



Analysis of the Effect of Lime Powder Substitution and Superplasticizer on the Compressive Strength of Mortar

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ABSTRACT

The increasing need for environmentally friendly construction materials encourages innovation in mortar development. This study analyzed the effect of lime powder substitution with superplasticizer on the compressive strength of mortar, using substitution variations of 0%, 5%, 10%, 15%, and 20% by weight of cement, and 2% superplasticizer addition. Tests were carried out at the age of 7, 14, 21, and 28 days with laboratory experimental methods according to SNI standards. The results showed that the combination of lime powder and superplasticizer significantly increased the compressive strength of mortar, with the optimum composition of 5% lime and 2% superplasticizer at 28 days reaching 16.29 MPa, an increase of 243.3% from the normal mortar of 4.74 MPa. The use of these additives improves mortar performance and supports cost efficiency and environmental sustainability.

INTRODUCTION

Rapid infrastructure development demands innovation in construction materials to be more efficient, economical, and environmentally friendly. Mortar is one of the main construction materials made from a mixture of cement, sand, and water. To improve the performance of mortar, various additives can be used, such as lime powder and superplasticizer, which serve to increase the compressive strength, workability, and durability of mortar. Lime powder has long been used in concrete and mortar mixes as an additive that can improve the mechanical properties of the material. Lime powder contains calcium carbonate that can react with cement, increase hydration, and improve the microstructure of mortar. In addition, its use also has the potential to reduce the need for cement, which contributes to reducing carbon dioxide emissions from the cement industry. On the other hand, superplasticizers are chemical additives that work to improve workability without the need to add large amounts of water. With the use of superplasticizers, mortar can have better rheological properties as well as a more significant increase in compressive strength compared to conventional mixes. The combination of lime powder and superplasticizer is expected to produce mortar that has superior mechanical properties.

Research on the effect of lime powder substitution and the use of superplasticizer on the compressive strength of mortar has not been conducted, especially in certain compositions that can provide optimal results. Therefore, this study aims to analyze the extent to which the substitution of lime powder and the use of superplasticizer can affect the compressive strength of mortar. In addition to the technical aspects, the utilization of lime powder in mortar mixes also has a high economic value. Lime is a relatively cheaper material than cement, so its use can reduce production costs without sacrificing mortar quality.

Thus, this research also has relevance in supporting more sustainable and cost-effective construction practices. In line with this, this research is expected to contribute to the development of more innovative construction materials, with the aim of analyzing the effect of the combination of lime powder and superplasticizer on the compressive strength of mortar, determining the optimal composition of lime powder and superplasticizer that can produce maximum mortar compressive strength, and evaluating the effect of the combination of lime powder and superplasticizer on the workability and durability of mortar. The results of this research can be used as a reference in the construction industry to improve the efficiency and sustainability of mortar materials, and provide solutions to the challenges faced in modern infrastructure development.

LITERATURE REVIEW

Mortar

Mortar is a mixture of building materials consisting of fine aggregates, water, and binders such as cement or lime, functioning as an adhesive between building elements and in plastering (Fuad, 2021). According to research by Zhang et al. (2023), the properties of mortar are affected by the composition and proportion of materials, where compressive strength, adhesion, and water resistance are key factors. The addition of additives such as silica fume, fly ash,

and superplasticizer can improve the mechanical properties of mortar, for example, silica fume increases compressive strength and reduces porosity. The addition of additives such as silica fume, fly ash, and superplasticizer is proven to improve the mechanical properties of mortar. Silica fume, for example, plays a role in improving compressive strength and reducing porosity as its fine particles fill micro voids and contribute to the formation of denser calcium silicate hydrate (C-S-H). Fly ash also improves the long-term durability and working properties of the mortar, while superplasticizers help improve the dispersion of cement particles and reduce water demand, which has a direct impact on increasing density and strength.

This finding is supported by the research of Li et al. (2020) which states that the simultaneous use of silica fume and superplasticizer results in an increase in compressive strength of up to 20% compared to the control mixture. Ahmed et al. (2020) also showed that the use of PCE-based superplasticizer significantly improved the mechanical properties and adhesion of mortar. Meanwhile, Rehman et al. (2022) confirmed that fly ash provides a pozzolanic effect that contributes to long-term strength and porosity reduction in mortar systems.

