Performance Evaluation of West Kupang Quarry Rock as Coarse Aggregate in a Class A Aggregate Base Mixture

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Article History

Received	Revised	Accepted	Published
July 09, 2026	*August 15, 2026*	*August 30, 2026*	*30 August 2026*

How to Cite

Tlonaen, A. (2026). Performance evaluation of West Kupang Quarry rock as coarse aggregate in a Class A aggregate base mixture. Cornerstone Civil Engineering Journal, 1(1), 77–85. https://ejournal.atkup.ac.id/index.php/ccej/article/view/9

ABSTRACT

Locally sourced rock can reduce haulage demand in road construction, but a Class A aggregate base must perform as an engineered granular mixture rather than as an unprocessed quarry material. This study evaluates crushed mountain rock from the West Kupang Quarry, East Nusa Tenggara, as the coarse-aggregate component of a Class A aggregate base blended with natural river sand. The laboratory blend comprised 30% 1.5-in crushed rock, 10% 0.75-in crushed rock, and 60% natural sand. Compliance was assessed using combined gradation, Los Angeles abrasion, fractured-particle content, Atterberg limits, fines indices, modified compaction, and soaked California Bearing Ratio (CBR), with the General Specifications of Bina Marga 2018 Revision 2 as the principal criterion. The measured blend remained within the Class A gradation envelope. Abrasion was 22.77%; particles with one or more fractured faces and two or more fractured faces were 96.86% and 91.20%, respectively. The liquid limit was 20.9%, the plasticity index was 4.67%, the PI-times-No.200 value was 11.1, and the No.200/No.40 passing ratio was 0.171. Maximum dry density was 2.068 g/cm³ at 5.66% optimum moisture content, and soaked CBR reached 92.4%. All measured criteria complied with Class A limits. Because the clay-lump/friable-particle result was not documented, final specification acceptance remains conditional on that verification and field quality control.

Keywords: *Class A aggregate base; coarse aggregate; gradation; fractured particles; soaked CBR*

ABSTRAK

Pemanfaatan batuan lokal dapat mengurangi kebutuhan pengangkutan material pada pekerjaan jalan, tetapi Lapis Fondasi Agregat Kelas A harus dinilai sebagai campuran granular yang direkayasa, bukan sekadar sebagai material quarry. Penelitian ini mengevaluasi batu cadas pecah dari Quarry Kupang Barat, Nusa Tenggara Timur, sebagai komponen agregat kasar dalam campuran Agregat Kelas A yang dipadukan dengan pasir alam sungai. Campuran laboratorium terdiri atas 30% batu pecah 1,5 inci, 10% batu pecah 0,75 inci, dan 60% pasir alam. Evaluasi meliputi gradasi gabungan, abrasi Los Angeles, butiran pecah, batas Atterberg, indikator fraksi halus, pemadatan berat, dan California Bearing Ratio (CBR) rendaman dengan Spesifikasi Umum Bina Marga 2018 Revisi 2 sebagai acuan utama. Gradasi campuran berada di dalam amplop Kelas A. Nilai abrasi 22,77%; butiran dengan satu atau lebih bidang pecah 96,86% dan dua atau lebih bidang pecah 91,20%. Batas cair 20,9%, indeks plastisitas 4,67%, hasil kali PI dengan persen lolos No.200 sebesar 11,1, dan rasio lolos No.200/No.40 sebesar 0,171. Berat isi kering maksimum 2,068 g/cm³ pada kadar air optimum 5,66%, sedangkan CBR rendaman mencapai 92,4%. Seluruh parameter terukur memenuhi batas Kelas A. Namun, hasil uji gumpalan lempung/butiran mudah pecah belum terdokumentasi sehingga penerimaan spesifikasi penuh tetap memerlukan verifikasi parameter tersebut dan pengendalian mutu lapangan.

