Available *online* at: http://journal.unj.ac.id

Jurnal Pensil Pendidikan Teknik Sipil

Journal homepage: http://journal.unj.ac.id/unj/index.php/jpensil/index

INVESTIGATION OF THE COMPRESSIVE STRENGTH OF CORAL AGGREGATE CONCRETE USING CORALLINE LIMESTONE AS COARSE AGGREGATE

Alva Yuventus Lukas [1], Rafael. J. W. M [2], Maria Y. M. Making [3], Dewi A. I. Wuwur [4]*

[1,2,3,4] Program Studi Teknik Sipil, Politeknik Negeri Kupang

Jalan Adi Sucipto Penfui Kupang Nusa Tenggara Timur P.O Box 139

[*1]alva.lukas@pnk.ac.id, [2]jusuf.rafael@pnk.ac.id, [3]maria.menge.making@pnk.ac.id, [4]ewi.ipah.wuwur@pnk.ac.id

P-ISSN: 2301-8437
E-ISSN: 2623-1085

ARTICLE HISTORY
Accepted:
30 Maret 2025
Revision:
20 Mei 2025
Published:
30 Mei 2025

ARTICLE DOI:
10.21009/jpensil.v14i2.54385

Abstract

Utilization coral limestone aggregate as a sustainable alternative in the construction industry has become critical in order to reduce reliance on traditional aggregates. Previous research Lukas A. Y, et al. revealed that concrete with fine aggregate of zone IV gradation and coarse aggregate coralline limestone replacing 25% coarse aggregate gravel can raise compressive strength concrete to 33.37 MPa. It is predicted that fine aggregate with a zone IV gradation, which has small particle sizes, will fill voids in concrete, enhancing its strength. However, increasing coralline limestone component to 50% reduces concrete compressive strength. This suggests that macroscopically, fine particles of zone IV grading have yet to make a significant contribution to increase in concrete compressive strength. Therefore, the current study attempts to optimize concrete mix employing fine aggregate with zone II gradation and its impact on concrete compressive strength. Meanwhile, study employs a laboratory experimental test for compressive strength and ultrasonic pulse velocity, with a target concrete compressive strength of 30 MPa. Study found concrete with coralline limestone content of 0%, 5%, 25%, 50%, and 75%, as well as fine aggregate from zone II grading, had 28-day compressive strengths of 20.27 Mpa, 22.10 Mpa, 23.80 Mpa, 24.42 Mpa, and 18.19 Mpa. Fine aggregate in Grading Zone II reduces concrete strength.

Keywords: Concrete Compressive Strength, Coralline Limestone Aggregate, Coral Aggregate Concrete, Fine Aggregate Gradation Zone

Introduction

As a result of technological advancements and their impact on resources, the building sector has undertaken a transformation toward greater sustainability. Using local materials in the manufacturing of concrete is one possible course of action.One environmentally friendly development in concrete forming materials is the use of coral aggregate (CA) as a local aggregate (Zhang. Jinhua. et al, 2021a); Wu. Zhangyu. et al, 2020). By using coral aggregate, we may lessen our reliance on conventional aggregates, which are frequently acquired through mining operations that impact to the environment. Utilizing coral aggregate in the production of concrete can also effectively mitigate the scarcity of building supplies in island regions, thereby reducing the energy required for their transportation from the mainland.

Coralline limestone is one example of a local coral aggregate that could be used in concrete manufacturing. According to geological studies, coralline limestone in East Nusa Tenggara is most commonly found on Semau Island, Rote Island, and Timor Island, especially in the western Kupang region (Krisnasiwi. I. F. et. al, 2025 ; Boimau. Y. et al, 2024 ; Kotta. H. Z. et. al, 2022 ; Setiani. E. et al, 2015). Although this rock has potential, its usage in the East Nusa Tenggara construction sector remains limited; it is now used only as a foundation layer in road construction, building foundations, and building walls(Made Suparta. I. et al, 2024 ; Leto. R. M. et al, 2023). As a result, more research is needed on the usage of coralline limestone aggregate in concrete.

In general, there are four methods that can be applied to improve the performance of concrete using coral aggregate (Huang. Yijie. et. al, 2024 ; Liang. Xiangzhou. et. al, 2021), namely: first, strengthening the coral aggregate itself through cleaning and reinforcement by applying a layer of cement (Chu. Yingjie. et al, 2021 ; Wang. Aiguo. et al, 2021). Second, optimizing the concrete mix. Third, adding cementitious materials (A. Wang et al., 2022 ; X. Wang et al., 2017). Fourth, blending fibers (Zhang et al., 2025a) ; (Dai et al., 2024). The optimization of concrete mixtures employing coralline limestone aggregate will be the main emphasis of this study. For getting clear of the chloride ions that are adhering to the coralline limestone aggregate, it will be cleaned with ordinary water before usage.

Concrete produced with coral aggregate (CA) can be referred to Coral Aggregate Concrete (CAC). Many studies have shown that it is feasible to use coral aggregate (CA) in concrete. However, it is necessary to develop the appropriate mix proportions based on the grading of CA and the grading of fine aggregates (Guo et al., 2024a). The advantage of CAC is that it has a higher initial strength than conventional concrete, but the strength will be slightly lower after more than 28 days. Additionally, high-quality CAC can last 10-15 years in its usage period (Zhou. Linlin. et al, 2021).

Coral aggregate concrete (CAC), which consists of coral coarse aggregate (CA), water, fine aggregate (sea sand or natural sand), and cement, has become a popular study topic due to its outstanding performance, specifically lightweight, high efficiency, cost-effectiveness, and the utilization of local materials. The study of CAC has been developing ever since 1951 and continues to this day (Da et al., 2016 ; (Yu et al., 2017)). A large number of studies on CAC materials and components, involving raw mix materials (Lyu Bangcheng. et al, 2019), preparation technology, basic mechanical properties (Wu Zhang. Yu. et al, 2021), and durability (Wu Zhang. Yu et al, 2020), has been systematically conducted by many scholars over the past few decades. However, there has been little published research on how the use of coralline limestone affects the static mechanics of CAC. Therefore, it is important to explore the effects of using coralline limestone on the mechanics of CAC, in terms of the proper mix proportions based on CA gradation, fine aggregate gradation, concrete density quality, concrete mix workability, specific gravity, and crack patterns.

Compressive strength of concrete is also influenced by the grading zone of fine aggregates (sand). Pramadani Mita. et al (2024), show the relationship between the influence of sand gradation zones and the compressive strength of mortar. Sand gradation zones of I and II reduce the workability of the mortar due to the extensive water absorption by the sand and poor setting time, thereby lowering the quality of the mortar. Meanwhile, sand grading zones of III and IV have better performance in increasing the compressive strength of mortar. Lukas A. Y et al., 2024 show that the use of zone IV sand applied to concrete with coralline limestone aggregate can enhance performance by increasing the compressive strength of the concrete to 33.37 MPa with a coralline limestone content of 25% as a substitute for gravel. However, when the percentage of coralline limestone increased to 50%, the compressive strength of the concrete decreased to 29.51 MPa. These findings indicate that sand grading of zone IV has not yet had a significant impact on the compressive strength of concrete when the proportion of coralline limestone aggregate in the concrete mix is increased. Therefore, the objective of this study is to optimize the concrete mix by evaluating the extent of the contribution of the sand grading of zone II and the amount of coralline limestone used as a substitute for gravel in influencing the compressive strength of the concrete.

Density of concrete directly affects the compressive strength of concrete. The greater the density of the concrete, the higher the compressive strength it usually produces. The increase in the number of particles in the concrete mix causes more intense interactions between the particles, thereby creating a denser and stronger structure. Thus, understanding the quality of concrete density is very important, Putra D. M (2021) shows that conventional concrete with higher density tends to exhibit lower porosity, thereby supporting increased compressive strength. Zhou Wen. et al (2020) reported that, compared to ordinary concrete, concrete made from coral aggregate (reef limestone) has a lower density. This is due to the porous structure of the coral aggregate (reef limestone). Fikri M. et. al (2024) and Abdullah D. M. et al (2024) inform that coarse aggregates derived from limestone can be utilized as materials in concrete production. At an aggregate water absorption rate of 2%, the compressive strength of the concrete reaches 27.88 MPa, whereas at a concentration of 6%, the compressive strength of the concrete decreases by 136.30 kg/cm². This indicates that the quality of concrete density is questionable. However, this research was not followed up with testing on the quality of concrete density. Lukas. A. Y & Rafael. J. W. M (2024) conducted an evaluation of the concrete density quality using limestone as coarse aggregate. The quality of concrete density was measured using the ultrasonic pulse velocity (UPV) method. The results of this study indicate that concrete using coarse limestone aggregate and fine aggregate in grading zone of IV has a concrete density quality classified as "Excelent" and a compressive strength of 33.37 MPa. However, this study is limited to the use of 50% limestone coarse aggregate in the concrete mix. Therefore, the innovation in this research is to assess the quality of concrete density and compressive strength using 75% coarse corraline limestone aggregate as a substitute for gravel coarse aggregate in concrete specimens. Meanwhile, for fine aggregate, natural sand in grading zone of II, which falls into the medium sand category, was used.

