR value to meet the specifications.

Figure 4 shows the OWC values for both 60-40 and 70-30 aggregate gradations that have been 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 a similar condition 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, resulted in the increase of OWC values.

Looking at the data, it can also be seen that the aggregates that have been mixed with cement has 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.

Figure 4. OWC test results for 60-40 and 70-30 aggregate gradations

The maximum dry density values for all variations that have been mixed with hydrated lime and cement are presented in Figure 5. 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, and hence, resulting in a denser mixture. However, putting too much cement or hydrated lime causes the mixture cannot bind well as there were excess material at fine size, which can be seen by the decreasing values of maximum dry density.

Figure 5. Dry density test results for 60-40 and 70-30 aggregate gradations

Figure 6 shows the results for CBR test results for specimens with 60% coarse aggregate and 40% fine aggregate that have been mixed with hydrated lime and cement. 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 was able to increase 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, when 9%, 12%, and 15% of hydrated lime was added onto the mixture, the CBR values gradually decreased. Similar patterns can also be observed with the specimens that were mixed with cement. Adding cement up to 6% was able to improve 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 was able to improve the CBR values from 56% to 73% and 75%, respectively. This, again, making the aggregate mixtures meet the specified requirement. Adding 9% cement also increase the CBR value from 56% to 65%, but this 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 drier mixture, as can be seen from the dry density results in Figure 5. 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% was to improve the CBR values at varying values that were above 60%. Adding 3% and 6% hydrated lime was able to increase the CBR values from 60% to 65% and 72%, respectively. Even though adding 9% and 12% hydrated lime was able to increase the CBR values compared to the control sample (from 60% to 64% and 61%), but the increase in CBR was not as much as 3% and 6%. Moreover, a similar trend was observed when adding cement onto the mixture. Adding 3% and 6% cement was able to improve the CBR values from 60% to 71% and 78%, respectively. Adding 9% and 12% was also able to increase 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 decreases from 60% to 56%.

From the data, it can be observed that there were different percentages of additives that can be mixed onto 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 was able to increase the CBR values, as the control sample has CBR value of 60% already. However, adding more than 6% of either of the additives only improves the CBR values by lesser amount compared to adding 3% or 6% of additives. Additionally, it can also be seen that adding cement onto the mixture was able to increase the CBR value more than adding hydrated lime.

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

**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 the values required in the Indonesian standards. There were two methods analyzed in this study, which were varying the aggregate gradations and adding 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 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 value. 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. From the data, it was found that adding lime and cement as stabilizers at the right amount was able to improve the CBR values. For the 60-40 aggregate gradation, adding up to 6% of either lime or cement was able to improve 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.

To sum up, the research results have shown that the marginal aggregate has the potential to be used as pavement layer by choosing the correct gradation and using cement and hydrated lime as stabilizers at the right amount was able to improve the CBR value. For further research, it is recommended to apply these techniques to other types of marginal aggregates and to apply the modified marginal aggregates in-field.

**REFERENCES**

[1] C. Maduabuchukwu Nwakaire, S. Poh Yap, C. Chuen Onn, C. Wah Yuen, and H. Adebayo Ibrahim, “Utilisation of recycled concrete aggregates for sustainable highway pavement applications; a review,” *Constr Build Mater*, vol. 235, p. 117444, 2020, doi: https://doi.org/10.1016/j.conbuildmat.2019.117444.

[2] G. B. Ramesh Kumar and U. K. Sharma, “Abrasion resistance of concrete containing marginal aggregates,” *Constr Build Mater*, vol. 66, pp. 712–722, 2014, doi: https://doi.org/10.1016/j.conbuildmat.2014.05.084.

[3] W. Li, D. J. Wilson, T. J. Larkin, and P. M. Black, “Factors determining the optimum moisture content (OMC) of greywacke aggregates from northern New Zealand,” *Transportation Geotechnics*, vol. 19, pp. 35–43, 2019, doi: https://doi.org/10.1016/j.trgeo.2019.01.006.

[4] W. Li, D. J. Wilson, T. J. Larkin, and P. M. Black, “An investigation into premium and marginal pavement aggregates from New Zealand,” *Quarterly Journal of Engineering Geology and Hydrogeology*, vol. 50, pp. 438–443, 2017, [Online]. Available: https://api.semanticscholar.org/CorpusID:135380008

[5] M. A. Franesqui, J. Yepes, and C. García-González, “Improvement of moisture damage resistance and permanent deformation performance of asphalt mixtures with marginal porous volcanic aggregates using crumb rubber modified bitumen,” *Constr Build Mater*, vol. 201, pp. 328–339, 2019, doi: https://doi.org/10.1016/j.conbuildmat.2018.12.181.

[6] H. R. A. Yamin, *Pemanfaatan dan Kinerja Agregat Substandar Sebagai Bahan Konstruksi Jalan*, 1st ed. 2013.

[7] H. R. A. Yamin, H. Vaza, and R. Sihotang, “Penggunaan Agregat Lokal Substandar di Kabupaten Talaud Sebagai Lapis Fondasi Jalan Ruas Beo-Esang,” *Jurnal HPJI* , vol. 1, no. 2, 2015.

[8] A. P. Adhitya, B. S. Subagio, D. Kosasih, and S. Hendarto, “Evaluasi Karakteristik Modulus Resilien dan Deformasi Permanen  Campuran Beton Beraspal (AC-Binder Course) Menggunakan Campuran  Agregat Berabrasi Tinggi,” *Jurnal Teknik Sipil*, vol. 23, no. 2, 2016.

