Equivalent: Jurnal Ilmiah Sosial Teknik
Volume 8, Issue 5, 2215-2225
e_ISSN: 2775-0833
https://jurnalequivalent.id/index.php/jequi/index
DOI: doi.org/10.59261/jequi.v8i5.474

Mechanical Test of Mortar with Addition of Fly Ash Using Seawater Immersion

Muh. Sayfullah. S*
Universitas Muhammadiyah Buton,
Indonesia

Muhammad Abdu
Universitas Muhammadiyah Buton,
Indonesia

Arjun
Universitas Muhammadiyah Buton,
Indonesia

***Corresponding author:**
Muh. Sayfullah. S,
Universitas Muhammadiyah Buton, Indonesia.
✉muh.sayfullahs@gmail.com

Article Info:

Article history:
Received: September 16, 2026
Revised: October 12, 2026
Accepted: October 14, 2026
Available Online: November 95, 2026

Keywords:
Compressive Strength;
Curing; Fly Ash;
Mortar;
Seawater.

This is an open access article under the CC BY-SA license.

Copyright © 2026 by Author. Published by Cerdika International Cyber Polytechnic

Abstract

Background: The rapid pace of infrastructure development has increased the demand for more environmentally friendly cement-based binders. One potential approach is the use of fly ash as a supplementary cementitious material in mortar.
Objective: To determine the compressive strength of mortar and evaluate the effects of fly ash replacement at proportions of 0%, 5%, 10%, and 15% by weight of cement, using two curing media: seawater and freshwater.
Method: This study employed a quantitative experimental approach involving laboratory testing to evaluate the effects of varying fly ash replacement proportions on the compressive strength and water absorption of mortar specimens cured in two different media.
Results: The compressive strength of mortar increased with increasing fly ash content and curing age in both curing media. The highest value was obtained with 15% fly ash replacement after 28 days of freshwater curing, reaching 31.53 kN, whereas seawater curing under the same conditions yielded 22.90 kN. Freshwater curing consistently resulted in higher compressive strength than seawater curing across all fly ash replacement proportions. Conversely, the 28-day water absorption test showed that specimens cured in seawater exhibited relatively higher water absorption than those cured in freshwater.
Conclusion: Chloride, calcium, magnesium, and sulfate ions in seawater may influence cement hydration. These effects may accelerate early-age strength development but may also increase porosity and compromise long-term durability. These findings provide preliminary insights into the potential benefits and limitations of using seawater as a curing medium for mortar.

To cite this article: S., M. S., Abdu, M., & Arjun. (2026). Mechanical test of mortar with addition of fly ash using seawater immersion. *Equivalent: Jurnal Ilmiah Sosial Teknik*, *8*(5), 2215–2225. https://doi.org/10.59261/jequi.v8i5.474

INTRODUCTION

The growing demand for construction materials has intensified the need to reduce the environmental burden associated with Portland cement production. Mortar remains essential for masonry, plastering, and other construction activities because of its relatively simple preparation and adaptable mechanical properties. Incorporating fly ash into cement-based mixtures offers an opportunity to utilize industrial by-products while investigating alternatives to conventional binder compositions (Hardjito, 2014). At the same time, mortar performance depends not only on its constituent materials but also on curing conditions, particularly the availability and chemical composition of the water used during hydration.

These considerations are especially relevant in Indonesian coastal settings, where seawater is readily available, but access to freshwater may be limited for certain construction

activities. Although seawater may provide an alternative immersion medium, its dissolved ions may influence the development and stability of hydration products. Consequently, it cannot be assumed that fly ash-containing mortar will perform similarly under seawater and freshwater curing conditions. The specific problem addressed in this study is how variations in fly ash content and curing medium are associated with the measured maximum compressive failure load at different curing ages and with water absorption at 28 days.

Previous research provides a basis for examining these conditions but also indicates that responses vary across material systems. Li et al. (2021) reviewed the effects of seawater constituents on cement hydration, microstructure, and mechanical performance, describing potentially beneficial early-age reactions alongside concerns about long-term material stability. Janowska-Renkas & Kaliciak (2021) investigated the durability of fly ash-containing mortars exposed to seawater and carbonation, demonstrating the importance of fly ash characteristics and exposure conditions. Hwang & Yeon (2022) examined fly ash-modified, seawater-mixed pervious concrete and reported performance trends associated with fly ash content. These studies establish the relevance of both fly ash incorporation and marine exposure; however, their distinct binder systems, mixture designs, and seawater applications do not directly establish the outcomes for the mortar composition and curing conditions investigated in the present study.