Kata Kunci: *Lapis Fondasi Agregat Kelas A; agregat kasar; gradasi; butiran pecah; CBR rendaman*

1. INTRODUCTION

Unbound aggregate base is a structural layer whose load-transfer capacity emerges from the interaction of particle size distribution, particle contact, density, moisture condition, and the quality of both coarse and fine fractions. Consequently, meeting a single strength index is not sufficient to demonstrate a reliable base-course material. Research on unbound aggregates shows that gradation, fines content, plasticity, dust ratio, particle morphology, and moisture condition can jointly affect strength, resilient response, and permanent deformation (Osouli et al., 2017, 2019, 2021a, 2021b).

For Class A aggregate base under the Indonesian General Specifications of Bina Marga 2018 Revision 2, this multi-parameter concept is translated into acceptance limits for gradation, Los Angeles abrasion, fractured-particle content, liquid limit, plasticity index, the product of plasticity index and percent passing the No. 200 sieve, clay lumps and friable particles, soaked CBR, and the ratio of percent passing the No. 200 and No. 40 sieves (Direktorat Jenderal Bina Marga, 2020). The specification requires, among other criteria, a maximum abrasion of 40%, fractured faces of 95/90 for one-or-more/two-or-more faces, a liquid limit not exceeding 25%, a plasticity index not exceeding 6%, and a soaked CBR of at least 90%.

The use of local quarry resources can be technically and economically attractive when long-distance haulage is a constraint, but local origin does not by itself imply compliance. Indonesian studies have reported substantial variability among quarry materials and mixture designs. Matulessy et al. (2022) reported a Class A base mixture from the Saoka Quarry with 20.93% abrasion and a CBR of 100%. Santoso et al. (2023) showed that changing the proportion of natural sand in a Class A base mixture changed both optimum moisture content and CBR, with one tested sand-rich variant falling below the 90% CBR requirement. Research in East Nusa Tenggara also confirms that local aggregate sources should be characterized individually because abrasion, absorption, and gradation can differ between quarries (Sasi et al., 2025).

Particle shape is particularly relevant to the coarse skeleton of an unbound base. Janoo et al. (2004) demonstrated that aggregate angularity influences the mechanical behavior of base materials, while later work has emphasized that the contribution of fines cannot be separated from gradation and plasticity (Osouli et al., 2017, 2021a, 2021b). These findings support an evaluation framework in which the coarse rock is assessed for durability and fractured faces, the fine fraction is assessed for plasticity, and the final blend is assessed for gradation, compaction, fines indices, and bearing capacity.

The West Kupang Quarry provides mountain rock that can be processed into crushed coarse aggregate. In this study, the engineering question is deliberately narrower than a general road-earthwork feasibility assessment: the objective is to determine whether crushed West Kupang rock, when used only as the coarse component and blended with natural river sand, can form a Class A aggregate base mixture that satisfies the measured Bina Marga criteria. This distinction is important because Class A aggregate base is an engineered mixture with a substantially higher bearing-capacity requirement than ordinary or selected fill.

Accordingly, this study aims to (1) evaluate the abrasion resistance and fractured-particle characteristics of West Kupang crushed rock; (2) evaluate the combined gradation and fines-related properties of a blend containing West Kupang rock and natural river sand; (3) determine its compaction characteristics and soaked CBR; and (4) establish a transparent compliance matrix against the Class A requirements. The novelty lies in separating the functional roles of the coarse quarry rock and the natural-sand stockpile while evaluating their combined performance as a designed Class A base mixture.

2. METHODS

2.1 Research Design

A laboratory experimental design with descriptive-comparative analysis was used. The test program was organized around the functional contribution of each stockpile and the performance of the combined mixture. Results were compared directly with the Class A aggregate-base limits in the General Specifications of Bina Marga 2018 Revision 2 (Direktorat Jenderal Bina Marga, 2020).

2.2 Materials and Mixture Design

The coarse component consisted of processed mountain rock from the West Kupang Quarry, Kupang Regency, East Nusa Tenggara. The fine component was natural river sand. The laboratory stockpile blend contained 30% 1.5-in crushed rock, 10% 0.75-in crushed rock, and 60% natural sand by mass. These are stockpile proportions; the final coarse/fine distribution is governed by the measured combined gradation rather than by the nominal stockpile labels alone.

