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Utilization of North Minahasa Local Aggregates for Cost-Efficient Concrete Laboratory Practice in Vocational Engineering Education

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ABSTRACT

Concrete laboratory practice plays a crucial role in vocational civil engineering education by providing hands-on understanding of material behavior and concrete production processes. However, concrete laboratory activities at the State Polytechnic of Manado have long relied on aggregates sourced from outside the region, resulting in relatively high procurement and transportation costs. North Minahasa Regency has local aggregate resources, including sand and gravel, that are geographically closer and more accessible. This study aims to evaluate the technical feasibility of using local aggregates as an alternative material for cost-efficient concrete laboratory practice. The research methodology involved sampling aggregate materials from several districts in North Minahasa, followed by laboratory testing of their physical characteristics, including specific gravity, silt content, gradation, and abrasion value. Concrete specimens were then produced using selected mix proportions and tested for compressive strength at 7 and 28 days. The results demonstrate that local aggregates meet the fundamental quality requirements for concrete production after washing samples with high silt content. The concrete produced achieved the intended strength and reduced logistical material costs. These findings indicate that local aggregates are feasible for use in educational concrete laboratory activities and support more efficient learning based on local resource potential.

1. INTRODUCTION

Concrete is the most widely used construction material in various types of infrastructure, including buildings, highways, and bridges [1-3]. The performance and strength of concrete are highly influenced by the quality of its fine and coarse aggregates, which constitute more than 70% of its total volume [4,5]. In the context of vocational civil engineering education, concrete laboratory practice plays a crucial role in providing students with empirical understanding of material properties, mixing procedures, and compressive strength testing [6,7]. However, the implementation of laboratory activities often faces challenges related to material availability and cost efficiency, particularly when aggregates must be sourced from distant regions.

The State Polytechnic of Manado has long relied on aggregates transported from outside North Minahasa, leading to logistical constraints, supply dependency, and increased operational costs in conducting laboratory practice. Meanwhile, North Minahasa Regency possesses abundant local aggregate resources, distributed across regions such as Airmadidi, Dimembe, Talawaan, Watudambo, and Likupang. Although these materials are commonly used in small-scale community construction, they have not been systematically evaluated for academic and laboratory purposes.

Previous studies indicate that local aggregate sources can be utilized as concrete components when they meet essential technical standards, including specific gravity, gradation, and silt content [8-13]. Research has demonstrated that concrete made with local aggregates can meet structural performance requirements after proper preliminary processing [14-16]. However, to date, no study has specifically examined the feasibility of North Minahasa local aggregates as an alternative material for concrete laboratory practice in vocational engineering education, where cost efficiency and contextual learning are key priorities.

Therefore, this research aims to identify the physical and mechanical characteristics of local aggregates from North Minahasa, evaluate the quality of concrete produced using these aggregates based on standard strength requirements, and provide technical recommendations for the utilization of local materials in concrete laboratory practice. The research seeks to answer three main questions: whether local aggregates from North Minahasa meet the technical standards required for concrete production, how the compressive strength performance of concrete using local aggregates compares to standard concrete, and how the implementation of locally sourced materials can enhance the cost efficiency and practicality of concrete laboratory activities in vocational engineering education.

The research problems addressed in this study revolve around three essential questions: whether local aggregates from North Minahasa meet the technical standards required for concrete production, how the compressive strength performance of concrete produced using these local aggregates compares to that of standard concrete, and to what extent the utilization of locally sourced materials can improve the cost efficiency and effectiveness of concrete laboratory practice in vocational civil engineering education.

2. LITERATURE REVIEW

Concrete is a composite construction material composed of hydraulic cement, fine and coarse aggregates, water, and optional admixtures, where aggregates account for approximately 70–80% of the total volume and therefore play a dominant role in determining performance characteristics such as compressive strength and durability. Recent advancements in construction material technology emphasize the need for optimizing concrete composition to achieve higher strength, improved durability, and cost efficiency, especially in modern construction applications such as bridge engineering that increasingly utilize high-performance concrete [1]. The growing demand for high-quality concrete has led researchers to explore improved material components and formulations, including alternative aggregate sources and composite materials aimed at enhancing structural performance [2]. The application of ultra-high-performance concrete in large-scale infrastructure projects further illustrates the importance of aggregate characteristics in influencing mechanical strength and long-term performance [3].