The research gap therefore concerns the combined and directly comparable behavior of Portland cement mortar incorporating 0%, 5%, 10%, and 15% fly ash when immersed in seawater or freshwater at the same curing ages. The distinction between using seawater as mixing water and using it exclusively as a curing medium is important because the specimens in the present study were prepared using freshwater as the mixing water. Comparing the two immersion media within a single experimental design allows observed differences to be evaluated in relation to fly ash content and curing age, while water absorption provides a supplementary indicator of material behavior. Water absorption alone, however, does not establish long-term durability or identify the underlying chemical mechanisms responsible for the observed performance.

This investigation is practically important because decisions concerning mortar curing in coastal environments require evidence regarding the performance trade-offs associated with seawater exposure. Without comparative test results, the availability of seawater could be mistaken for evidence of its suitability as a direct substitute for freshwater as a curing medium. In addition, the use of fly ash in cement-based materials requires systematic evaluation across defined replacement levels rather than the assumption that increasing fly ash content will invariably improve performance. The present study addresses these concerns under controlled laboratory conditions relevant to the materials and environmental setting under consideration.

The novelty of this study lies in its combined experimental comparison of four fly ash proportions (0%, 5%, 10%, and 15%), two immersion-curing media (seawater and freshwater), and three curing ages (3, 7, and 28 days), together with water absorption measurements at 28 days. Unlike the cited investigations involving seawater as mixing water or different binder systems, the present study focuses on Type I Portland cement mortar mixed with freshwater and subsequently immersed in either seawater or freshwater for curing. The objective is to compare the measured maximum compressive failure load across these experimental combinations and evaluate differences in water absorption between the two curing media. The laboratory specimens consisted of 5 × 5 × 5 cm cubes prepared using a cement-to-sand ratio of 1:3 under the specified experimental conditions.

The expected benefit is an empirical basis for assessing the behavior of fly ash-containing mortar under contrasting curing conditions and informing further research on construction materials in coastal areas. In practical terms, the findings may help identify the limitations of seawater immersion when freshwater curing is available, while providing preliminary information for evaluating mortar applications in settings where freshwater resources are constrained. The implications are necessarily limited to the materials tested, the fly ash content range, and the 28-day observation period. Recommendations regarding structural applications or long-term marine durability would require additional investigations, including compressive strength testing, microstructural characterization, ion transport analysis, and extended exposure testing.

METHOD

The research was conducted at the Civil Engineering Laboratory, Faculty of Engineering, University of Muhammadiyah Buton, in Baubau City, Southeast Sulawesi, Indonesia, over a period of two months (April–May 2026).

This study employed a quantitative approach involving laboratory experiments to investigate the effects of varying fly ash replacement levels (0%, 5%, 10%, and 15%) on the compressive strength and water absorption of mortar specimens subjected to two different curing media. The experimental design employed a two-factor factorial arrangement, comprising fly ash content (four levels) and curing medium (two levels). The dependent variables were compressive strength at three testing ages and water absorption at 28 days.

The materials used in this study included Type I Portland cement (Tonasa cement), natural sand obtained from Batauga, fly ash, fresh water for mixing, and seawater and fresh water as curing media for comparison. The equipment included 5 × 5 × 5 cm cube molds, digital scales, measuring cylinders, standard sieves for aggregate sieve analysis, tamping rods, immersion tanks, and a hydraulically operated compression testing machine for determining compressive strength.

The mortar mixture proportions were based on the provisions of SNI 03-2834-2000 National Standardization Agency (2000), using a cement-to-sand ratio of 1:3 by mass, a target strength designation of K-125, and cube-shaped test specimens measuring 5 × 5 × 5 cm. Before mixing, the fine aggregate (sand) was tested for its physical properties, including particle-size distribution (sieve analysis), specific gravity, moisture content, silt content, and bulk density, at the Laboratory of the Faculty of Engineering, University of Muhammadiyah Buton.

Each fly ash content was evaluated at 3, 7, and 28 days, with five specimens allocated to seawater curing and five to freshwater curing at each testing age. Thus, the total number of specimens for compressive strength testing was 120. In addition, 40 specimens were prepared for water absorption testing at 28 days, comprising 20 specimens for each curing medium. Therefore, the total number of specimens used in the study was 160, as presented in Table 1.

Table 1
Matrix of Number of Test Objects

Fly Ash Percentage	Age of the Test Piece	Seawater	Fresh Water	Quantity
0%	3, 7, 28 days	15	15	30
5%	3, 7, 28 days	15	15	30
10%	3, 7, 28 days	15	15	30
15%	3, 7, 28 days	15	15	30
0%, 5%, 10%, 15%	Water absorption, 28 days	20	20	40

Each test specimen was prepared by mixing cement, fly ash, sand, and water. The fresh mortar was then placed in a cube mold and compacted using 32 strokes of a tamping rod per layer. The surface was leveled, and the specimens were left in the molds for approximately 24 hours before demolding. Compaction was intended to reduce entrapped air and produce specimens with a more uniform density. After demolding, each specimen was labeled according to its fly ash content, curing medium, and testing age to facilitate identification throughout the curing and testing procedures.