Meanwhile, the assessment of concrete density quality is based on the BS (British Standard) 1881 Part 203, ACI 214R-02, and ASTM C597-16 standards (Hutagalung L. P. et. al, 2022 ; Ma'arif et al., 2022). The assessment of concrete density quality refers to the average value of the longitudinal wave propagation speed of the UPV device and the coefficient of variation, as shown in Table 1 and Table 2 below.

The contribution of this research is to introduce the use of coralline limestone as coarse aggregate in concrete, which can reduce dependence on conventional aggregates and provide guidance to practitioners in the construction industry regarding the use of environmentally friendly local aggregates, as well as the potential to enhance sustainability in infrastructure development in East Nusa Tenggara.

Table 1. Concrete quality classification using the UPV tool's wave propagation velocity

	Pulse Velocity (m/s)	**Concrete conditions**
Concrete Quality	> 4500	Excelent
	3500 - 4500	Good
	3000 – 3500	Medium
	< 3000	Doubtful

Table 2. Concrete Control Standard

Class of Operation	Coefficient of Variation for Diefferent Controls Standard, %				
	Excelent	**Very Good**	**Good**	**Fair**	**Poor**
Field Construction Testing	< 3	3 to 4	4 to 5	5 to 6	> 6

Research Methods

Material

This study uses coarse gravel aggregate, coralline limestone aggregate, and fine aggregate (natural sand) according to the particle sizes shown in Figure 1. Coarse gravel aggregate falls within grading of zone II according to SNI 03:2834:2000 and SNI 7619:2012, with broken grains, sharp edges, and rough surfaces, while the maximum aggregate size is 40 mm. Fine aggregate uses natural sand with grading of zone II grading according to SNI 03:2834:2000, categorized as medium sand as shown in Figure 2.

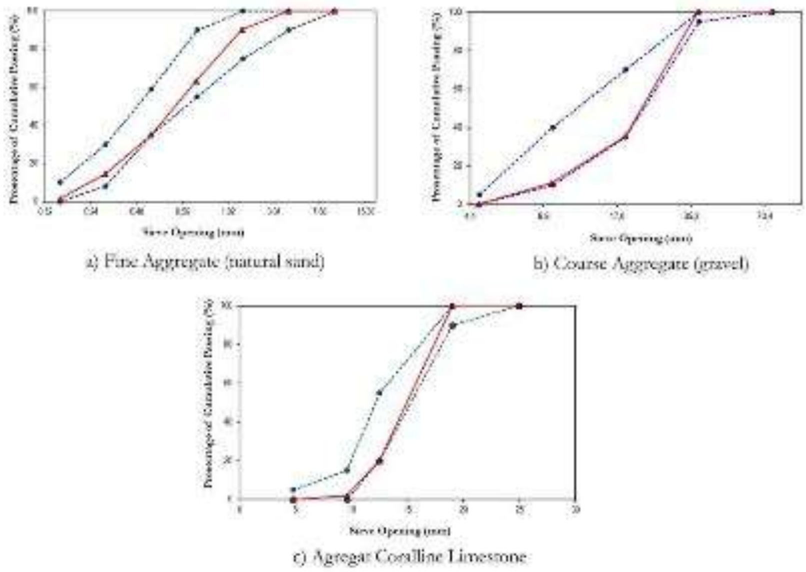

Figure 1. Aggregate particle size distribution curve

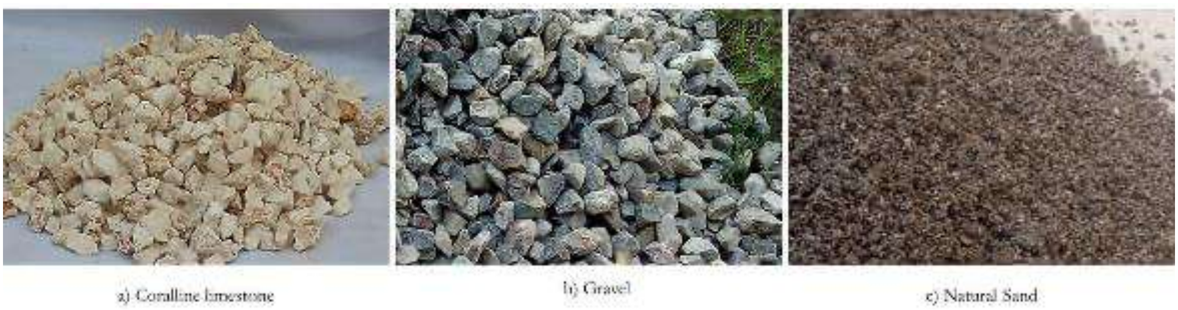

Figure 2. Concrete forming aggregate

The coarse coral aggregate used in concrete formation, the type of coralline limestone, is sourced from Timor Island in East Nusa Tenggara. As shown in Figure 3, the aggregate size is 5 mm – 25 mm, with a block shape, cubic (not flat and elongated). In order to get a block cubical shape, the pieces must first be manually broken down into smaller particles. This is the method that is described. A rough and porous surface is characteristic of this aggregate's surface.

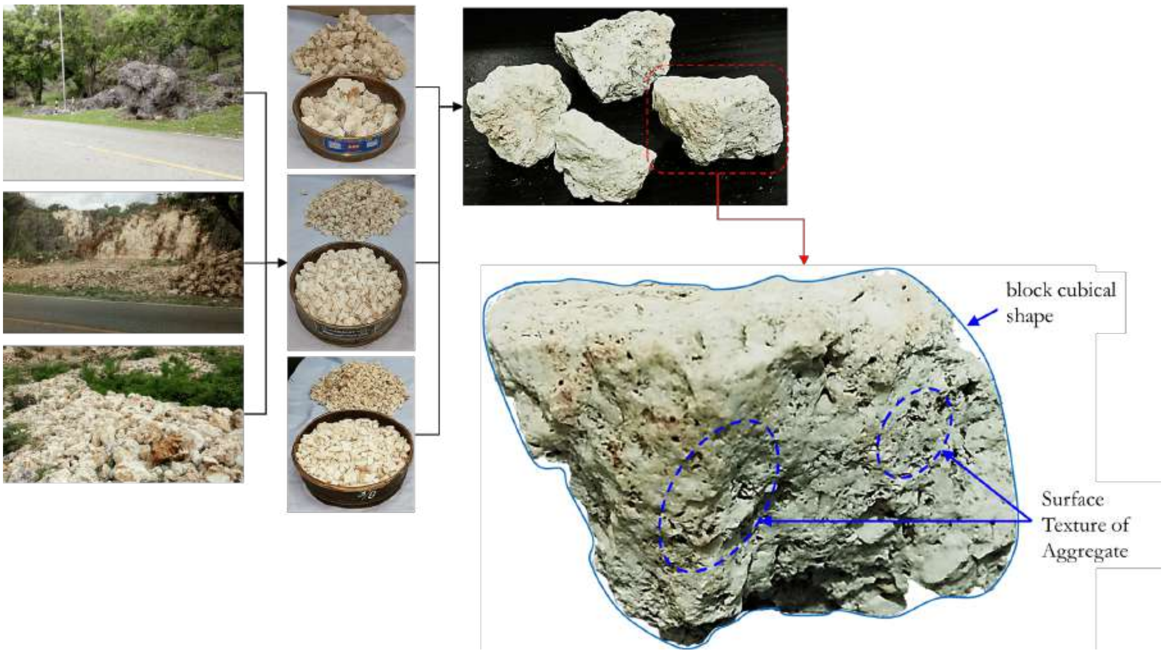

Figure 3. Coralline limestone aggregate in a cubical block shape, both complete and fragmented

The use of PCC (portland composite cement) with SiO2 content of 23.91%, Al2O3 of 7.21%, Fe2O3 of 3.62%, CaO of 56.02%, MgO of 1.98%, and SO3 of 1.24%. Meanwhile, the physical parameters of the concrete aggregate are shown in Table 3.