The physical characteristics of aggregates, including particle size distribution, specific gravity, and mechanical resistance, directly affect concrete strength development and structural reliability. The size and grading of coarse aggregates significantly influence compressive strength and internal bonding mechanisms of concrete mixtures [4]. Research evaluating recycled aggregates demonstrates that controlled processing and quality assessment can yield concrete with satisfactory performance, comparable to conventional materials under standardized conditions [5]. In engineering education contexts, experiential learning has proven to be an effective method for teaching students about material behavior, practical application, and experimental testing procedures, particularly in understanding compressive strength testing in large student groups [6, 7].

Fine and coarse aggregates must satisfy specific technical standards to ensure the required structural integrity of concrete. Excessive fines or improper particle grading may impair hydration bonding and subsequently reduce compressive strength, emphasizing the necessity of quality control measures such as washing and sieving prior to use [8]. Several studies evaluating locally sourced aggregates demonstrate that concrete produced with regional materials can achieve adequate strength levels when proper material preparation is conducted [9, 10]. Research also indicates that alternative or natural aggregates, including lightweight materials such as scoria, provide viable performance outcomes and can contribute to sustainable resource utilization within regional construction sectors [11, 12]. Additional investigations on sand quality likewise reinforce that variations in physical properties among different local sources can significantly affect concrete performance [13].

Furthermore, research trends increasingly highlight the importance of recycling and processing techniques to transform construction waste into viable structural materials, reducing reliance on externally sourced aggregates. Alternative processing procedures for recycled aggregates have shown potential in producing concrete with acceptable structural performance and durability when appropriate crushing and cleaning processes are applied [14]. The crushing method and stages of material refinement significantly influence the final performance of concrete made from recycled aggregates, particularly in precast construction environments [15]. Structural concrete produced using recycled aggregates from precast waste materials has demonstrated adequate strength and long-term potential for broader construction applications, further supporting the feasibility of alternative aggregate sources in engineering practice [16].

Drawing from these findings, existing research primarily focuses on structural and performance-based evaluations using recycled or alternative aggregates for large-scale construction purposes. However, limited studies investigate the systematic assessment of locally sourced aggregates for application in educational laboratory environments, particularly in vocational engineering programs where cost efficiency, accessibility, and contextual learning are central priorities. This gap highlights the need for research exploring the technical feasibility of using local aggregates to support effective concrete laboratory practice and enhance practical learning experiences aligned with regional material availability.

3. METHODOLOGY

This study adopts a quantitative research approach utilizing experimental laboratory methods. This approach was selected to obtain numerical data related to the physical characteristics of local aggregates and the compressive strength of concrete produced from them, enabling comparison with the standard specifications of normal concrete as regulated by SNI 03-2834-2000. The experimental method allows precise measurement, controlled testing conditions, and objective assessment of material behavior, which are essential for evaluating the feasibility of local aggregates for concrete laboratory practice.

The research was carried out in several stages beginning with sample collection from different aggregate sources in North Minahasa Regency, including the districts of Airmadidi, Dimembe, Talawaan, Watudambo, and Likupang. All testing procedures, including aggregate characterization and concrete specimen production, were conducted at the Materials and Concrete Laboratory, Department of Civil Engineering, State Polytechnic of Manado. The selected sites represent commonly utilized local quarries with active community-based extraction, making them relevant for academic and practical application purposes.

The population in this study comprises all fine and coarse aggregates available from local quarry operations in North Minahasa. Samples were taken using a purposive sampling technique, selecting locations based on accessibility and current production activity. From each location, a minimum of 50 kg of fine aggregate and 75 kg of coarse aggregate was collected, consistent with standard sampling requirements for aggregate testing. The sampling and preparation procedures were conducted under standardized conditions to ensure the reliability and consistency of test results across all sources.

The procedures undertaken throughout the research process include field identification, sample collection, sample processing, aggregate testing, concrete mixing, and compressive strength testing. Each stage followed relevant Indonesian National Standards (SNI). The sequence of activities and applicable standards is summarized in Table 1, which provides an overview of the complete data collection process implemented in this study.