The specimens were subsequently immersed in tanks containing seawater or fresh water, depending on the assigned curing condition, until the designated testing age. The seawater was collected from coastal waters around Baubau City without special treatment to represent naturally occurring seawater that may be available to coastal communities.

The workability of the fresh mortar mixture was assessed before molding. The slump test was conducted in accordance with SNI 1972:2008 (BSN, 2008), as cited in the original methodology. However, the applicability of this standard to mortar, rather than concrete, should be verified. The compressive strength test was conducted in accordance with SNI 03-6825-2002

(BSN, 2002) at the ages of 3, 7, and 28 days using a hydraulically operated compression testing machine. The load was applied gradually until failure occurred. Compressive strength was determined from the maximum load sustained by each specimen divided by its loaded cross-sectional area and should be reported in megapascals (MPa). Water absorption was evaluated at 28 days by comparing the specimen mass before and after the specified soaking procedure, following the general principle of water absorption testing for cement-based materials. The precise conditioning, drying, and weighing procedures should be specified to ensure that the water absorption results are reproducible.

The compressive strength and water absorption data were analyzed using descriptive quantitative methods. The mean value was calculated for each combination of fly ash content, testing age, and curing medium, as applicable. The results were presented in tables and compared to identify trends associated with the independent variables. Comparisons were made between fly ash contents under the same curing conditions and between curing media at the same fly ash content to identify consistent patterns of increases or decreases in compressive strength and water absorption.

Overall, the research was conducted in the following stages: (1) preparation and characterization of the mortar constituent materials; (2) determination of the mixture proportions based on the cited SNI standard; (3) preparation of the test specimens and initial curing in the molds for 24 hours; (4) immersion of the specimens in seawater or fresh water according to the experimental design; (5) compressive strength testing at 3, 7, and 28 days and water absorption testing at 28 days; (6) data tabulation and analysis; and (7) formulation of conclusions and recommendations.

RESULTS AND DISCUSSION

Results

Characteristics of Mortar Constituent Materials

The results of the tests on the characteristics of Batauga sand showed a bulk specific gravity of 2.72, a saturated surface-dry (SSD) specific gravity of 2.57, an apparent specific gravity of 2.62, a water absorption of 2.13%, a moisture content of 2.7%, and a silt content of 2.08%. However, the specific gravity values appear internally inconsistent and should be verified against the original test data. The loose bulk density (0.75 kg/L) and compacted bulk density (0.91 kg/L) were below the specified range of 1.4–1.9 kg/L, indicating that the sand had a relatively low bulk density.

The sieve analysis showed that the largest proportions of sand were retained on sieve No. 60 (39%) and sieve No. 30 (34%), indicating that the sand gradation was dominated by fine to medium-sized particles. This characteristic provided a basis for determining the mortar mixture proportions using a cement-to-sand ratio of 1:3 (1 PC:3 Ps), in accordance with the procedure referenced as SNI 03-2834-2000. The applicability of this standard to mortar proportioning, rather than concrete mix design, should be verified.

Compressive Strength Mortar

A summary of the average mortar failure loads obtained at different fly ash replacement levels and curing ages is presented in Table 2.

Table 2

Recapitulation of Average Values of Compressive Strength of Mortar (KN)

Age	Media Curing	0%	5%	10%	15%
3 Days	Seawater	6,87	8,57	11,20	13,57
3 Days	Fresh Water	8,60	10,10	12,33	16,80
7 Days	Seawater	10,63	13,03	15,20	18,67
7 Days	Fresh Water	14,17	14,47	16,80	22,50

Age	Media Curing	0%	5%	10%	15%
28 Days	Seawater	14,43	14,80	17,33	22,90
28 Days	Fresh Water	16,17	16,80	18,53	31,53

In general, Table 2 shows three main trends. First, the mortar failure load increased with curing age in both curing media, from 3 to 28 days. Second, the failure load increased with increasing fly ash content across all curing ages and media. The highest value was obtained with 15% fly ash after 28 days of freshwater curing, reaching 31.53 kN, compared with 22.90 kN under the same conditions of fly ash content and curing age in seawater. Third, freshwater curing consistently produced higher failure loads than seawater curing at all tested fly ash contents and curing ages. The difference generally became more pronounced at higher fly ash contents and longer curing ages. Mechanistic interpretations of these patterns, together with comparisons with previous studies, are presented in the Discussion section.