Tabel 3. Physical Aggregate Parameters

Item test	Agregat coralline limestone	Coarse aggregate gravel	Fine aggregate
Fineness modulus	7.78	7.52	2.88
Specific gravity (Bulk)	2.09	2.64	2.45
Specific gravity (SSD)	2.19	2.66	2.54
Specific gravity (Apparent)	2.31	2.69	2.71
24-Hour Water Absorption	4.5%	0.7%	4.0%
Water content	4%	0.8%	3.05%
Aggregate degradation	72%	34%	-

Preparation of Test Specimens

This study uses cylindrical test specimens measuring 15/30 cm with a total of 60 test specimens, while the standard for making the test specimens refers to SNI 2493 : 2011. The observation of concrete compressive strength was conducted at the ages of 7, 14, 21, and 28 days. A method of curing concrete specimens involves submerging them in water. The treatment applied to the test specimens is the method of replacing gravel aggregate with coralline limestone aggregate. According to the weight of the gravel aggregate, the test specimens' coralline limestone aggregate contents were 5%, 25%, 50%, and 75%.

Concrete mix composition

The concrete mix design is planned to have a compressive strength of fc' = 30 MPa with a water-cement ratio, w/c = 0.5. Meanwhile, the composition of the constituent materials is presented in Table 4.

Table 4. Composition materials coral aggregat concrete

Materials	CAC 0%	CAC 5%	CAC 25%	CAC 50%	CAC 75%	Unit
Water	194.09	194.4	195.4	196.6	197.8	liter
PCC	404.30	404.3	404.3	404.3	404.3	kg
Fine Aggregate (natural sand)	618.70	615.20	600.62	582.57	564.18	kg
Coarse Aggregat (gravel)	1159.98	1095.80	844.61	546.16	264.46	kg
Coralline Limestone Aggregat	0.0	57.38	280.10	543.36	789.31	kg

CAC 0% - CAC 75% is the code given to test specimens that contain coralline limestone aggregate replacing the presence of gravel. Coralline limestone aggregate needs to be first cleaned and soaked (pre-wet) for 24 hours before used in the concrete mixing process. The purpose is to clean the aggregate from adhering microorganisms and to reduce excessive water absorption due to the porosity of the coralline limestone aggregate (Wei Jingli. et al, 2023).

Testing of Test Specimens

The compressive strength testing of concrete with coarse aggregate of coralline limestone is conducted using an analog concrete compressive strength testing machine (electric hydraulic pump) with a capacity of 2000 kN, following the ASTM-C39 test standard, which does not produce a stress-strain curve. Meanwhile, to determine the concrete density quality of the test specimens, ultrasonic pulse velocity (UPV) testing was conducted using the Proceq Pundit lab (+) device with a bandwidth of 20-500kHz. The initial stage of the test is to measure the ultrasonic pulse velocity (UPV) using 60 concrete specimens. After that, the same specimens will be tested to determine the compressive strength of the concrete.

The ultrasonic pulse velocity (UPV) test was conducted on the test specimen at 28 days of age by placing the transducer and receiver at 7 observation points, while the transmission of ultrasonic waves by the transducer and repeated by the receiver was repeated 25 times at one observation point. The testing method refers to the guidelines PROCEQ, (2014), while the testing standards refer to ASTM D 2845 1999b , ASTM-C597-09 , BS 1881-Part 207-92.

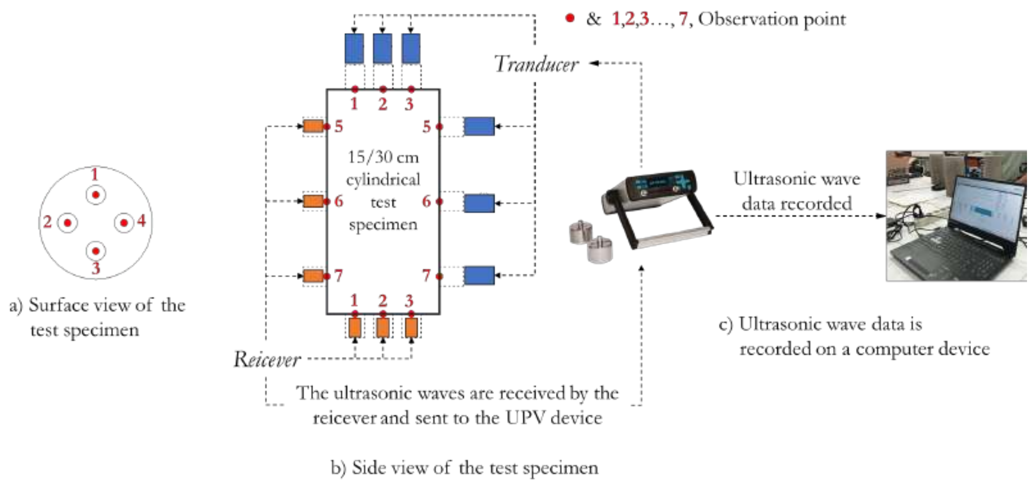

Figure 4. The process of ultrasonic pulse velocity (UPV) testing

Research Results and Discussion

Compressive Strength of Concrete.

Concrete mix design is specified to have a compressive strength of fc' = 30 MPa with a water-to-cement ratio, w/c = 0.5. Standard for concrete mixtures refers to SNI 03:2834:2000. Results of this study indicate that concrete that doesn't contain coarse aggregate from coralline limestone (CAC 0%) and only utilizes coarse aggregate from gravel has compressive strength values at 7, 14, 21, and 28 days of 17.16 MPa; 19.90 MPa; 18.86 MPa; and 20.27 MPa, respectively. The compressive strength value of the CAC 0% concrete specimens is below the planned concrete compressive strength of 30 MPa. The explanation of this strength reduction is the use of fine aggregate that was previously classified in grading zone IV (fine sand category), which has now shifted to fine aggregate that meets the requirements of grading zone II (medium sand category).

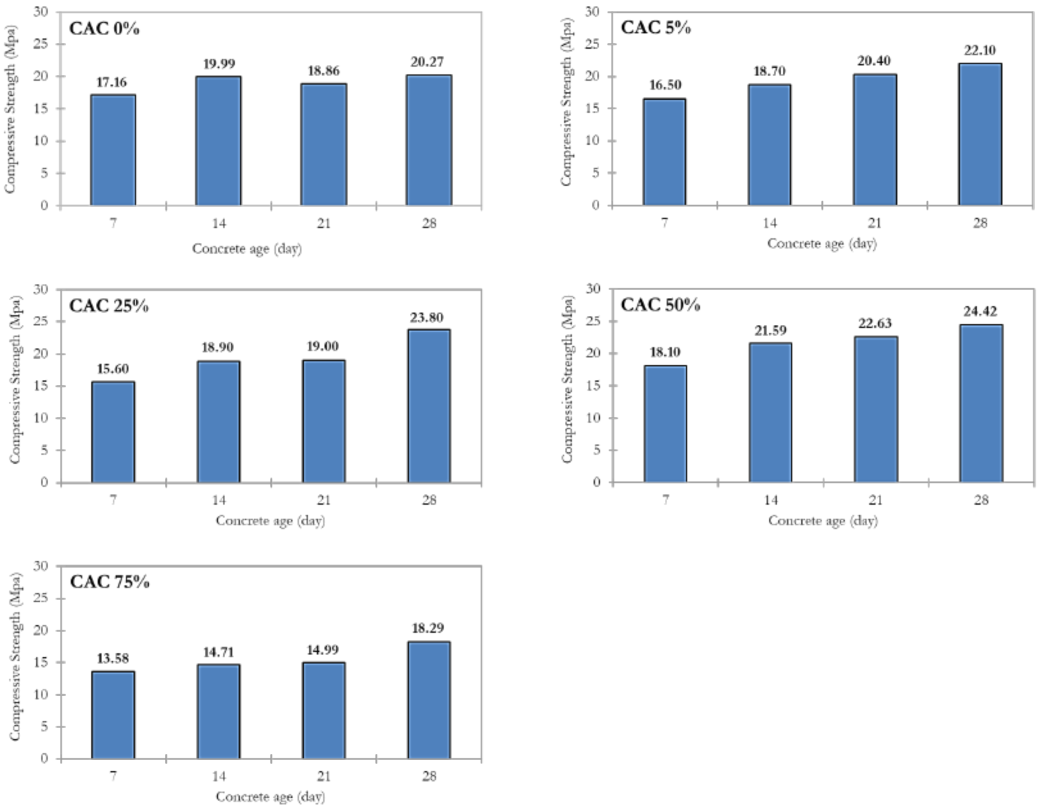

Figure 5. The compressive strength of concrete in each type of test specimen

Concrete containing coarse aggregate of coralline limestone at 5% - 50% (CAC 5%, CAC 25%, CAC 50%) has compressive strengths of 22.1 MPa, 23.8 MPa, and 24.42 MPa, respectively. The increase in compressive strength of concrete for CAC 5%, CAC 25%, and CAC 50% compared to CAC 0% is 8.84%, 17.21%, and 20.47%, respectively. It shows that the higher the content of coarse coralline limestone aggregate in the concrete specimens, the more positive the impact on the increase in concrete compressive strength. The research of Golewski, (2023), coarse coralline limestone aggregate shows good characteristics to form a bond with cement paste. A greater percentage of coarse coralline limestone aggregate will strengthen the bond between the aggregate and the cement paste, thereby increasing the strength of the concrete. However, in this study, the extent of the role of the bond between the aggregate and the cement paste in enhancing the compressive strength of concrete has not yet been analyzed. Therefore, further research is needed on the microstructure of the aggregate and cement paste bonds.