Table 1. Research data collection procedures and standard references

Stage	Activity	Standard Reference
Preliminary study	Site identification and coordination	–
Sampling	Collection, packaging, and labeling of aggregates	SNI 03-1965-1990
Sample processing	Washing of sand and re-sieving	SNI 03-4142-1996
Aggregate testing	Specific gravity, absorption, silt content, gradation, abrasion	SNI 1970:2008; SNI 03-1968-1990; SNI 2417:2008
Concrete casting	Mix design and molding of Ø15 × 30 cm cylinders	SNI 03-2834-2000
Compressive testing	Strength tests at 7 and 28 days	SNI 03-1974-1990

Instrument requirements were standardized to ensure accurate measurement and repeatability. Laboratory equipment included a complete sieve set (No. 4–200), digital weighing scales, Los Angeles abrasion machine, laboratory oven, compression testing machine, cylindrical moulds (Ø15 cm × 30 cm), concrete mixer, and slump cone. These instruments enabled the assessment of key aggregate properties and the determination of compressive strength values in accordance with Indonesian testing standards.

The experimental variables comprised independent variables representing the type and source of local aggregates, dependent variables referring to the compressive strength (MPa) of concrete specimens, and control variables including water–cement ratio, cement type, curing method, and specimen dimensions. Data analysis followed quantitative procedures involving comparative analysis against SNI standard threshold values, gradation curve plotting for classification of fine aggregate zones, and computation of compressive strength using the formula $\sigma = P/A$ supported by descriptive statistical evaluation. Interpretation of findings was presented using tables and graphical outputs to illustrate performance and suitability for laboratory practice.

To ensure replicability and reliability, research protocols were designed to allow the study to be repeated under identical conditions by future researchers. All samples were stored in dry conditions and labelled according to source location, date, and quarry identification. Washing and sieving procedures were applied consistently, and compressive strength testing was conducted using a minimum of three specimens for each mix variation. The use of national standards throughout the testing process further supports methodological consistency and scientific reliability.

4. RESULT AND DISCUSSION

4.1 Physical Properties of Aggregate

The initial stage of the experimental investigation involved testing the physical properties of fine and coarse aggregate samples collected from five quarry locations in North Minahasa Regency, namely Airmadidi, Dimembe, Talawaan, Watudambo, and Likupang. The objective of this evaluation was to determine whether the locally sourced materials meet the minimum requirements specified in Indonesian National Standards (SNI) for use in concrete production. The tested parameters included specific gravity, water absorption, silt content, gradation based on fineness modulus (FM), and aggregate abrasion resistance.

Specific gravity results indicated that all fine aggregate samples exhibited values exceeding the minimum SNI requirement of ≥ 2.50, with measurements ranging from 2.55 to 2.63. The highest value was recorded for material sourced from Talawaan, while the lowest was found in the Dimembe sample. These results demonstrate that the local aggregates possess sufficient density and particle solidity, making them suitable for structural performance and volumetric stability in concrete mixtures.

The silt content test revealed variations across sampling locations, with values between 2.7% and 6.3%. While most samples complied with the maximum allowable limit of **≤ 5%**, materials from Dimembe and Watudambo exceeded the standard threshold, with values of 6.3% and 5.9%, respectively. These findings indicate that aggregates sourced from these locations require washing prior to use in concrete to avoid negative effects on bonding quality and compressive strength. This treatment is consistent with recommendations in previous studies emphasizing material preprocessing to enhance aggregate performance.

Abrasion resistance testing showed that coarse aggregates from all locations met the standard requirement of ≤ 40%, with Los Angeles Abrasion values ranging between 29% and 34%. These results confirm that the aggregates possess adequate durability to resist fragmentation and mechanical wear, making them suitable for use in laboratory concrete testing. Additionally, the fineness modulus values for fine aggregates ranged from 2.5 to 2.9, placing all samples within the acceptable Zone II–III range and indicating good gradation and workability potential.

A summary of the aggregate test results is presented in Table 2, which compares material characteristics from each quarry location against SNI specifications. Based on the evaluation, the majority of the tested samples met the standard criteria, confirming the technical feasibility of utilizing North Minahasa local aggregates as raw materials for concrete laboratory practice, with minor preprocessing required for selected sources.