Mortars are used in various construction applications to ensure the strength and stability of structures. Therefore, proper selection of materials and additives is essential to achieve strong and durable mortar, and support sustainability, according to (Hunggurami et al., 2025) it is certain that the better the quality of fine aggregate and coarse aggregate, the better the quality of concrete and mortar. Further research is also needed to explore the optimal combination of ingredients and understand the mechanism of improving mortar performance.

METHODOLOGY

This study uses a quantitative method to analyze the combination of lime powder and superplasticizer on the compressive strength of mortar by mixing mortar using lime substitution (0-20%) and 2% superplasticizer, then testing the compressive strength at 7, 14, 21, and 28 days to analyze the effect of the composition variation.

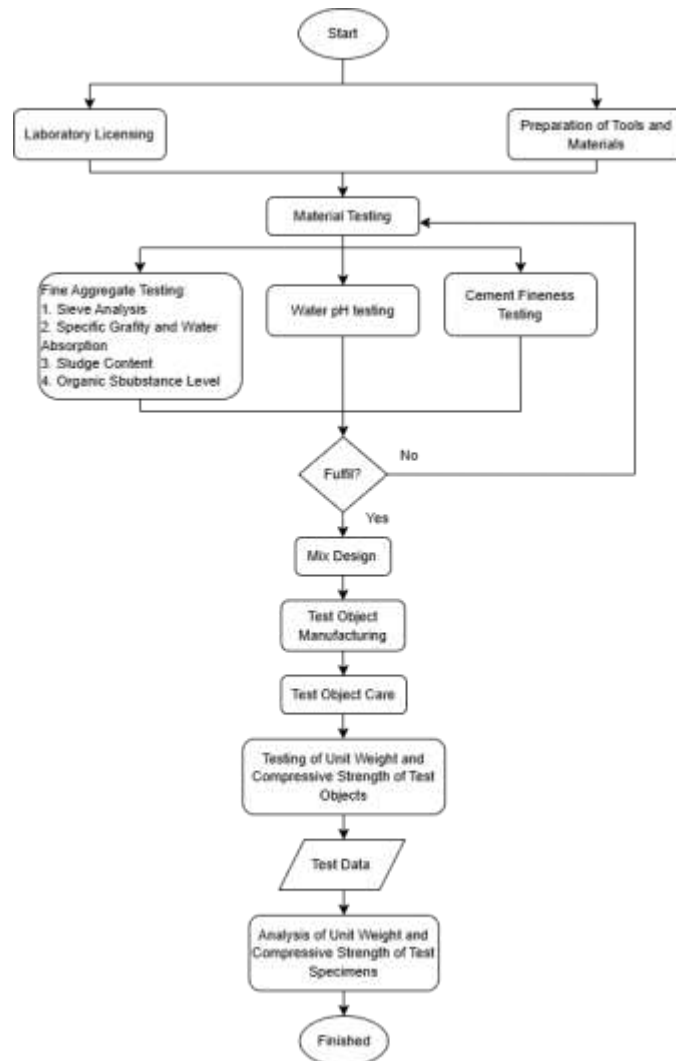


Figure 2. Research Flowchart

RESEARCH RESULTS

In order to conduct mortar testing, it was necessary to conduct a series of tests on fine aggregate materials and water in order to assess their suitability as mortar mixes. Subsequently, the weight content of the mortar was checked to evaluate the density and homogeneity. After all the material tests were completed, the compressive strength of the mortar was tested to measure the strength of the mortar according to the standard.

Aggregate and Water Material Testing

Fine aggregates were tested through sieve analysis based on SNI 03-1968-1990 and SNI 03-1750-1990, while specific gravity and water absorption refer to SNI 1969-2008 and SK SNI T-15-1990-03. In addition, mud and clay content follow SNI 03-4142-1996, and organic matter content refers to SNI 03-2816-1992. For water, testing was conducted based on SNI 7974:2013 and construction and building manuals.