Water Absorption Mortar

The results of the water absorption tests conducted on 28-day-old mortar specimens at the tested fly ash contents are summarized in Table 3.

Table 3

Recapitulation of the Average Value of Water Absorption of Mortar Age 28 Days

Media Curing	Age	Average Water Absorption Value (%)
Seawater	28 Days	9,3
Fresh Water	28 Days	8,5

Table 3 shows that the specimens cured in seawater had a higher average water absorption (9.3%) than those cured in freshwater (8.5%). The difference was 0.8 percentage points. Although relatively small in absolute terms, this result contrasts with the higher failure loads obtained under freshwater curing and warrants further discussion in terms of the material's pore structure and potential durability.

Discussion

Mechanisms of Development of Stress to Treatment Age

The relatively low failure loads observed at 3 days across all fly ash contents are consistent with the slower development of pozzolanic reactions in fly ash compared with the initial hydration reactions of Portland cement. Consequently, the contribution of fly ash to strength development may be limited at early ages. Astuti et al. (2013) showed that reducing fly ash particle size to the nanoscale can accelerate pozzolanic reactions at early ages. In contrast, the conventional fly ash used in this study may have had a coarser particle size, potentially delaying its contribution to strength development. However, this explanation would need to be confirmed through particle-size characterization and microstructural analysis.

The more pronounced increase in failure load at 28 days, particularly with 15% fly ash under freshwater curing, is consistent with the gradual development of pozzolanic reactions that produce additional calcium silicate hydrate (C–S–H) through reactions between reactive silica in fly ash and calcium hydroxide generated during cement hydration. This pattern of strength development over the medium to long term is also consistent with the findings of Janowska-Renkas & Kaliciak (2021) on mortars containing fly ash from fluidized-bed combustion (FBC), which indicated that pozzolanic activity can continue to develop under aggressive exposure conditions. Similarly, Donatello et al. (2013) reported that cement pastes and mortars containing high volumes of fly ash can maintain or improve their mechanical performance at later ages under certain aggressive exposure conditions.

Effect of Fly Ash Percentage: Pozzolanik Reaction versus Cement Dilution Effect

The consistent increase in failure load across the tested range of 0–15% fly ash indicates that, under the conditions investigated, the combined effects of pozzolanic reaction and particle packing may have outweighed the reduction in cement content associated with fly ash replacement. This finding is consistent with Wenno et al. (2014), who reported an increase in mortar compressive strength with fly ash addition up to a certain level, followed by a decrease.

In contrast, Nana Patria & Haikal (2022) reported that the compressive strength of high-performance concrete at 7 days decreased as the fly ash replacement level increased within a higher range of 10–40%, even when a high-range water-reducing admixture was used. This difference suggests that the balance between the benefits of fly ash and the dilution of cement depends on the replacement level, water-to-binder ratio, admixture use, and other mixture characteristics. However, the present results alone do not establish the threshold at which the dilution effect becomes dominant.

Hwang & Yeon (2022), in their study of pervious concrete mixed with seawater, found that the optimum fly ash proportion relative to the total binder content was approximately 15%. This value is close to the highest replacement level examined in the present study and suggests that 15% may be a promising proportion under certain mixture conditions. Nevertheless, the optimum content cannot be established without testing additional replacement levels. In a different binder system involving slag-based cement mortar and alkali-activated slag–fly ash materials, Pang & Liu (2026) showed that compressive strength depended strongly on the type and dosage of alkaline activators. Direct comparisons with ordinary Portland cement systems, such as the one used in this study, should therefore be made cautiously.

Influence of Seawater and Freshwater Curing Media: A Chemical Perspective

Freshwater curing consistently resulted in higher failure loads than seawater curing across all tested fly ash contents and curing ages. According to the review by Li et al. (2021), seawater contains substantial concentrations of chloride, sulfate, calcium, magnesium, and sodium ions that can influence cement hydration through several mechanisms. At early ages, chloride and sulfate ions may accelerate certain hydration reactions and the formation of phases such as chloroaluminate hydrates and ettringite. However, under prolonged exposure, the formation of certain reaction products, ion exchange, and calcium leaching may alter the stability and microstructure of the cement paste. The actual effects depend on the exposure conditions and the chemical composition of the binder and seawater.

This interpretation is broadly consistent with Janowska-Renkas & Kaliciak (2021), who reported the migration of Ca^{2+} ions in fly ash mortar immersed in seawater, although they did not observe significant changes in expansion when the fly ash content remained within a moderate range of up to 35%.