2.3 Laboratory Testing

The coarse rock was evaluated using Los Angeles abrasion (SNI 2417:2008) and fractured-particle testing (SNI 7619:2012). Fine-material consistency was evaluated using the liquid-limit test (SNI 1967:2008) and the plastic-limit/plasticity-index test (SNI 1966:2008). The combined blend was assessed by sieve analysis against the Class A gradation envelope, modified/heavy compaction (SNI 1743:2008), and soaked CBR (SNI 1744:2012). The Bina Marga requirement for clay lumps and friable particles refers to SNI 4141:2015; however, a numerical result for this test was not present in the available laboratory record and is therefore treated as an unverified acceptance item rather than assumed to comply.

2.4 Derived Indices and Compliance Logic

Two fines-related indices were calculated from the reported test data. First, the product of plasticity index and percent passing the No. 200 sieve was calculated as PI × P200. Second, the dust ratio was calculated as P200/P40. For minimum requirements, a result was classified as compliant when the measured value equaled or exceeded the specified threshold; for maximum requirements, compliance required the measured value not to exceed the limit. Parameters without documented test results were classified as not verified.

2.5 Standards and Technical Criteria

Table 1. Evaluation framework for Class A aggregate base

Parameter	Reference	Class A criterion
Combined gradation	Bina Marga 2018 Rev. 2	Within Class A envelope
Los Angeles abrasion	SNI 2417:2008	≤ 40%
Fractured particles retained No. 4	SNI 7619:2012	≥95% one-or-more faces; ≥90% two-or-more faces
Liquid limit	SNI 1967:2008	≤ 25%
Plasticity index	SNI 1966:2008	≤ 6%
PI × % passing No. 200	Calculated	≤ 25
Clay lumps/friable particles	SNI 4141:2015	≤ 5%
Soaked CBR	SNI 1744:2012	≥ 90%
% passing No. 200 / No. 40	Calculated	≤ 2/3

Source: Direktorat Jenderal Bina Marga (2020) and applicable SNI standards.

3. RESULTS

3.1 Coarse-Aggregate Durability and Fractured Faces

The Los Angeles abrasion trials produced losses of 22.58% and 22.96%, giving an average abrasion value of 22.77%. This is 17.23 percentage points below the 40% maximum. The reported fractured-particle percentages were 96.86% for particles with at least one fractured face and 91.20% for particles with at least two fractured faces. When stated in the order used by Bina Marga (one-or-more/two-or-more), the result is therefore 96.86/91.20, which exceeds the 95/90 requirement.

Table 2. Coarse-aggregate abrasion and fractured-particle results

Test	Trial I	Trial II	Reported/derived result
Abrasion (%)	22.58	22.96	Average = 22.77%
One or more fractured faces (%)	95.70	98.03	Average = 96.86%
Two or more fractured faces (%)	92.55	89.86	Average = 91.20%

Source: Laboratory test records supplied by the author.

3.2 Combined Gradation

The measured stockpile blend was 30% 1.5-in crushed rock, 10% 0.75-in crushed rock, and 60% natural sand. The combined passing percentages were 100.00% at 37.5 mm, 83.54% at 25.0 mm, 47.60% at 9.50 mm, 38.93% at 4.75 mm, 25.94% at 2.00 mm, 13.89% at 0.425 mm, and 2.37% at 0.075 mm. Every measured point fell inside the Class A envelope.

Table 3. Stockpile and combined gradation of the Class A mixture

Sieve	mm	30% rock 1½ in	10% rock ¾ in	60% natural sand	Blend passing (%)	Class A range	Status
1½ in	37.5	100.00	100.00	100.00	100.00	100	Complies
1 in	25	72.47	100.00	86.34	83.54	79–85	Complies
3/8 in	9.5	0.91	3.64	78.27	47.60	44–58	Complies
No. 4	4.75	0.00	1.18	64.69	38.93	29–44	Complies
No. 10	2	0.00	0.25	43.19	25.94	17–30	Complies
No. 40	0.425	0.00	0.19	23.12	13.89	7–17	Complies
No. 200	0.075	0.00	0.11	3.92	2.37	2–8	Complies

Source: Laboratory sieve-analysis record and Bina Marga Class A gradation limits.