Table 1. Fine Aggregate Testing Results

N	Test	Test Result
1	Gradation Zone	II
2	Fineness Modulus (%)	2,155
3	Bulk Specific Gravity (gram)	2,513
4	Bulk Specific Gravity (SSD) (grams)	2,577
5	Apparent Specific Gravity (grams)	2,687
6	Absorption (%)	0,026
7	Silt and clay content (%)	1,712
8	Organic matter content	No. 2

Table 2: Water Testing Results

No.	Test	Test Result
1	State of water	Clear
2	Water taste	Fresh
3	Water odor	Odorless
4	water pH	7

Mortar Content Weight Test

Table 3. Results of Average Compressive Strength Recapitulation

No.	Mix Variation	Average Content Weight (g/cm ²)			
		7 day	14 day	21 day	28 day
1	Normal Mortar	1,05	1,11	1,11	1,10
2	Mortar Subs Lime 0% + SP 2%	1,19	1,15	1,26	1,22
3	Mortar Subs Lime 5% + SP 2%	1,19	1,27	1,21	1,19
4	Mortar Subs Lime 10% + SP 2%	1,23	1,21	1,22	1,26
5	Mortar Subs Lime 15% + SP 2%	1,20	1,19	1,18	1,27

	Mortar Subs				
6	Lime 20% + SP 2%	1,20	1,23	1,17	1,16

The results of bulk density testing of mortar at the ages of 7, 14, 21, and 28 days indicate that there were no significant changes in density, despite the variations in the addition of lime and superplasticizer. This is primarily because both materials were used in small amounts as partial substitutes for cement and possess relatively similar specific gravities. Furthermore, suboptimal compaction processes may have introduced pores within the mixture, thereby reducing the bulk density of the mortar. Consequently, the findings related to bulk density were not included as a primary focus of this research.

Mortar Compressive Strength Test

Table 4. Recapitulation of Average Compressive Strength of Mortar

No.	Mixture Variation	Average Compressive Strength (Mpa)			
		7 Days	14 Days	21 Days	28 Days
1	Normal Mortar	2,57	4,06	2,86	4,74
2	0% Lime Subs Mortar + 2% SP	6,27	7,84	11,04	12,62
3	5% Lime Subs Mortar + SP 2%	10,01	12,82	13,43	16,29
4	10% Lime Subs Mortar + SP 2%	7,58	10,33	13,85	15,46
5	15% Lime Subs Mortar + SP 2%	6,14	8,73	10,00	10,55
6	20% Lime Subs Mortar + SP 2%	7,08	7,35	9,60	9,80

Graph of Recapitulation of Average Compressive Strength of Mortar

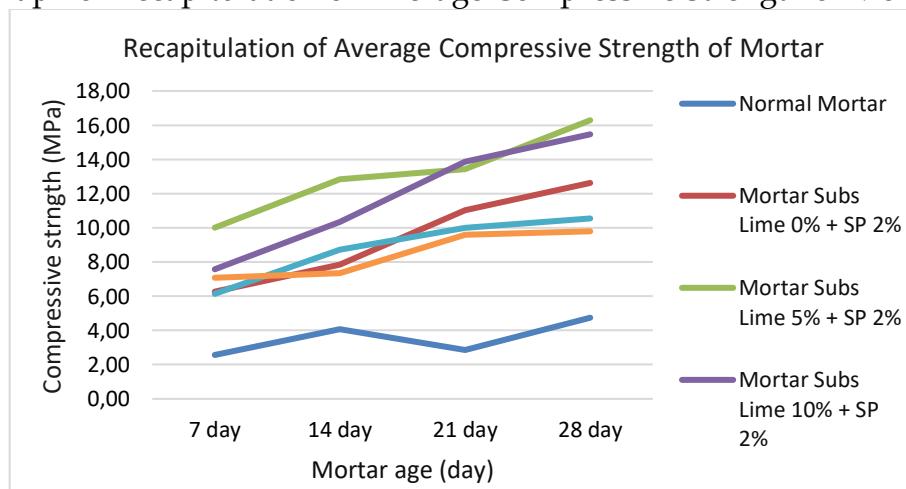


Figure 3. Recapitulation Graph of Average Compressive Strength of Mortar

The test results show that the compressive strength value of mortar is influenced by the levels of lime and superplasticizer (SP) as a substitute for cement. The optimal combination was found in a mixture with 5% lime and 2% SP, resulting in a compressive strength of 10.01 MPa at 7 days, 12.82 MPa at 14 days, 13.43 MPa at 21 days, and 16.29 MPa at 28 days. The synergistic effect between lime and SP increased density and reduced voids in the mortar, resulting in increased compressive strength. However, higher levels of lime or SP than the optimum combination caused a decrease in strength. Excess lime can result in inefficient reactions and segregation, while excess SP disrupts the bond between cement particles.