The observation that seawater-cured specimens still exhibited increasing failure loads with age, although their values were lower than those of freshwater-cured specimens, is consistent with findings reported in several studies involving Portland cement-based materials. For example, Irawan et al. (2023) reported a decrease in concrete compressive strength as the duration of seawater immersion increased compared with protected exposure conditions. Similarly, Zahlim et al. (2022) found that high-performance concrete containing fly ash and prepared or cured using seawater exhibited lower compressive strength than concrete treated with freshwater. Dirgantara (2025) reported a similar trend in fly ash concrete immersed in brackish water: fly ash addition increased strength under both exposure conditions, although the absolute values differed with salinity. In another study involving self-compacting geopolymer concrete, Nurtanto et al. (2021) reported lower compressive strength under seawater curing than under freshwater curing. Because geopolymer binders differ chemically from conventional Portland cement systems, this comparison should be interpreted in the context of binder composition.

Importantly, the influence of seawater is not universally negative and depends strongly on the binder system. Yahya et al. (2021) showed that alkali-activated fly ash paste could achieve a compressive strength of 71.10 MPa at 28 days when printed directly in seawater, with a strength reduction of only approximately 12% compared with dry conditions. Similarly, Priastiwi et al.

(2024) found that geopolymer concrete made with fly ash and white soil and exposed to seawater exhibited higher compressive strength and lower permeability than concrete without seawater exposure. They attributed these findings to the development of a denser matrix resulting from interactions between seawater ions and aluminosilicate gels in the geopolymer system. These comparisons suggest that seawater ions may have different effects depending on the binder chemistry. In conventional Portland cement systems, seawater exposure may adversely affect certain mechanical and durability properties, whereas in some alkali-activated systems, seawater ions may promote the formation or modification of binding gels. Therefore, generalizations about the effects of seawater on mortar and concrete should account for the type of binder and the exposure conditions.

Consistency of Findings with Previous Research on Fly Ash and Seawater Mortar/Concrete

The findings of this study, namely that seawater-cured specimens exhibited increasing failure loads with age, although their values remained lower than those of freshwater-cured specimens, can be compared with the findings of (Lim et al., 2015). Those authors reported that seawater could produce compressive strength comparable to that obtained with freshwater, particularly at longer curing ages. However, their study used seawater as mixing water rather than exclusively as a curing medium, as in the present study. The study presented at the De La Salle University Research Congress (2013) also indicated that direct seawater exposure may increase compressive strength at early ages but can raise concerns about long-term durability, particularly the corrosion of steel reinforcement in reinforced concrete. The higher water absorption observed in the seawater-cured specimens in the present study is relevant to durability considerations, although water absorption alone does not establish chloride penetration or reinforcement corrosion.

In the Indonesian context Siba et al. (2023), who investigated prolonged seawater immersion and the compressive strength of Kupang cement concrete containing fly ash, found that compressive strength increased up to a certain immersion age before decreasing after longer exposure periods of 60–90 days. This finding suggests that the beneficial effects of fly ash and seawater exposure on strength may vary over time. The potential for a similar trend in the present study cannot be determined because the maximum curing age was 28 days.

The feasibility study titled Study of Fly Ash Biomass on Mortar with Seawater Curing (2024) also supports the possibility of using fly ash, including biomass-derived fly ash, as a partial cement replacement in mortar exposed to marine environments. However, the suitability of such materials depends on the ash composition, replacement level, and exposure conditions. Conversely, Dasar & Patah (2024), who investigated palm oil fuel ash (POFA) and beach sand in concrete, reported lower compressive strength than that of conventional concrete. This finding illustrates that the type of pozzolanic ash, particle size, and pretreatment can influence whether the combination of waste-derived ash and marine-origin materials improves mechanical performance. The general observation that partial substitution of conventional materials with pozzolanic waste can improve strength up to an optimum level is also consistent with Riyana & Walujodjati (2022), who investigated partial fine-aggregate replacement using cowhide waste ash.

Water Absorption and Implications for Durability

The higher water absorption of the seawater-cured specimens (9.3%) compared with that of the freshwater-cured specimens (8.5%) may indicate differences in pore structure or moisture transport. However, these results alone cannot establish that seawater exposure increased capillary porosity or caused calcium leaching. Janowska-Renkas & Kaliciak (2021) documented the migration of Ca^{2+} ions in fly ash mortar exposed to seawater, which may be relevant to changes in the pore structure and transport properties of cementitious materials. The extent and direction of these changes depend on the chemical composition of the binder, exposure duration, and environmental conditions.