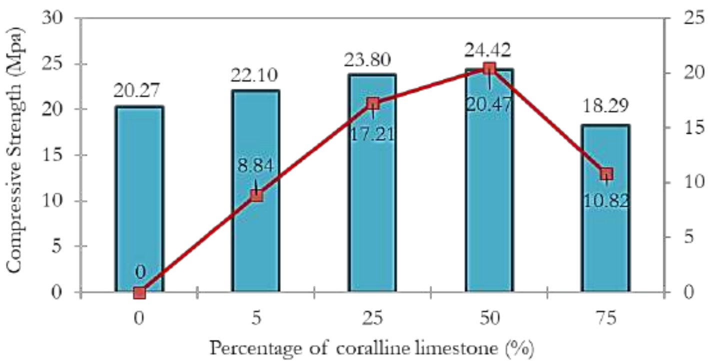

Figure 6. Effectiveness of increasing concrete compressive strength at 28 days

Different conditions in concrete specimens using 75% coarse coralline limestone aggregate (CAC 75%) as a substitute for coarse gravel aggregate. The compressive strength of the concrete decreased by 9.65% compared to CAC 50%, resulting in 18.29 MPa. Research by Ajay Kumar Jha, (2020), coral coarse aggregate typically has a lower density compared to conventional aggregates like gravel, which can negatively impact the compressive strength of concrete. According to Golewski, (2023), the varying sizes of coral coarse aggregate can result in an uneven load distribution, which can reduce the compressive strength of concrete. Therefore, the higher the content of coarse coralline limestone aggregate in the concrete sample, the more it potentially reduces the compressive strength of the concrete. This is evident in the CAC 75% concrete specimens, which show a decrease in compressive strength.

To solve a problem of coral coarse aggregate density, Wang. Aiguo. et al, (2021) recommended strengthening coral aggregate by washing the aggregate with acetic acid and coating the aggregate with geopolymer, while according to Huang. Yijie. et. al, (2024) recommended strengthening coral aggregate by coating the aggregate with paste and Ordinary Portland Cement powder. Zhang et al., (2025) recommended strengthening concrete using coarse aggregate from coral, where the strengthening involves adding polypropylene fibers into the concrete mix. Therefore, for future research, it can be directed towards strengthening coarse corraline limestone aggregate before it is used as coarse aggregate in concrete production.

Table 5. Concrete's compressive strength is affected by the content of coral limestone

Source	Concrete age (day)	Coralline limestone content (% , Mpa)					Treatment
		0	5	25	50	75	
(Lukas. A. Y, Rafael. J. W, et al., 2024)	7	23.52	22.83	25.49	22.26	-	Fine aggregate (natural sand) in grading of zone 4
	14	24.88	28.32	27.97	24.95	-	
	28	29.89	31.35	33.37	29.51	-	
(Lukas. A. Y, Rafael J. W. M, et al., 2024)	7	-	-	21.33	-	-	Fine aggregate in the grading of zone 4 + content Superplasticizer 0.8%
	14	-	-	22,.65	-	-	
	21	-	-	24.25	-	-	
	28	-	-	26.23	-	-	
Present Study	7	17.16	16.50	15.60	18.10	13.58	Fine aggregate (natural sand) in grading of zone 2
	14	19.99	18.70	18.90	21.59	14.71	
	21	18.86	20.40	19.00	22.63	14.99	
	28	20.27	22.10	23.80	24.42	18.29	

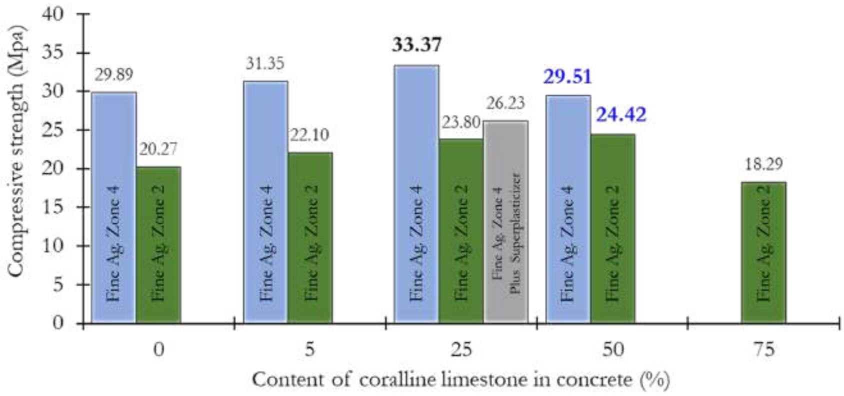

Figure 7. Comparing the compressive strength of concrete for each concrete content of coralline limestone, as well as for each fine aggregate gradation zone

Previous research by Lukas. A. Y, et al., (2024) (Table 5), showed that 25% coralline limestone aggregate replacing gravel and using fine aggregate in the IV grading zone, categorized as fine sand, was able to achieve concrete compressive strength of fc' = 33.37 Mpa. Under the same treatment and with the addition of a superplasticizer of 0.8% of the binder weight, the research results showed a decrease in concrete strength performance by 27% to fc' = 26.23 Mpa. (Lukas. A. Y, Rafael J. W. M, et al., 2024). It should be noted that both of these preliminary studies still utilize the capability of 75% gravel and 25% coralline limestone in concrete.

In this study, coarse aggregate content from coralline limestone between 5% to 75% will be used as a substitute for gravel in concrete production. This study also modifies the fine aggregate, which was previously in the grading zone IV (categorized as fine sand), to fine aggregate that meets the requirements of grading zone II (medium sand category). Fine aggregates in the grading zone II reduce the compressive strength of concrete, as shown in this study. The reduction in concrete compressive strength reaches 36.65%, where the initial compressive strength of 33.37 MPa decreases to 24.42 MPa (Figure 7).

Additional information obtained from this study shows that the use of 50% coralline limestone aggregate in concrete, along with the application of fine aggregate (natural sand) in grading of zone IV, results in a concrete compressive strength fc' of 29.51 MPa. This value is 17.25% higher compared to concrete that also contains 50% coralline limestone but uses fine aggregate (natural sand) in grading of zone II, which results in a concrete compressive strength fc' of 24.42 MPa. Thus, it can be concluded that concrete containing 50% coralline limestone and using fine aggregates in the gradation of zone II category shows a decrease in compressive strength compared to concrete with the same coralline limestone content but using fine aggregates in the gradation of zone IV category, which has proven to be more effective in increasing the compressive strength of the concrete.

The compressive strength of the CAC 50% concrete specimen, which reached 24.42 MPa, indicates adequate mechanical characteristics for use in building structures, in accordance with the provisions set forth in SNI 2847:2019, Article 19.2.1, which states that concrete must have a minimum compressive strength of 21 MPa. However, further research is needed regarding the stress-strain behavior and durability of concrete using coarse aggregate from coralline limestone, due to the presence of chloride ions and porosity that may affect the quality of the material.

Concrete Density Quality

The results of the ultrasonic pulse velocity (UPV) test in Table 6 show that the average ultrasonic wave velocity sent by the transducer and received by the receiver from the three test specimens CAC % and CAC 5% is greater than 4.5 km/s, thus the concrete density quality based on the average longitudinal wave velocity falls into the "excellent" category. However, unlike the

CAC 25% to CAC 75% test specimens, which fall between 3.5 km/s and 4.5 km/s, the quality category of concrete density is classified as "good." based on the standards ASTM-C597-09, ASTM D 2845 1999b, and BS 1881-Part 207-92.

CAC 0% and CAC 5% are test specimens that contain 100% and 95% coarse aggregate gravel, respectively, so the quality of concrete density is supported by the presence of gravel with a solid and hard aggregate structure. Meanwhile, in CAC 25%, CAC 50%, and CAC 75%, the presence of gravel begins to decrease as it is replaced by coralline limestone aggregate, which has a brittle and porous aggregate structure. However, the density quality of CAC 25% - CAC 75% concrete is still acceptable, because the coralline limestone aggregate is well-distributed and can fill the voids in the concrete mix. Additionally, coralline limestone aggregate, characterized by its unique properties has a rough surface, which enhances the bond between the aggregate and cement paste, reduces porosity, and increases overall density during the concrete mixing process up to the concrete hardening process.

Putra D. M (2021) proposed to improve the quality of concrete density through concrete compaction techniques, which will affect the quality of density and compressive strength of concrete better by using a vibrator. An effective compaction process can reduce porosity and prevent segregation. In this study, the concrete mixing technique begins with mixing coarse aggregate gravel, coralline limestone aggregate with cement, then adding fine aggregate followed by water. When the concrete mixture is poured into the mold, compaction is carried out using a vibrator. This treatment was carried out on test specimens with CAC 0% to CAC 75%.