DISCUSSION

The test results show that the compressive strength value of mortar is strongly influenced by the percentage levels of lime and superplasticizer (SP) as cement substitutes. The optimal combination was found in the mixture with 5% lime and 2% SP, which produced compressive strengths of 10.01 MPa at 7 days, 12.82 MPa at 14 days, 13.43 MPa at 21 days, and 16.29 MPa at 28 days. The synergistic effect between lime and superplasticizer increased the density and reduced voids in the mortar structure, resulting in significantly increased compressive strength. However, higher levels of lime or SP than the optimum combination caused a decrease in strength, as excess lime can result in inefficient reactions and segregation, while excess SP can disrupt the bond between cement particles. Thus, selecting the right proportion of lime and superplasticizer is essential to achieve maximum mechanical performance, and the results of this study are in line with recent findings that emphasize the importance of optimizing the composition of additives in mortar mixes to improve compressive strength and durability.

The results of the compressive strength test showed that the optimal mixture was found in the composition of 5% lime powder and 2% superplasticizer (SP), with a compressive strength value of 16.29 MPa at 28 days of age. This increase is due to the role of lime in filling voids in the mortar structure as well as the effectiveness of SP in dispersing cement particles more evenly, thus increasing the efficiency of the hydration process. In terms of microstructure, lime reacts with silicate compounds in cement to form additional hydrate compounds such as calcium silicate hydrate (C-S-H), while superplasticizer expands the surface of hydrated cement particles, accelerates chemical reactions, and produces a denser cement paste. The combination of these two ingredients significantly decreases the porosity and increases the cohesiveness of the mortar, as described by Zhang et al. (2023). These findings are in line with the research of Ahmed et al. (2020) and Wang et al. (2018), which showed that the use of lime as an active filler with SP significantly increased the density and compressive strength of mortar, supporting a stronger and more sustainable mortar formulation approach.

CONCLUSIONS AND RECOMMENDATIONS

The results showed that the use of a combination of lime and superplasticizer as a partial substitution of cement in mortar mixes significantly increased the compressive strength. Tests showed that mortar mixed with 5% lime and 2% superplasticizer at 28 days reached a maximum compressive strength of 16.29 MPa, an increase of 243.3% compared to normal mortar which only reached 4.74 MPa. This combination not only demonstrates superior mechanical efficiency, but also opens up opportunities to reduce the use of cement, which has a positive impact on cost efficiency and environmental sustainability. This improved performance is attributed to the increased mortar density and reduced porosity (voids) in the structure due to the synergistic interaction between lime and superplasticizer, which strengthens the bond between cement particles. However, this effectiveness is optimum; increasing the lime content above 5% or superplasticizer beyond the correct proportion can actually reduce the compressive strength. This is due to segregation, disruption of the bond between particles, and inefficient chemical reactions. In particular, a significant decrease in compressive strength was recorded at lime content above 10%, which confirms the importance of determining the optimum limit in mix proportioning so that the structural performance of the mortar is not compromised.

ADVANCED RESEARCH

For further research development, it is recommended to conduct long-term durability testing of the mortar mix, including resistance to carbonation, sulfate attack, and chloride ion penetration. In addition, it is necessary to compare the performance of different types of superplasticizers such as polycarboxylate ether (PCE), naphthalene sulfonate formaldehyde (NSF), and melamine formaldehyde sulfonate (MFS), to evaluate their respective effects on the rheology and compressive strength of the mortar. The research direction can also be extended to the structural concrete scale, by testing other mechanical properties such as elastic modulus and split tensile. In addition, a Life Cycle Assessment (LCA) approach is important to comprehensively assess the environmental impact of applying these alternative materials, in order to support more sustainable construction.

Further research on the analysis of the effect of lime powder substitution and superplasticizer on the compressive strength of mortar is highly relevant in the context of modern construction technology. The optimal combination of these two materials can increase density and reduce voids in mortar, which contributes to better mechanical strength. Thus, the use of lime and superplasticizer as cement substitutes can reduce dependence on more expensive and potentially environmentally damaging raw materials. In addition, this innovation supports the principle of sustainability in development, in line with the times that emphasize environmental friendliness. More efficient and sustainable construction technologies are urgently needed to meet the increasing demands of infrastructure development.

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