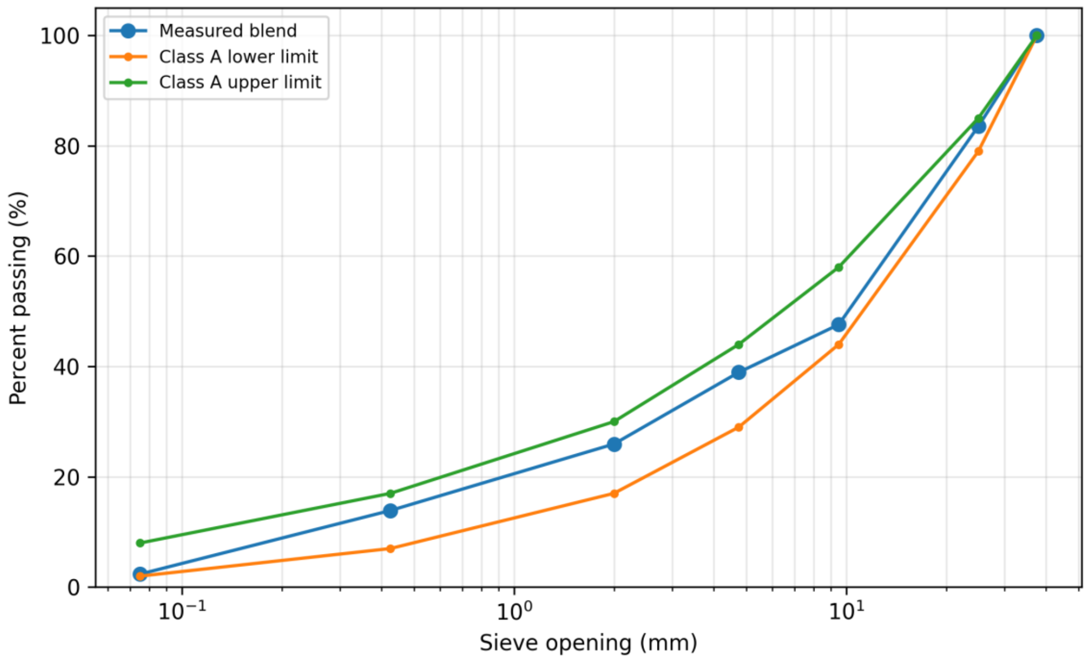

Figure 1. Measured combined gradation relative to the Class A specification envelope

Source: Author's analysis based on laboratory gradation data and Direktorat Jenderal Bina Marga (2020).

3.3 Fine-Fraction Consistency and Fines Indices

The liquid limit of the fine fraction was 20.9%, while the plastic limit was 16.23%, producing a plasticity index of 4.67%. The blend contained 2.37% passing the No. 200 sieve and 13.89% passing the No. 40 sieve. Accordingly, PI × P200 = 4.67 × 2.37 = 11.07 (reported as 11.0), and the P200/P40 ratio = 2.37/13.89 = 0.171. Both derived indices comply with the specified maxima of 25 and 2/3, respectively.

Table 4. Fine-fraction and fines-related compliance results

Fine/fines parameter	Result	Class A limit	Status
Liquid limit	20.9%	≤25%	Complies
Plastic limit	16.23%	Informative	—

Plasticity index	4.67%	≤6%	Complies
PI × P200	11.07	≤25	Complies
P200/P40 ratio	0.171	≤0.667	Complies
Clay lumps/friable particles	Not documented	≤5%	Not verified

Source: Laboratory test records and calculations in this study.