Table 6. Results of the Ultrasonic Pulse Velocity (UPV) Test

Coralline limestone content	**Concrete age**	**Test Specimen**			**Velocity Average (km/s)**	**St. Dev.**	**Coeff. of var.**	**Concrete Quality Based on**	
		1	**2**	**3**				**Average Velocity**	**Average Coeff. of Var.**
CAC 0%	7	4.537	4.616	4.627	4.593	0.050	0.011	Excelent	Excelent
	14	4.625	4.489	4.591	4.568	0.070	0.015	Excelent	Excelent
	21	4.533	4.583	4.523	4.546	0.032	0.007	Excelent	Excelent
	28	4.693	4.524	4.649	4.622	0.087	0.019	Excelent	Excelent
CAC 5%	7	4.634	4.579	4.508	4.574	0.063	0.014	Excelent	Excelent
	14	4.655	4.728	4.687	4.690	0.037	0.008	Excelent	Excelent
	21	4.626	4.580	4.588	4.598	0.024	0.005	Excelent	Excelent
	28	4.588	4.508	4.467	4.521	0.062	0.014	Excelent	Excelent
CAC 25%	7	4.383	4.343	4.385	4.370	0.023	0.005	Good	Excelent
	14	4.529	4.526	4.476	4.510	0.029	0.007	Excelent	Excelent
	21	4.460	4.472	4.526	4.486	0.035	0.008	Good	Excelent
	28	4.576	4.353	4.534	4.487	0.118	0.026	Good	Excelent
CAC 50%	7	4.430	4.424	4.366	4.407	0.035	0.008	Good	Excelent
	14	4.360	4.332	4.300	4.330	0.030	0.007	Good	Excelent
	21	4.335	4.442	4.396	4.391	0.054	0.012	Good	Excelent
	28	4.386	4.497	4.488	4.457	0.061	0.014	Good	Excelent
CAC 75%	7	4.181	4.211	4.179	4.190	0.018	0.004	Good	Excelent
	14	4.119	4.021	4.192	4.111	0.086	0.021	Good	Excelent
	21	4.282	4.212	4.258	4.251	0.036	0.008	Good	Excelent
	28	4.174	4.191	4.308	4.225	0.073	0.017	Good	Excelent

The basic concept of ultrasonic testing utilizes wave propagation; from the propagation data, the density of the concrete being inspected can be interpreted PROCEQ, (2014). Based on Neville, (2011), one of the benefits of UPV testing is determining the uniformity of concrete density quality.

Because the UPV test utilizes data in the form of wave propagation velocity, concrete with poor quality, such as inadequate compaction, weak compressive strength, and uneven distribution of aggregates, will affect the wave velocity, leading to degradation. However, if the ultrasonic wave accelerates, it can be indicated that the concrete has good density quality.

In this study, although the UPV results showing the density quality of concrete using coarse coralline limestone aggregate have been described, the discussion has not yet elaborated in detail on the possible microscopic effects, such as the porosity of coarse coralline limestone aggregate in concrete or micro-cracks that occur at the interface between coarse coralline limestone aggregate and cement paste, which could impact the density and strength of the concrete structure. The study by Zhang. Jinhua. et al, (2021) and Gao. Weiquan. et. al, (2024) outlines the importance of studying the microscopic structure of concrete that uses coarse coralline limestone aggregate. Microscopic studies are capable of revealing the mechanisms of damage and crack propagation occurring at the microscopic level, which cannot be detected through macroscopic analysis. Coral aggregate with a high porosity level can create voids in the concrete mix, potentially reducing the overall density of the concrete. Therefore, it is recommended to conduct further research focusing on the microscopic analysis of the concrete structure using coarse coralline limestone aggregate.

Concrete Slump Test.

The consistency or workability of the CAC concrete mix from 5% to 75% is not significantly different from CAC 0%. The slump value is between 9 cm and 10,5 cm with a water-cement ratio, w/c = 0.5.

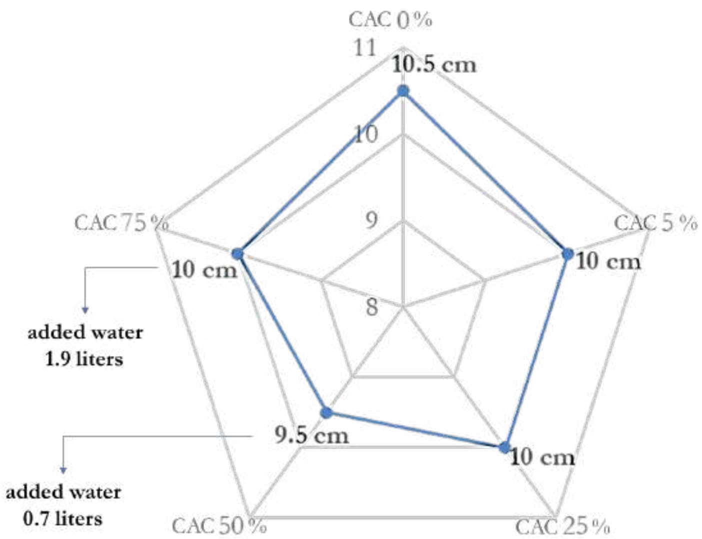

Figure 8. Slump value (cm)

For reinforced concrete work, the slump value recommended by ACI 211.1-91 ranges from 2.5 cm to 10 cm. This range is considered optimal to ensure that the concrete mix has good workability, allowing it to flow well and fill the spaces between the reinforcement without compromising the strength of the concrete. The presence of coralline limestone aggregate in concrete at 50% - 70% replacing gravel (CAC 50% - 75%) has a slump value of 9.5 cm and 10 cm. However, to maintain the slump value at 9.5 cm – 10 cm, an additional water amount of 0.7 liters for CAC 50% and 1.9 liters for CAC 75% is required during the concrete mixing process. This is due to the concrete mixture being thicker because the porous coralline limestone absorbs more water than the planned amount. The resulting impact is that the water-cement ratio increases to w/c = 0.6.

Density Of Concrete

After 28 days in CAC 0% conditions, the three test specimens weigh 12.798,83 grams on average, and the 15/30 cm test specimens have a volume of 0.0053 m^3 thus, the specific gravity of the concrete is 2415.44 kg/m^3. The value density of concrete in the CAC 0% condition is the density of normal concrete formed from normal aggregates, namely gravel and natural sand. It will be different when the normal aggregate content is replaced by coralline limestone aggregate, as shown in the test specimens with CAC conditions of 5% = 2371.47 kg/m^3 ; 25% = 2310.60 kg/m^3 ; 50% = 2286.26 kg/m^3 ; and 75% = 2203.14 kg/m^3.

The concrete's specific gravity decreases with a higher content of coralline limestone in place of gravel. The specific gravity of concrete decreased by 8.79% compared to concrete with coarse gravel aggregate. Zhou. Linlin. et al (2021) and Meng. Jian. et al (2022), show that concrete with coral aggregate generally has a density of 1.900 kg/m^3, but there are differences in terms of concrete compressive strength performance, failure mechanisms, and energy dissipation. The density of concrete in this study, which had 75% coralline limestone content, was 2203.14 kg/m^3, which was not in compliance with the criteria for lightweight concrete. According to Neville, (2011) lightweight concrete with a density between 1400 to 2000 kg/m^3 can be used for medium structures.

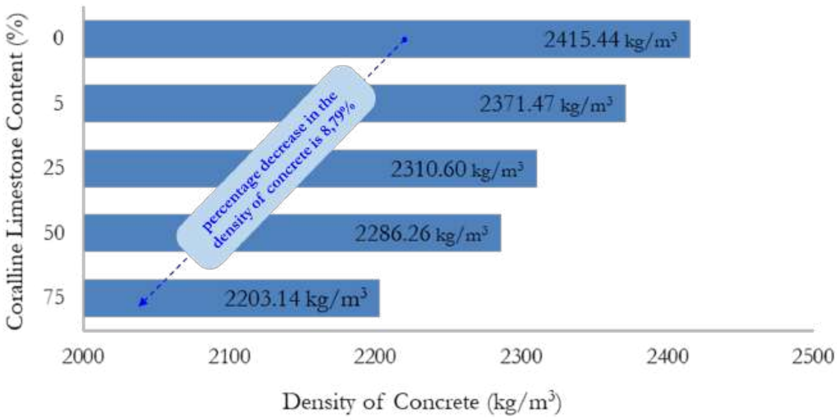

Figure 9. Density of concrete (kg/m^3)

A decrease in the specific gravity of the concrete is caused by the use of coarse coralline limestone aggregate, which reaches 75%, replacing the coarse gravel aggregate in the concrete specimens. The specific gravity (apparent) of the coarse aggregate coralline limestone in this study is 2.31 g/cm^3, which is lower than the specific gravity (apparent) of the coarse aggregate gravel, which reaches 2.69 g/cm^3. This is one of the reasons why the higher the content of coarse aggregate of coralline limestone in concrete, the lower the specific gravity of the concrete.