Greater water absorption can indicate a pore network that allows moisture to enter the material more readily, potentially increasing exposure to dissolved salts and other aggressive substances. In coastal environments, repeated wetting and drying may further affect long-term

durability. These concerns are also relevant to the chloride penetration tests reported by Dasar & Patah (2024) for concrete containing POFA and sea sand. Although the study reportedly indicated passive conditions with respect to reinforcement corrosion, chloride ingress remains a potential concern for concrete exposed to seawater.

To mitigate such risks, Zhang et al. (2024) showed that adding magnesium-based materials, including magnesium oxide (MgO) and layered double hydroxides (LDHs), to alkali-activated fly ash–slag mortar could significantly improve resistance to chloride diffusion. Similar approaches may warrant investigation for improving the durability of fly ash-modified Portland cement mortar exposed to seawater. However, their effectiveness in the present material system would need to be established experimentally.

Practical Implications, Research Limitations, and Directions for Further Research

The findings of this study have several potential practical implications for construction in coastal areas where freshwater is scarce. First, seawater curing may be considered for selected nonstructural mortar applications, provided that the material meets the applicable performance requirements. The measured failure loads increased with curing age and fly ash content under seawater curing, although they remained lower than those obtained under freshwater curing. Research by Farina et al. (2022) on lightweight cellular concrete containing fly ash illustrates the potential for using fly ash in nonstructural construction products. Nevertheless, the suitability of seawater-cured mortar for specific applications must be assessed based on relevant strength, durability, and exposure requirements rather than on failure load alone.

Second, the use of seawater as a curing medium in structural applications requiring long-term durability should be evaluated carefully, particularly where chloride exposure could affect embedded steel reinforcement. The higher water absorption measured in the seawater-cured specimens indicates a potential difference in moisture uptake but does not, by itself, establish increased porosity or long-term degradation.

Third, fly ash addition was associated with increased failure loads under both seawater and freshwater curing within the tested range. This suggests that fly ash may offer benefits in mortar formulations where freshwater availability is limited. However, its suitability depends on the type of ash, replacement level, binder composition, curing conditions, and intended application. Further testing is required before the combination of fly ash and seawater can be recommended for specific construction uses.

This study has several limitations that should be addressed in future research. First, the maximum curing age of 28 days is relatively short compared with investigations that have examined fly ash mortar and concrete exposed to seawater or aggressive solutions for 90 days or longer, such as (Janowska-Renkas & Kaliciak, 2021; Sultan et al., 2023). Long-term behavior, including the possibility of strength reduction after prolonged immersion, as reported by Siba et al. (2023) for exposure periods of 60–90 days, should be investigated using the fly ash proportions and materials examined in the present study.

Second, drying shrinkage was not measured, although it can provide additional information about dimensional stability and the risk of cracking in cementitious materials. The study titled Study of Drying Shrinkage Mortar Fly Ash with Seawater (2015) may provide relevant context for this issue. Third, microstructural characterization using scanning electron microscopy (SEM) and X-ray diffraction (XRD), as employed by Yahya et al. (2021), was not conducted. Such analyses could help establish whether the observed differences in failure load and water absorption are associated with changes in hydration products, pore structure, or other microstructural features.

Finally, the tested fly ash replacement range of 0–15% was relatively narrow compared with the ranges examined by Nana Patria & Haikal (2022) and Hwang & Yeon (2022), who investigated higher proportions and, in some cases, identified optimum replacement levels. Future research should therefore investigate a wider range of fly ash contents, extend the immersion period, characterize the microstructure, and evaluate mitigation strategies such as magnesium-based additives (Zhang et al., 2024). These steps would provide a more comprehensive understanding of the long-term mechanical performance and durability of fly ash-modified mortar exposed to seawater.

CONCLUSION

The experimental results indicate that, across the investigated fly ash contents of 0%, 5%, 10%, and 15%, the measured maximum failure load generally increased with fly ash content and curing age (3, 7, and 28 days) under both freshwater and seawater curing. At 28 days, the specimens containing 15% fly ash recorded the highest failure loads: 31.53 kN under freshwater curing and 22.90 kN under seawater curing. Freshwater-cured specimens consistently exhibited higher failure loads than seawater-cured specimens across all tested combinations. At 28 days, average water absorption was 8.5% under freshwater curing and 9.3% under seawater curing, a difference of 0.8 percentage points. Because the mechanical results are reported as failure loads in kN, they should not be presented as compressive stress in MPa without conversion using the loaded cross-sectional area of the specimens.