3.4 Compaction and Soaked Bearing Capacity

The heavy-compaction dataset produced a reported maximum dry density of 2.068 g/cm³ at an optimum moisture content of 5.66%. The individual laboratory points show the expected rise and fall in dry density around the optimum zone. At the reported maximum dry density condition, the soaked CBR was 92.4%, exceeding the Class A minimum by 2.4 percentage points.

Table 5. Compaction test points

Measured moisture content (%)	3.09	4.76	6.32	7.21	8.15
Dry density (g/cm³)	1.96	2.05	2.07	2.02	1.97

Source: Laboratory test records supplied by the author.

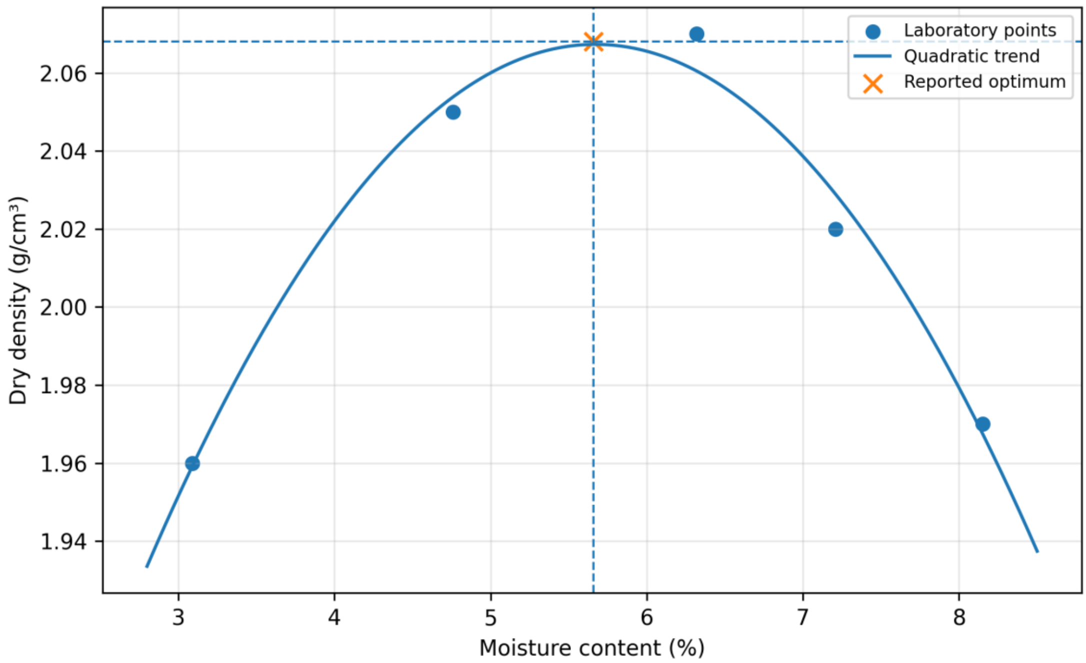

Figure 2. Moisture–dry density relationship and reported optimum condition

Source: Author’s analysis of the reported compaction data.