Table 7. Density of concrete and compressive strength

Coralline limestone content	Concrete Age (day)	Weight Specimen (gr)	Density of concrete (kg/m^3)	Percentage of Decrease in Concrete Density (%)	Concrete Compressive Strength (Mpa)
CAC 0%	28	12798.83	2415.44	0.00	20.27
CAC 5%	28	12565.83	2371.47	1.82	22.10
CAC 25%	28	12243.27	2310.60	4.34	23.80
CAC 50%	28	12114.30	2286.26	5.35	24.42
CAC 75%	28	11673.90	2203.14	8.79	18.29

The results shown in this study in Table 7 explain that the decrease in concrete density affects the compressive strength value of the concrete, particularly in CAC specimens from 0% to 50%. The addition of coarse coralline limestone aggregate in the concrete samples up to 50% resulted in a decrease in concrete density, followed by an increase in concrete compressive strength from 20.27 MPa to 24.42 MPa. However, when the content of coralline limestone coarse aggregate in the concrete specimens reached 75%, the compressive strength of the concrete decreased to 18.29 MPa. However, the specific gravity of the concrete continues to decrease until it reaches 2203.14 kg/m^3.

Research by Golewski, (2023), the rough texture of coral aggregates helps enhance the interaction between the aggregates and the cement paste. This rough structure plays a role in building a stronger bond between the aggregate and the cement paste, which is crucial for the strength and stability of the concrete. Therefore, as shown in this study, the CAC 5% - 50% concrete samples exhibit an increase in compressive strength, despite a decrease in the concrete's specific gravity.

After the percentage of coarse coralline limestone aggregate in the concrete sample reaches 75%, the compressive strength of the concrete decreases. This is due to the brittle nature of the coarse coralline limestone aggregate. Based on research of Huang. Yijie. et. al, (2024), coral aggregate is a type of aggregate that exhibits a high level of brittleness due to the porosity both inside and outside the aggregate. The deficiency in coral aggregate results in increased brittleness of the concrete, leading to a reduction in compressive strength. The solution is to strengthen the coral aggregate by washing it to remove trapped sediments, then coating it with paste or cement powder. In this study, coarse aggregate content from coral limestone was used up to 75% in concrete, and reinforcement on coralline limestone aggregate has not been conducted. This means that the defect spaces in the concrete are increasing, resulting in a decrease in the compressive strength of the concrete to 18.29 MPa.

In this study, the initial treatment of coralline limestone aggregate is the pre-wet method, where the coralline limestone aggregate is soaked in water for a period of 24 hours before use. This method is not sufficient to address the weaknesses of coralline limestone aggregate. For further research, it is necessary to improve the strength of coralline limestone aggregate initially before it is used as coarse aggregate in concrete.

Crack Pattern of Test Specimen.

The crack patterns on 15/30 cm concrete cylinders are a valuable indicator of the properties and quality of the concrete mix used. The failure shape is evaluated using SNI 1974: 2011. Failure mode of CAC cylinder specimens after concrete compressive strength test is displayed in Figure 10. The test specimen's failure mode usually falls into the cone and shear failure categories at CAC 5%. At CAC 25%, the test specimen's failure mode tends to be classified as shear failure. At CAC 50%, the failure mode of the test specimen tends to fall into the shear failure category, while at CAC 75% the failure mode of the test specimen tends to fall into the shear failure category.

The failure mode of cylindrical specimens containing 25% to 75% coralline limestone (CAC 25%, CAC 50%, and CAC 75%) replacing gravel is dominated by shear failure. As the load increases, the crack pattern on the cylindrical specimens forms a diagonal direction along the entire surface of the cylindrical specimens without concentrating on the weakest areas. Compared to the cylindrical specimens containing 5% coralline limestone, the failure mode is conical and shear failure. The conical and shear failure forms in the cylindrical specimens occur due to shear stress exceeding the material's capacity, causing cracks and deformation. This type of failure frequently occurs in concrete subjected to vertical loads, where shear forces create a conical pattern in the weakest areas (Wang. X. et al., 2017).

The form of destruction of the CAC 25%, CAC 50%, and CAC 75% cylinder specimens is caused by a weak material structure (Guo et al., 2024). Materials with non-homogeneous internal structures or defects (such as cracks, pores, or inclusions) are more susceptible to shear failure. These defects may serve as starting points for cracks that develop along the shear plane (Golewski, 2023). From the crack patterns of the cylindrical specimens, further investigation of the microstructure of the coralline limestone material is needed.

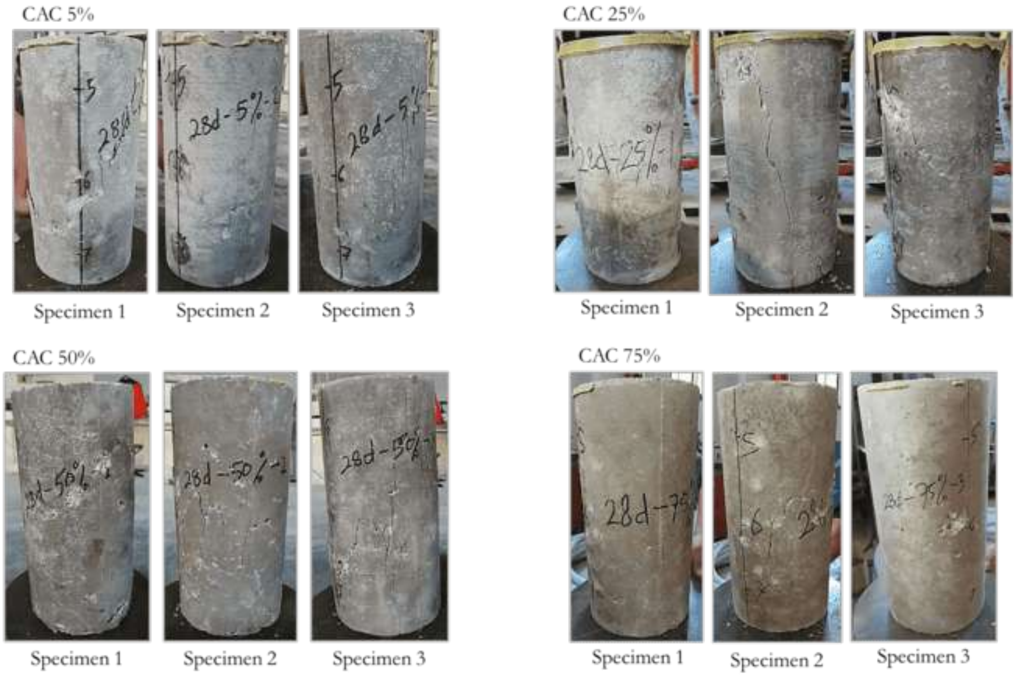

Figure 10. The failure modes of cylinder specimen of CAC

The mode of failure in various concrete cylinder specimens is consistent with the research by Zhang. Bai. et al (2023). Concrete cylinder specimens with coral aggregate (reef limestone) experienced gradual cracking, developing and spreading to both ends of the specimen as the load value increased. When the applied load approaches the maximum value, the cylindrical specimen suddenly fails and is accompanied by the formation of cracks along the diagonal and axial directions. According to Zhang. Jintuan. et al (2023), the main reason for the occurrence of diagonal cracks is the low strength of coral aggregate, particularly on the aggregate surface that is not strongly bonded to the cement matrix. The friction marks that appear on the shear surface will become more pronounced as the normal stress increases. The wear on the coral aggregate at the shear surface will worsen, causing damage to the aggregate and cement matrix.