[9] J. Cook, E. C. Bishop, C. Gourley, and N. E. Elsworth, “Promoting the use of marginal materials.,” 2000. [Online]. Available: https://api.semanticscholar.org/CorpusID:128251617

[10] J. R. Cook, R. C. Petts, and J. Rolt, “Low Volume Rural Road Surfacing and Pavements A Guide to Good Practice,” 2013.

[11] M. Pasetto, A. Baliello, A. Galgaro, E. Mogentale, and A. Sandalo, “Preliminary Study of an Energy Harvesting System for Road Pavements Made with Marginal Aggregate,” in *Proceedings of the 5th International Symposium on Asphalt Pavements & Environment (APE)*, M. Pasetto, M. N. Partl, and G. Tebaldi, Eds., Cham: Springer International Publishing, 2020, pp. 101–113.

[12] Q. L. Robnett, “Use of Marginal Materials in Highway Constructions,” 1980.

[13] Leksminingsih, “Penggunaan Agregat Sub Standar dan Agregat Lokal Untuk Campuran Beraspal,” *Jurnal Jalan Jembatan*, vol. 22, no. 4, 2005.

[14] R. C. Ahlrich, “Marginal Aggregates in Flexible Pavements: Laboratory Evaluation,” Washington, DC , 1977.

[15] B. K. Majumder, D. Animesh, and B. B. Pandey, “Cement Treated Marginal Aggregates for Roads,” *Journal of Materials in Civil Engineering*, vol. 11, no. 3, pp. 257–265, Aug. 1999, doi: 10.1061/(ASCE)0899-1561(1999)11:3(257).

[16] D. Y. Lee, “ Treating Iowa’s Marginal Aggregates and Soils by Foamix Process,” 1980.

[17] R. C. Ahlrich and R. S. Rollings, “Marginal Aggregates in Flexible Pavements: Background Survey and Experimental Plan,” 1994.

[18] P. G. Bly and C. A. Weiss Jr, “Performance of Concrete Pavement Mixtures with Marginal Aggregates: Laboratory Investigation,” in *10th International Conference on Concrete Pavements*, 2012.

[19] F. G. Bartley, “Marginal Aggregate Pavement Trials - Quarry Road, Drury,” 1984.

[20] E. H. Tan, E. M. M. Zahran, and S. J. Tan, “A comparative experimental investigation into the chemical stabilisation of sandstone aggregates using cement and styrene-butadiene copolymer latex for road sub-base construction,” *Transportation Geotechnics*, vol. 37, p. 100864, 2022, doi: https://doi.org/10.1016/j.trgeo.2022.100864.

[21] F.G. Bartley, C.C. Harvey, A.B. Christie, A. Reyes, R. Soong, and K. Faure, “Clay Mineralogy of Modified  Marginal Aggregates ,” Wellington, 2007.

[22] S. Begam Rasheda, B. Debnath, and D. Sarkar, “Application of nano-silica in rubber modified asphalt mix made with marginal aggregates,” *Mater Today Proc*, vol. 65, pp. 669–675, 2022, doi: https://doi.org/10.1016/j.matpr.2022.03.261.

[23] W. Li, D. J. Wilson, T. J. Larkin, and P. M. Black, “Laboratory Evaluation of Cement- and Lime-Treated Marginal Greywacke Aggregate,” *Journal of Transportation Engineering, Part B: Pavements*, vol. 145, no. 3, p. 4019027, 2019, doi: 10.1061/JPEODX.0000127.

[24] J. Nelson and D. J. Miller, *Expansive Soils: Problems and Practice in Foundation and Pavement Engineering*. Wiley, 1997.

[25] I. Jawad, I. Jawad, M. R. Taha, Z. Majeed, Z. Majeed, and T. A. Khan, “Soil Stabilization Using Lime: Advantages, Disadvantages and Proposing a Potential Alternative,” *Research Journal of Applied Sciences, Engineering and Technology*, vol. 8, pp. 510–520, 2014, [Online]. Available: https://api.semanticscholar.org/CorpusID:55590997

[26] A. A. Al-Rawas, A. W. Hago, and H. Al-Sarmi, “Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman,” *Build Environ*, vol. 40, no. 5, pp. 681–687, 2005, doi: https://doi.org/10.1016/j.buildenv.2004.08.028.

[27] Kementerian Pekerjaan Umum dan Perumahan Rakyat, “Spesifikasi Umum 2018 Untuk Pekerjaan Konstruksi Jalan dan Jembatan.” 2018.

[28] Badan Standardisasi Nasional, “SNI 1744: 2012 Metode Uji CBR Laboratorium (=AASHTO T 193-81).” Jakarta, 2012.

[29] A. Ullah, D. Boumezerane, and F. Ahmad, “Subgrade improvement with mixed lime and cement as additives,” *Mater Today Proc*, 2023, doi: https://doi.org/10.1016/j.matpr.2023.05.706.

[30] J.-P. Magnan and M. Ndiaye, “Determination and assessment of deformation moduli of compacted lateritic gravels, using soaked CBR tests,” *Transportation Geotechnics*, vol. 5, pp. 50–58, 2015, doi: https://doi.org/10.1016/j.trgeo.2015.09.006.