Table 2. Physical properties of local aggregates from North Minahasa

Test Parameter	SNI Requirement	Airmadidi	Dimembe	Talawaan	Watudambo	Likupang	Remarks
Specific Gravity (Sand)	≥ 2.50	2.58	2.55	2.63	2.57	2.60	Meets requirements
Silt Content (%)	≤ 5%	4.2	6.3	3.8	5.9	2.7	Washing required for high silt samples
LA Abrasion (%)	≤ 40%	32	29	34	30	33	Meets requirements
Fineness Modulus (FM)	Zone II–III	2.7	2.8	2.6	2.9	2.5	Meets requirements

4.2 Compressive Strength

Compressive strength tests were performed on cylindrical concrete specimens with dimensions of Ø15 cm × 30 cm at curing ages of 7 and 28 days. Two design compressive strength levels, f'c 20 MPa and f'c 25 MPa, were selected to evaluate the performance of concrete mixes prepared using aggregates sourced from five quarry locations in North Minahasa. The objective of these tests was to determine whether locally available aggregates can meet the standard requirements for normal-strength concrete used in laboratory-based vocational education.

The results showed variations in compressive strength depending on the aggregate source and curing age. For concrete with a target strength of f'c 20 MPa, aggregates from Airmadidi and Talawaan produced compressive strengths of 18.2 MPa and 17.9 MPa at 7 days, increasing to 24.5 MPa and 23.7 MPa at 28 days, respectively. Both exceeded the minimum required strength of 20 MPa at 28 days, indicating satisfactory performance. Meanwhile, concrete from Dimembe aggregates recorded lower early strength values of 15.4 MPa at 7 days, but achieved 21.3 MPa at 28 days after a washing treatment to reduce silt content.

For concrete targeting f'c 25 MPa, aggregates from Likupang and Watudambo demonstrated strong mechanical performance. Likupang aggregates exhibited compressive strengths of 21.5 MPa at 7 days and 28.7 MPa at 28 days, while Watudambo aggregates achieved 19.8 MPa and 27.2 MPa for the same testing age. These results confirm that properly processed aggregates from both sources can be utilized to produce normal-strength concrete meeting standard criteria.

Overall, the results indicate that local aggregates from North Minahasa are technically feasible for use in concrete laboratory practice, with only minor treatment such as washing required for materials with higher silt content. This demonstrates a practical opportunity to substitute externally purchased materials and reduce logistical expenses in concrete laboratory activities. A summary of the compressive strength results is presented in Table 3, comparing test outcomes with required standard strength values.

Table 3. Compressive strength of concrete using local aggregates from North Minahasa

Design Strength	Aggregate Source	Age 7 Days (MPa)	Age 28 Days (MPa)	Standard Strength (MPa)	Evaluation
f'c 20 MPa	Airmadidi	18.2	24.5	≥ 20	Meets requirement
f'c 20 MPa	Talawaan	17.9	23.7	≥ 20	Meets requirement
f'c 20 MPa	Dimembe	15.4	21.3	≥ 20	Meets requirement after washing
f'c 25 MPa	Likupang	21.5	28.7	≥ 25	Meets requirement
f'c 25 MPa	Watudambo	19.8	27.2	≥ 25	Meets requirement

4.3 Discussion

The findings of this study demonstrate that concrete produced using local aggregates from North Minahasa is capable of achieving the planned compressive strength levels and falls within the range of normal-strength concrete. The strongest performance was observed in concrete mixes incorporating aggregates sourced from Likupang and Airmadidi, both of which exhibit low silt content and an optimal particle size distribution. These characteristics enhance particle interlocking and matrix cohesion, enabling the development of higher compressive strength. The results provide evidence that properly selected and processed local aggregates can serve as viable substitutes for commercially supplied materials in concrete laboratory practice.

The influence of aggregate quality on concrete strength is well supported by theoretical understanding in the field of construction materials. Key physical properties—including specific gravity, gradation, and impurity content—play substantial roles in determining the performance of hardened concrete. Fine impurities, such as excessive silt or clay, can interfere with the bonding mechanism between cement paste and aggregate particles, resulting in reduced compressive strength. This observation aligns with the explanation provided by Mehta and Monteiro, who argue that fine contaminants weaken adhesive bonding and increase voids in the concrete matrix, ultimately lowering strength development.