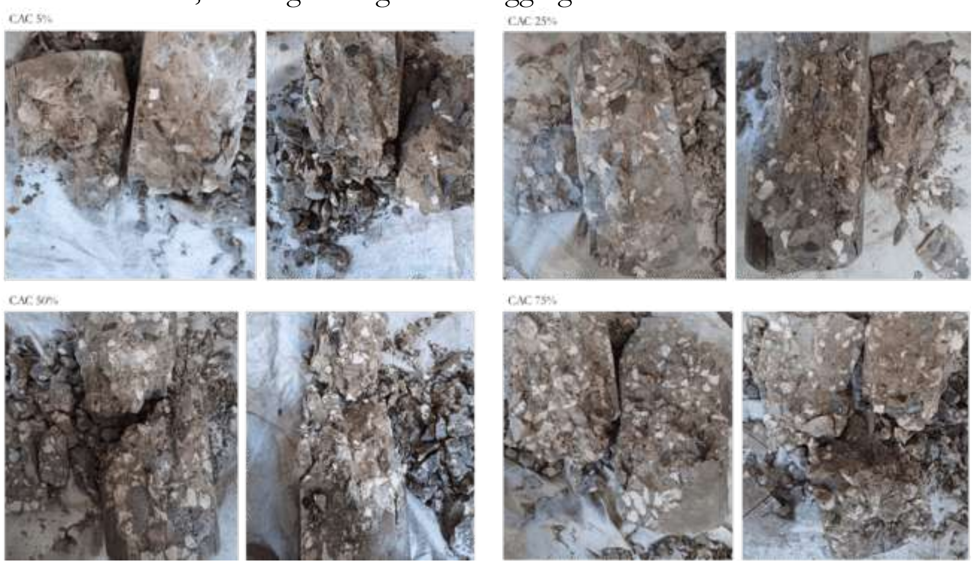

Figure 11. Distribution of coral aggregate particles on cylindrical specimens of CAC

Gao. Weiquan. et. al (2024) reported a number of concrete cylinder specimens with coral aggregate (reff limestone) at a temperature of 25°C tend to show typical brittle failure characteristics. As the compressive strength level increases, the specimens become increasingly brittle. Upon closer observation, the cracks on the specimen reveal themselves as diagonal cracks that penetrate into the coral aggregate. Coral aggregates experience cracking and breaking. Luo. Yi. et al (2023) found that the way reef limestone aggregates fail happens along the growth line of the coral aggregate, showing failures that look like fins of different sizes. The same thing was found in this study, a number of concrete specimens using coralline limestone aggregate tended to show shear failure characteristics. This shear failure is associated with increased stress concentration in the specimens, making them susceptible to cracking under external forces. The subsequent crack propagation causes further damage to the specimen. Figure 11 shows that a few coralline limestone aggregates also experienced cracking or breaking when the load was applied; some coralline limestone aggregates still appeared intact and adhered to the cement paste, while more cracks occurred in the cement paste.

Conclusion

The research on the use of coarse coralline limestone aggregate in concrete concludes as follows: First, coralline limestone aggregate from Timor Island – East Nusa Tenggara, is suitable to be used as a substitute for coarse gravel aggregate in concrete formation, whether considering the use of fine aggregate in the grading zone II or in the grading zone IV. Second, concrete with 25% coralline limestone replacing gravel and fine aggregate in the grading zone IV has a compressive strength of 33.37 MPa. Meanwhile, with the same coralline limestone content and fine aggregate in grading zone II, the concrete compressive strength value decreases to 23.80 MPa. Meanwhile, concrete with 50% coralline limestone replacing gravel and fine aggregate in grading zone IV has a compressive strength of 29.51 MPa, and fine aggregate in grading zone II has a compressive strength of 24.42 MPa. This shows that the smaller the grading zone of the fine aggregate, the lower the compressive strength of the concrete. Third, concrete using coarse coralline limestone aggregate 5%-75% has concrete density quality in the very good category, without any segregation, and results in a concrete density lower than 2400 kg/m3. Fourth, the workability of concrete mixtures containing 50%-75% coarse coralline limestone aggregate replacing gravel aggregate requires special attention regarding water usage (w/c), as the concrete mix becomes thicker due to the porous nature of the coarse coralline limestone aggregate, which absorbs more water than the planned amount. Fifth, concrete specimens using coarse coralline limestone aggregate tend to exhibit shear failure characteristics.

Further research is recommended to conduct a more in-depth study on strengthening of coral limestone aggregates. Strengthening includes aggregate cleaning techniques as well as coating the aggregate with cement paste or cement powder. Further research can focus on the microstructure of aggregates, particularly the relationship between aggregates and cement paste.

References

Abdullah. Dinar Mardiana, Hi., Mustaman, Sutrisno., & Suartana, Putu. (2024). Feasibility Study Of Using Limestone (Gamping) As A Concrete Mix. *SIPARSTIKA : Scientific Journal of Engineering Science, Faculty of Engineering, Tompotika University Luwuk Publishers*, *4*(1), 50–61. https://doi.org/https://doi.org/10.55114/siparstika.v4i1.770

Ajay Kumar Jha. (2020). Dynamic Fracture Toughness Tests on Limestone. *Journal of Geological Resource and Engineering*, *8*(5). https://doi.org/10.17265/2328-2193/2020.05.005

ASTM D 2845 1999b. *Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock 1*.

ASTM-C597-09. *Standard Test Method for Pulse Velocity Through Concrete 1*. https://doi.org/10.1520/C0597-0

Boimau Y. et al. (2024). Analysis of Subsurface Rocks of Kolbano Beach Based on Geoelectric Resistivity Data. In *Jurnal Teori dan Aplikasi Fisika* (Vol. 12, Issue 02). https://doi.org/https://doi.org/10.23960/jtaf.v12i02.385

BS 1881-Part 207-92. Testing concrete part 207. Recommendations for the assessment of concrete strength by near-to-surface tests Committees responsible for this British Standard Institution of Civil Engineers Institution of Highways and Transportation Institution of Structural Engineers Institution of Water and Environmental Management National House-Building Council Sand and Gravel Association Society of Chemical Industry.

Chu. Yingjie. et al. (2021). Enhancing the performance of basic magnesium sulfate cement-based coral aggregate concrete through gradient composite design technology. *Composites Part B: Engineering. Elsevier Science Publishers*, *227*, 1–13. https://doi.org/https://doi.org/10.1016/j.compositesb.2021.109382

Da, B., Yu, H., Ma, H., Tan, Y., Mi, R., & Dou, X. (2016). Experimental investigation of whole stress-strain curves of coral concrete. *Construction and Building Materials*, *122*, 81–89. https://doi.org/10.1016/j.conbuildmat.2016.06.064

Dai, J., Yin, S., Wang, F., & Ge, M. (2024). Analysis of microstructure and compressive properties of full coral concrete under fiber reinforcement. *Journal of Building Engineering*, *93*. https://doi.org/10.1016/j.jobe.2024.109826

Fikri. M. et. al. (2024). Study of The Use Of Limestone as A Coarse Aggregate Material in the Compressive Strength Test of K-250 Concrete (Case Study: in Mengkendek Sub-District Tana Toraja District). *Ecosystem Scientific Journal : Institute for Research and Community Service, Bosowa University Publishers*, *24*(1), 29–38. https://doi.org/https://doi.org/10.35965/eco.v24i1.4199

Gao. Weiquan. et. al. (2024). Mesoscopic Mechanical Study On Quasi-Static Compression Of Coral Aggregate Seawater Concrete After High Temperature Exposure. *Journal of Building Engineering. Elsevier Science Publishers*, *88*, 1–20. https://doi.org/https://doi.org/10.1016/j.jobe.2024.109160

Golewski, G. L. (2023). Effect of Coarse Aggregate Grading on Mechanical Parameters and Fracture Toughness of Limestone Concrete. *Infrastructures*, *8*(8). https://doi.org/10.3390/infrastructures8080117

Guo, J., Yu, H., Ma, H., Quan, S., Liu, T., & Dai, X. (2024). Impact Toughness Analysis and Numerical Simulation of Coral Aggregate Concrete at Various Strength Grades: Experimental and Data Investigations. *Buildings*, *14*(6). https://doi.org/10.3390/buildings14061605

Huang. Yijie. et. al. (2024). Experimental And Numerical Studies On The Improvements In Mechanical Properties Of Coral Aggregates Concrete Through Aggregates Strengthening Method. *Construction and Building Materials, Elsevier Science Publishers*, *438*, 1–25. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2024.137243

Hutagalung. L. P. et. al. (2022). Application of Non Destructive Test in Investigation of Reliability of Bridge Concrete Structure (Case Study: Aek Boga I Bridge, Singkuang-Natal Road Section). *ATDS SAINTECH : Journal of Engineering, Deli Serdang Engineering Academy Publishers*, *3*(1), 82–88. https://ojs.atds.ac.id/index.php/atdssaintech/article/view/136

Kotta. H. Z. et. al. (2022). Diageness And Age Identification Of The Maubisse Formation, Oinlation Region, Oinlasi Village, Kie District, South Timor Regency, East Nusa Tenggara

Province, NTT Province. *Scientific Journal of the Faculty of Science and Engineering. University of Nusa Cendana Publishers*, *16*(2), 1–8. https://ejurnal.undana.ac.id/index.php/jurnal_teknologi/article/view/8988

Krisnasiwi. I. F. et. al. (2025). *Estimation of Groundwater Potential Using Geoelectric Method in Semau, Kupang Regency, NTT Province* (Vol. 10, Issue 1). https://doi.org/https://doi.org/10.35508/fisa.v10i1.20541