These findings provide an empirical basis for comparing the effects of fly ash content and curing medium on the measured mechanical response and water absorption of mortar under the conditions investigated. Although fly ash addition was associated with increased failure loads under both curing conditions, the lower failure loads and higher water absorption observed after seawater curing warrant caution when considering seawater as an alternative curing medium, particularly for applications requiring reliable long-term performance. The results do not establish the chemical mechanisms governing hydration or demonstrate long-term durability because microstructural characteristics, chloride transport, and exposure beyond 28 days were not evaluated. Further research should extend the immersion period, investigate additional fly ash proportions, report calculated compressive stress in MPa, and examine microstructural and durability indicators before recommendations are developed for structural applications.

ACKNOWLEDGEMENT

The author expresses his gratitude to the Universitas Muhammadiyah Buton for the academic support provided during the implementation of this research. The author also expresses his appreciation to all parties who have provided input, suggestions, and support during the research process and manuscript preparation. The various inputs provided have helped improve the quality, accuracy, and scientific presentation of this article so that it is worthy of publication.

AUTHOR CONTRIBUTION STATEMENT

All authors contributed to the preparation of this research. Muh. Sayfullah. S, as the first author, plays a role in initiating the research concept, preparing the research framework, collecting and analyzing data, interpreting the results, and preparing the initial draft of the manuscript. Muhammad Abdu and Arjun contribute to the development of research ideas, academic supervision, methodology refinement, validation of research results, and final revision of the manuscript. The author has read, approved, and is responsible for the final version of the published manuscript and ensures the integrity, accuracy, and transparency of all research content.

REFERENCES

Astuti, A. W., Fathias, E., Purwanto, P., & ... (2013). Studi Eksperimental Aplikasi Material Nano Fly Ash Terhadap Kuat Tekan Mortar Beton. *Jurnal Karya Teknik …*.

Badan Standardisasi Nasional. (2000). SNI 03-2834-2000: Tata Cara Pembuatan Rencana Campuran Beton Normal. Jakarta: BSN.

Badan Standardisasi Nasional. (2002). SNI 03-6825-2002: Metode Pengujian Kekuatan Tekan Mortar Semen Portland untuk Pekerjaan Sipil. Jakarta: BSN.

Badan Standardisasi Nasional. (2008). SNI 1972:2008: Cara Uji Slump Beton. Jakarta: BSN.

Dasar, A., & Patah, D. (2024). Kekuatan dan Durabilitas Beton Menggunakan Palm Oil Fuel Ash (POFA) dan Pasir Pantai. *Borneo Engineering : Jurnal Teknik Sipil*, *8*(1), 83–94. https://doi.org/10.35334/be.v8i1.5090

Dirgantara, F. Y. D. (2025). *Pengaruh rendaman air payau terhadap kuat tekan pada beton campuran fly ash*. Universitas Islam Sultan Agung.

Donatello, S., Palomo, A., & Fernández-Jiménez, A. (2013). Durability of very high volume fly ash cement pastes and mortars in aggressive solutions. *Cement and Concrete Composites*, *38*.

https://doi.org/10.1016/j.cemconcomp.2013.03.001

Farina, I., Moccia, I., Salzano, C., Singh, N., Sadrolodabaee, P., & Colangelo, F. (2022). Compressive and Thermal Properties of Non-Structural Lightweight Concrete Containing Industrial Byproduct Aggregates. *Materials*, *15*(11). https://doi.org/10.3390/ma15114029

Hardjito, D. (2014). Abu Terbang Solusi Pencemaran Semen. *Igarss 2014*, (1).

Hwang, S., & Yeon, J. (2022). Fly Ash-Added, Seawater-Mixed Pervious Concrete: Compressive Strength, Permeability, and Phosphorus Removal. *Materials*, *15*(4), 1407. https://doi.org/10.3390/ma15041407

Irawan, D., Niken, C., Zaenudin, A., & Helmi, M. (2023). Pengaruh Perendaman Air Laut Terhadap Kuat Tekan dan Permeabilitas Beton. *Jurnal Rekayasa Sipil Dan Desain*, *11*(4). https://doi.org/10.23960/jrsdd.v11i4.3840

Janowska-Renkas, E., & Kaliciak, A. (2021). Impact of Fly Ashes from Combustion in Fluidized Bed Boilers and Siliceous Fly Ashes on Durability of Mortars Exposed to Seawater and Carbonation Process. *Materials*, *14*(9), 2345. https://doi.org/10.3390/ma14092345

Li, P., Li, W., Sun, Z., Shen, L., & Sheng, D. (2021). Development of sustainable concrete incorporating seawater: A critical review on cement hydration, microstructure and mechanical strength. *Cement and Concrete Composites*, *121*. https://doi.org/10.1016/j.cemconcomp.2021.104100

Lim, E. D., Roxas, C. L., Gallardo, R., Nishida, T., & Otsuki, N. (2015). Strength and corrosion behavior of mortar mixed and/or cured with seawater with various fly ash replacement ratios. *Asian Journal of Civil Engineering*, *16*(6).