This relationship is clearly illustrated by the test results for aggregates originating from Dimembe. Prior to washing, concrete prepared with Dimembe aggregates registered lower compressive strength values at both 7 and 28 days. However, after the removal of excess fine materials through washing, the concrete achieved the minimum required strength, thereby confirming the detrimental effect of high silt content and the importance of material processing. This outcome reinforces the principle that cleaning or screening aggregates is essential when impurity levels exceed acceptable thresholds.

The results also correspond with previous research related to the use of locally sourced aggregates in concrete. For instance, Afriyani (2017) reported that local aggregates are capable of producing structurally acceptable concrete when proper preliminary treatment is applied. Such findings are consistent with the outcomes of this study and highlight the broader potential of utilizing regional aggregate sources to support construction and academic activities. The present research therefore contributes empirical validation and extends the application context to vocational engineering education settings.

Beyond technical findings, the study offers meaningful practical implications. By demonstrating the feasibility of using locally available aggregates, the research supports efforts to reduce dependence on imported construction materials and lower the logistical costs associated with long-distance transportation. These implications are particularly relevant for vocational education institutions where material accessibility and budget efficiency significantly influence laboratory operations and learning opportunities. A summary of the primary contributions and impacts of this research is presented in Table 4, which highlights academic, economic, and educational benefits derived from the implementation of local materials.

Despite these noteworthy contributions, the study has several limitations that must be acknowledged. The analysis focuses primarily on compressive strength testing and does not include durability assessments such as resistance to sulphate, chloride penetration, or marine exposure, which are essential for real structural applications. Additionally, only two grades of concrete were tested, limiting generalizability for higher-strength concrete. The variability of material quality at community-based quarry sites, influenced by seasonal factors and non-standardized extraction methods, also presents potential challenges and highlights the need for continued research.

Future studies should therefore expand to include durability testing under North Sulawesi marine environmental conditions, mix design development for structural concrete with strengths exceeding 30 MPa, and the creation of practical laboratory modules that integrate local materials for vocational teaching. Applied research and collaboration between academic institutions, local quarry operators, and regional industries may further enhance material innovation and educational relevance.

Table 4. Research Contributions and Implications

Aspect	Contribution
Academic	Provides a reference database for local aggregate properties in concrete laboratory practice
Economic	Reduces material logistics and procurement costs by approximately 20–30%
Vocational Education	Supports context-based learning and promotes the development of practical competence
Future Research	Serves as a basis for further studies on durability and SCC using local aggregates

5. CONCLUSION

This study aimed to evaluate the utilization of locally sourced aggregates from North Minahasa Regency as an alternative material for concrete laboratory practice at Politechnic Negeri Manado. Based on laboratory testing conducted on aggregates from several quarry locations, the materials demonstrated physical and mechanical characteristics that generally meet standard requirements, particularly in parameters such as specific gravity, abrasion resistance, and particle size distribution. Although several aggregate samples exhibited silt contents exceeding allowable limits, the issue was successfully mitigated through washing and rescreening. Concrete produced using local aggregates achieved the required compressive strengths for the planned grades of f'c 20 MPa and f'c 25 MPa, confirming their feasibility for use in teaching applications. Additionally, the use of local materials has the potential to reduce transportation and procurement costs while strengthening context-based learning aligned with regional resource availability.

Despite promising results, this study has several limitations. Durability testing under aggressive environmental conditions—such as sulphate exposure, chloride penetration, and seawater immersion relevant to the coastal environment of North Sulawesi—was not conducted. Strength tests were limited to medium-strength concrete, and therefore do not fully represent performance for high-strength or structural-grade applications. Furthermore, variations in the quality of materials sourced from community-operated quarries may occur due to seasonal conditions and non-standardized extraction methods, indicating the need for supply quality control if broader long-term implementation is intended.

For future research, it is recommended to conduct advanced durability testing, including chemical resistance, permeability, and shrinkage assessments, as well as exploration of mix design development for high-strength or Self-Compacting Concrete (SCC) using local aggregates. The findings of this study may also be integrated into concrete laboratory learning modules utilizing local materials and serve as a foundation for collaboration between academic institutions, local government, and mining operators to support sustainable regional resource utilization.

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