Leto. R. M. et al. (2023). Analysis of the Physical and Mechanical Properties of Coral Stone in Kupang. *Journal of Mechanical Engineering. Nusa Cendana University Kupang Publisher*, *10*(01), 1–7. https://doi.org/https://doi.org/10.35508/ljtmu.v10i01.11670

Liang. Xiangzhou. et. al. (2021). Mechanical properties and gas permeability of coral aggregate concrete incorporating supplementary cementitious materials. *Construction and Building Materials*, *302*, 1–11. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.124237

Lukas. A. Y, & Rafael. J. W. M. (2024). Ultrasonic Pulse Velocity Test On Normal Concrete Using Coral Stone As A Substitute For Gravel. *Civil Engineering Journal : Faculty of Engineering, Jakarta State University Publishers*, *19*(1), 17–27. https://doi.org/https://doi.org/10.21009/jmenara.v19i1.35591

Lukas. A. Y, Rafael. J. W, M., & Ar, Z. (2024). Laboratory Studies on Compressive Strength of Normal Concrete Using Coral Limestone on Timor Island, East Nusa Tenggara Province as a Substitute for Coarse Aggregate. *Journal of Engineering : Faculty of Engineering, Pancasakti University, Tegal Publishers*, *15*(2), 17–26. https://doi.org/https://doi.org/10.24905/jureng.v15i2.42

Lukas. A. Y, Rafael J. W. M, & AR. Zulfiani. (2024). Sika Viscocrete Laboratory Study On Normal Concrete Using Coarse Aggregate Of Coral. *PROTEKSI (Publikasi Riset Orientasi Teknik Sipil) : Civil Engineering Journal, Department of Civil Engineering - Faculty of Engineering, Universitas Negeri Surabaya Publishers*, *6*(1), 1–10. https://doi.org/https://doi.org/10.26740/proteksi.v6n1.p1-10

Luo. Yi. et al. (2023). Dynamic compressive characteristics and damage constitutive model of coral reef limestone with different cementation degrees. *Journal Construction and Building Materials. Elsevier Science Publishers*, *362*, 1–14. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2022.129783

Lyu. Bangcheng. et al. (2019). Coral aggregate concrete: Numerical description of physical, chemical and morphological properties of coral aggregate. *Cement and Concrete Composites*, *100*, 25–34. https://doi.org/https://doi.org/10.1016/j.cemconcomp.2019.03.016

Ma'arif, F., Yasin, I., & Haza, Z. F. (2022). Experimental Study of Non-Destructive Test with Semi-Direct Method on Concrete. *INERSIA : Journal of Information and Exposure of Civil Engineering and Architecture Research Results, Department of Civil Engineering, Faculty of Engineering, Yogyakarta State University and INTAKINDO Publishers*, *18*(1), 44–53. https://doi.org/http://dx.doi.org/10.21831/inersia.v18i1.49118

Made Suparta. I. et al. (2024). Analysis of the Quality Feasibility of Concrete Blocks with Limestone Aggregate from Small-Scale Industry Production in Kupang City. In *Jurnal Teknik Gradien* (Vol. 16, Issue 02). https://doi.org/https://doi.org/10.47329/teknik_gradien.v16i02.1277

Meng. Jian. et al. (2022). Experimental Study on the Mechanics and Impact Resistance of Multiphase Lightweight Aggregate Concrete. *Journal Sustainability (Switzerland). MDPI Publishers*, *14*(15), 1–15. https://doi.org/https://doi.org/10.3390/su14159606

Neville, A. M. (2011). *Properties of Concrete 5th Edition*.

Pramadani. Mita. et al. (2024). Effect of the Use of Fine Aggregate Variations on the Compressive Strength of the Mortar. *Proceedings of the National Seminar of the Lhokseumawe State Polytechnic*, *7*(1), 107–112. https://e-jurnal.pnl.ac.id/semnaspnl/article/view/5119

PROCEQ. (2014). *Evaluation of Strength Test Results of Concrete*. https://media.screeningeagle.com/asset/Downloads/Pundit%20Lab_Operating%20Instructions_English_high.pdf

Putra. D. M. (2021). Study on the Effect of K-300 Concrete Compaction Method on Compressive Strength and Segregation. In *Jurnal Statika* (Vol. 7, Issue 2). https://doi.org/https://doi.org/10.53494/jts.v7i2.116

Setiani. E. et al. (2015). Coral Limestone Lithology Identification Study Based on GPR Method on Nemberala Coast, Rote Regency, East Nusa Tenggara Province. In *Prosiding Seminar Sains dan Teknologi FMIPA Unmul* (Vol. 1, Issue Desember). https://fmipa.unmul.ac.id/jurnal/detail/57

SNI 2493:2011. (2011). *" Standar Nasional Indonesia*. www.bsn.go.id

Wang, A., Huang, M., Chu, Y., Zhu, Y., Liu, K., Guo, L., Liu, P., & Sun, D. (2022). Optimization of mix proportion of basic magnesium sulfate cement-based high-strength coral concrete. *Construction and Building Materials*, *341*. https://doi.org/10.1016/j.conbuildmat.2022.127709

Wang. Aiguo. et al. (2021). A gentle acid-wash and pre-coating treatment of coral aggregate to manufacture high-strength geopolymer concrete. *Construction and Building Materials. Elsevier Science Publishers*, *274*, 1–13. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2020.121780

Wang, X., Yu, R., Shui, Z., Song, Q., & Zhang, Z. (2017). Mix design and characteristics evaluation of an eco-friendly Ultra-High Performance Concrete incorporating recycled coral based materials. *Journal of Cleaner Production*, *165*, 70–80. https://doi.org/10.1016/j.jclepro.2017.07.096

Wei. Jingli. et al. (2023). Review on the characteristics and multi-factor model between pore structure with compressive strength of coral aggregate. In *Journal Construction and Building Materials. Elsevier Science Publishers* (Vol. 370, pp. 1–17). Elsevier Ltd. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2023.130326

Wu Zhang. Yu et al. (2020). Rebar corrosion in coral aggregate concrete: Determination of chloride threshold by LPR. *Journal Corrosion Science. Elsevier Science Publishers*, *163*, 1–11. https://doi.org/https://doi.org/10.1016/j.corsci.2019.108238

Wu. Zhang. Yu. et al. (2021). Experimental and mesoscopic investigation on the dynamic properties of coral aggregate concrete in compression. *Journal Science China Technological Sciences. Springer Nature Link Publishers*, *64*(6), 1153–1166. https://doi.org/https://doi.org/10.1007/s11431-020-1739-y

Wu. Zhangyu. et al. (2020). Coupling effect of strain rate and specimen size on the compressive properties of coral aggregate concrete: A 3D mesoscopic study. *Composites Part B: Engineering. Elsevier Science Publishers.*, *200*, 1–20. https://doi.org/https://doi.org/10.1016/j.compositesb.2020.108299

Yu, H., Da, B., Ma, H., Zhu, H., Yu, Q., Ye, H., & Jing, X. (2017). Durability of concrete structures in tropical atoll environment. In *Ocean Engineering* (Vol. 135, pp. 1–10). Elsevier Ltd. https://doi.org/10.1016/j.oceaneng.2017.02.020

Zhang. Bai. et al. (2023). Durability of seawater coral aggregate concrete under seawater immersion and dry-wet cycles. *Journal of Building Engineering. Elsevier Science Publishers*, *66*, 1–12. https://doi.org/https://doi.org/10.1016/j.jobe.2023.105894

Zhang, H., Zheng, S., Li, X., Pan, L., Cao, Z., Shuai, B., Shen, C., & Zhao, Z. (2025). Impact splitting tensile properties and microstructural analysis of polypropylene fiber reinforced coral seawater concrete. *Construction and Building Materials*, *471*. https://doi.org/10.1016/j.conbuildmat.2025.140747

Zhang. Jinhua. et al. (2021). Mesoscopic characteristics and macroscopic mechanical properties of coral aggregates. *Construction and Building Materials. Elsevier Science Publishers*, *309*, 1–13. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.125125

Zhang. Jintuan. et al. (2023). Mechanical properties and damage model of coral seawater sea sand concrete under compression-shear composite action. *Journal Case Studies in Construction Materials.Elsevier Science Publishers*, *19*, 1–15. https://doi.org/https://doi.org/10.1016/j.cscm.2023.e02682

Zhou. Linlin. et al. (2021). Mechanical behavior and durability of coral aggregate concrete and bonding performance with fiber-reinforced polymer (FRP) bars: A critical review. In *Journal of Cleaner Production. Elsevier Science Publishers* (Vol. 289, pp. 1–20). Elsevier Ltd. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.125652

Zhou. Wen. et al. (2020). Constitutive relations of coral aggregate concrete under uniaxial and triaxial compression. *Journal Construction and Building Materials. Elsevier Science Publishers*, *251*, 1–14. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2020.118957