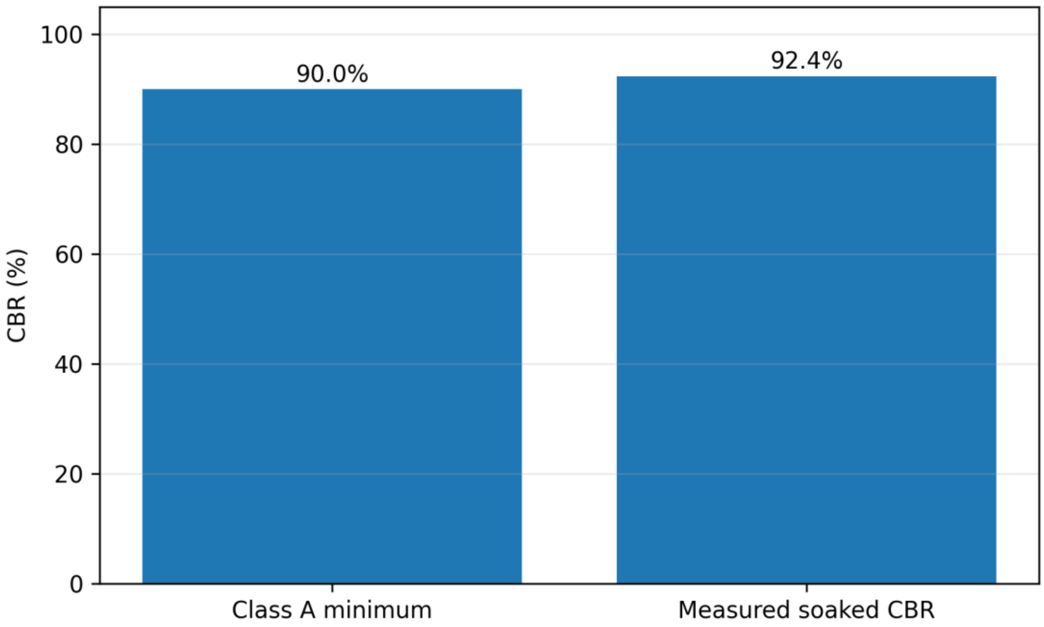

Figure 3. Soaked CBR result relative to the Class A minimum requirement
Source: Author's analysis based on laboratory CBR data and Direktorat Jenderal Bina Marga (2020).

3.5 Compliance Summary

Table 6. Compliance matrix for the reported Class A mixture

Acceptance item	Evidence	Evaluation
Combined gradation	All measured sieve points within envelope	Complies
Los Angeles abrasion	22.77% ≤ 40%	Complies
Fractured particles	96.86/91.20 ≥ 95/90	Complies
Liquid limit	20.9% ≤ 25%	Complies
Plasticity index	4.67% ≤ 6%	Complies
PI × P200	11.07 ≤ 25	Complies
P200/P40	0.171 ≤ 0.667	Complies
Soaked CBR	92.4% ≥ 90%	Complies
Clay lumps/friable particles	No numerical laboratory result available	Not verified

Source: This study, evaluated against Direktorat Jenderal Bina Marga (2020).

4. DISCUSSION

The results indicate that the West Kupang crushed rock performs satisfactorily as the coarse skeleton of the tested Class A blend. An abrasion value of 22.77% is comfortably below the 40% limit and is comparable to values reported for other Indonesian quarry materials. Matulessy et al. (2022), for example, reported 20.93% abrasion for a Class A mixture using Saoka Quarry material, while Sasi et al. (2025) reported 17.19% and 25.10% for two local aggregate sources in North Central Timor. The West Kupang value falls within this local range, supporting its durability against laboratory impact and abrasion.

The fractured-face result is also structurally relevant. Expressed in the specification order, 96.86% of the coarse aggregate had at least one fractured face and 91.20% had two or more fractured faces, exceeding the 95/90 requirement. This high proportion of crushed surfaces is expected to support particle interlock and friction within the granular skeleton. Janoo et al. (2004) showed that aggregate angularity affects the mechanical response of base materials, although angularity alone does not uniquely determine resilient behavior. The present result should therefore be interpreted as a favorable coarse-aggregate quality indicator that works together with gradation and compaction rather than as an independent guarantee of performance.

The combined gradation is a major strength of the mixture design. All measured points lie within the Class A envelope, including the 2.37% passing No. 200 and 13.89% passing No. 40. The calculated dust ratio of 0.171 is well below the Bina Marga limit of 2/3. International research has shown that fines content, plasticity, dust ratio, and gradation interact in controlling both CBR and repeated-load deformation (Osouli et al., 2017, 2019, 2021a, 2021b). In the present blend, the low PI of 4.67% and low dust ratio indicate that the fine fraction is unlikely to dominate the mixture through excessive plastic fines under the tested condition.