Nana Patria, A. S., & Haikal, F. (2022). Pengaruh Kadar Fly Ash Terhadap Kuat Tekan Beton Mutu Tinggi Menggunakan Admixture High Range Water Reducer. *Jurnal Teknik Sipil*, *15*(2), 12–22. https://doi.org/10.56444/jts.v15i2.210

Nurtanto, D., Rahayu, A. A., & Wahyuningtyas, W. T. (2021). Pengaruh Perawatan Air Laut dan Air Tawar terhadap Kuat Tekan Beton Geopolymer yang Memadat Sendiri. *Rekayasa*, *14*(1), 32–38. https://doi.org/10.21107/rekayasa.v14i1.8375

Pang, K., & Liu, L. (2026). Compressive Strength of Alkali-Activated Slag-Fly Ash Mortar Under Low Temperature Curing: An ANN and SHAP Analysis. In *RILEM Bookseries* (Vol. 73). https://doi.org/10.1007/978-3-032-30128-4_59

Peneliti DLSU Research Congress. (2013). Corrosion behavior of steel embedded in fly ash mortar mixed with seawater. Presented at Research Congress 2013, De La Salle University, Manila.

Priastiwi, ST. MT. , Y. A., Wibowo, H., Puwanto, P., Hidayat, A., Ulayya, I., & Carita, N. (2024). The influence of Sea Water on Compressive Strength, Permeability, and Geopolymer Concrete Microstructure with Fly ash and White Soil as a Substitute for Cement. *MEDIA KOMUNIKASI TEKNIK SIPIL*, *30*(1), 65–74. https://doi.org/10.14710/mkts.v30i1.63604

Riyana, H., & Walujodjati, E. (2022). Pengaruh Substitusi Sebagian Agregat Halus dengan Abu Limbah Kulit Sapi Terhadap Kuat Tekan Beton. *Jurnal Konstruksi*, *20*(2). https://doi.org/10.33364/konstruksi/v.20-2.1210

Studi Biomass Fly Ash pada Mortar dengan Curing Air Laut. (2024). Feasibility study of biomass fly ash as a partial cement replacement in mortar cured in seawater. Borneo Engineering: Jurnal Teknik Sipil.

Studi Drying Shrinkage Mortar Fly Ash dengan Air Laut. (2015). Drying shrinkage of fly ash mortar mixed with seawater. Applied Mechanics and Materials, 802, 118–123.

Siba, M. M., Sina, D. A., & Rizal, H. A. H. (2023). Pengaruh Waktu Perendaman Air Laut Terhadap Kuat Tekan Beton Menggunakan Semen Kupang dengan Bahan Tambah Fly Ash. *JURNAL FORUM TEKNIK SIPIL (J-ForTekS)*, *3*(1), 19–23. https://doi.org/10.35508/forteks.v3i1.7150

Sultan, M. A., Hakim, R., & Kurniawan, K. (2023). Efek Larutan Asam Terhadap Kuat Tekan dan Penyerapan Mortar dengan Bahan Tambah Fly Ash. *Rekayasa Sipil*, *17*(2). https://doi.org/10.21776/ub.rekayasasipil.2023.017.02.5v

Wenno, R., Wallah, S. E., & Pandaleke, R. (2014). Kuat Tekan Mortar Dengan Menggunakan Abu Terbang (Fly Ash) Asal Pltu Amurang Sebagai Substitusi Parsial Semen. *Jurnal Sipil Statik*, *2*(5).

Yahya, Z., Abdullah, M. M. A. B., Li, L., Burduhos Nergis, D. D., Hakimi, M. A. A. Z., Sandu, A. V., Vizureanu, P., & Razak, R. A. (2021). Behavior of Alkali-Activated Fly Ash through Underwater Placement. *Materials*, *14*(22), 6865. https://doi.org/10.3390/ma14226865

Zahlim, A., Bachtiar, E., & Makbul, R. (2022). Efek Curing Air Laut Terhadap Kuat Tekan Beton Mutu Tinggi Yang Menggunakan Fly Ash Sebagai Subtitusi Pasir. *Borneo Engineering : Jurnal Teknik Sipil*, *1*(1). https://doi.org/10.35334/be.v1i1.2161

Zhang, J., Ma, Y., Zhang, Z., Yang, X., Nong, X., & Wang, H. (2024). Effects of Mg-based admixtures on chloride diffusion in alkali-activated fly ash-slag mortars. *Case Studies in Construction Materials*, *21*, e03659. https://doi.org/10.1016/j.cscm.2024.e03659