The use of a natural-sand stockpile deserves specific attention because the nominal 60% stockpile proportion does not imply that 60% of the final mixture is finer than the No. 4 sieve. The natural-sand stockpile itself has a distributed gradation; after blending, only 38.93% of the mixture passes the No. 4 sieve. This distinction is important when interpreting mix proportions and helps explain why a high nominal sand-stockpile percentage can still produce a compliant dense gradation. Santoso et al. (2023) found that increasing natural-sand substitution can materially change Class A CBR, with one tested composition falling below 90%. Their result supports the need to control the actual combined gradation rather than relying on stockpile percentages alone.

The soaked CBR of 92.4% confirms adequate bearing capacity under the tested condition, but the margin above the 90% minimum is relatively narrow. This 2.4-percentage-point margin implies that field variability in moisture content, segregation, fines content, or compaction could move production material below the acceptance threshold if quality control is weak. The result should therefore be treated as compliant but not overinterpreted as having a large reserve. The reported optimum moisture content of 5.66% and maximum dry density of 2.068 g/cm³ provide practical targets for laboratory-to-field compaction control.

Compared with other local-material studies, the present work contributes a more function-specific assessment. Sirait et al. (2023) emphasized the need to determine a suitable mixture composition when local quarry materials are used for Class A aggregate base, while Sasi et al. (2025) showed that even geographically related local sources can have materially different properties. The West Kupang mixture adds evidence from Timor Island that locally processed rock can satisfy the measured Class A criteria when the coarse stockpile is intentionally blended with a compatible natural-sand component.

Two limitations should be resolved before final publication and field acceptance. First, the available laboratory record does not contain a numerical result for clay lumps and friable particles, although this is an explicit Class A acceptance parameter. Second, the raw fractured-particle worksheet should be rechecked for mass-balance consistency before archival publication; the percentage results are internally usable for compliance evaluation, but the reported raw masses in one trial do not fully reconcile with the stated total sample mass. These issues do not change the reported abrasion, gradation, plasticity, compaction, or CBR results, but transparent verification will strengthen the traceability of the study.

5. CONCLUSION

This study concludes that crushed mountain rock from the West Kupang Quarry is technically suitable as the coarse-aggregate component of the tested Class A aggregate base blend on the basis of the documented acceptance parameters. The mixture, composed of 30% 1.5-in crushed rock, 10% 0.75-in crushed rock, and 60% natural sand, satisfied the Class A gradation envelope. The coarse aggregate recorded 22.77% Los Angeles abrasion, 96.86% particles with one or more fractured faces, and 91.20% with two or more fractured faces. The fine fraction had a liquid limit of 20.9% and a plasticity index of 4.67%; PI × P200 was 11.07 and the P200/P40 ratio was 0.171. The mixture reached a maximum dry density of 2.068 g/cm³ at 5.66% optimum moisture content and a soaked CBR of 92.4%, exceeding the 90% minimum. These results demonstrate that the engineered blend meets all measured Class A criteria. Final specification acceptance should nevertheless remain conditional on documenting the clay-lump/friable-particle test and maintaining strict field control of gradation, moisture, and compaction because the CBR margin above the minimum is modest.

ACKNOWLEDGEMENTS

The author would like to express sincere appreciation to the laboratory personnel and technical staff who assisted with aggregate preparation and laboratory testing. The author also acknowledges the Civil Engineering Study Program, Kupang Academy of Engineering, for its academic and institutional support during the preparation of this study.

AUTHOR CONTRIBUTIONS

Agnesius Tlonaen was solely responsible for conceptualization, methodology, laboratory investigation, data collection, data analysis and interpretation, validation of results, preparation of the original manuscript, review, editing, and final approval of the manuscript for publication.

FUNDING STATEMENT

This research received no external funding.

CONFLICT OF INTEREST STATEMENT

The author declares that there is no conflict of interest regarding the publication of this article.

DATA AVAILABILITY STATEMENT

The laboratory data and supporting records used in this study are available from the corresponding author upon reasonable request.

ETHICAL STATEMENT

This study was based on laboratory testing of construction materials and did not involve human participants or experimental animals. All cited data sources and technical references have been properly acknowledged.

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