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Analysis of the Effect of Concrete Waste Addition as a Cement Substitution on the Compressive Strength of Mortar

Ahmad Fathoni*, Ali FahmiSidik, Ridta Dwi Septyan
Universitas Swadaya Gunung Jati, Indonesia
Email: fathoniarchy@gmail.com*, alifahmisidik@gmail.com, dwiridta@gmail.com

Abstract
The construction sector heavily consumes cement and concrete, contributing to resource depletion and waste. To promote sustainability, using recycled concrete waste as a cement substitute in mortar mixtures is a promising solution. This study examines the effect of concrete waste as a partial cement substitute on mortar compressive strength to identify feasible substitution levels. The research method was a laboratory experiment involving mortar samples measuring 5 × 5 × 5cm with a mix proportion of 1PC:3PS. The mixture design was calculated and measured for each component—water, cement, and fine aggregate (sand)—with substitution achieved by reducing the cement volume by 0%, 5%, 10%, 15%, 20%, and 30%, respectively. Mortar compressive strength testing was conducted at ages of 7, 14, 21, and 28 days with proper curing. The results showed that, relative to the normal/control sample (0%) at 30.67 MPa (28 days), significant decreases occurred at 25% (24.67 MPa; 19.56% decrease) and 30% (25.33 MPa; 17.41% decrease). Decreases at 5%, 10%, 15%, and 20% remained within normal limits, with values of 28 MPa, 28.67 MPa, 29.33 MPa, and 29.33 MPa, respectively. The mixtures closest to the baseline were 15% and 20% (both 29.33 MPa; 4.37% decrease) at 28 days.

Keywords: Concrete Waste; cement substitution; Compressive Strength; Mortar.

INTRODUCTION

Since 1950 global cement material production has increased more than 30 times, and almost 4 times since 1990 with a higher growth value than global fossil energy production in the last 2 decades, this is due to the drastic increase in development growth in various parts of the world, especially China (Andrew R.M., 2018; Farfan et al., 2019; Gilfillan & Marland, 2021; He et al., 2019; Xi et al., 2016).This expansion highlights the need for sustainable alternatives in construction materials. Mortar, a fundamental building material composed of cement, fine aggregate, and water, serves as a binder in masonry, plastering, and finishing work. In contemporary research, mortar mixtures are often enhanced through the addition of admixtures or substitute materials to develop new, sustainable options without compromising quality (Ababneh et al., 2020; Nassar et al., 2024; Prokopski et al., 2020; Yazıcı et al., 2024). Cement acts as the hydraulic binder that hardens and binds aggregates upon reaction with water. One promising substitute is concrete waste—material obtained from crushing demolished concrete into fine aggregate. In this study, concrete waste was sourced from residual cylindrical test specimens (15 cm diameter × 30 cm height) with compressive strengths ranging randomly from K225 to K300.

Previous studies support the viability of partial cement substitution in mortar. For instance, (Taufik & Djauhari, 2013) found that substituting 2.5% cement with coconut fibre ash yielded optimal compressive strength at 28 days. Similarly, (Wenno et al., 2014) reported that fly ash substitutions of 5% and 15% achieved compressive strengths up to 27.7 MPa. Research by (Sutriono et al., 2018) on silica fume substitution (5–15%) showed that an 8% mix produced the highest strength (312.574 kg/cm²), while (Lado et al., 2018) observed improved compressive strength in mortar using varied sand ratios. Collectively, these studies indicate that cement substitution with alternative materials is feasible within certain mixture limits, providing a foundation for exploring concrete waste as a sustainable substitute in mortar formulations.

Crushed to fine concrete waste has the potential to be used as a cement substitution material in mortar mixtures, the basic properties of concrete have characteristics that are close to that of mortar mixtures, which will be a supporting factor in cement substitution in mortar mixtures. Fine aggregates can serve as a substitute for increasing density and have limited pozolanic activity (Binti Sayono et al., 2023; Prasetyo et al., 2024; Zuraidah & Hastono, 2018). Some previous studies have shown that substitution of cement with fine aggregates in low percentages can maintain or even slightly increase the compressive strength of mortar.. However, a higher percentage of substitution tends to lower compressive strength due to reduced active cement compounds.

Based on the above references, the author conducted research and testing using concrete waste materials with the aim of obtaining the limit value of mixing use in mortar aggregate to be used in construction industry practices so as to produce sustainable or long-term construction materials. Based on the background and literature review, this study aims to analyze the effect of cement substitution with concrete waste on the compressive strength of mortar and determine the limit of the percentage of substitution that can be applied without sacrificing the technical performance of the material. Theoretically, this research is expected to enrich the treasure of sustainable construction materials science, especially related to the use of construction waste. Practically, the research findings can be a reference for the construction industry in adopting recycled materials, reducing dependence on cement, and supporting more environmentally friendly and economical construction practices.

METHOD

This type of research uses quantitative experimental methods carried out at the Laboratory of PT. SACNA - MINARTA JO, Jatibarang. The research design was a pure laboratory experiment with variations in the percentage of concrete waste substitution (0%, 5%, 10%, 15%, 20%, 25%, 30%) and maturation ages of 7 days, 14 days, 21 days and 28 days with treatment. The following is a flow-chart of the implementation of the research carried out.

1. Research Flow-Chart

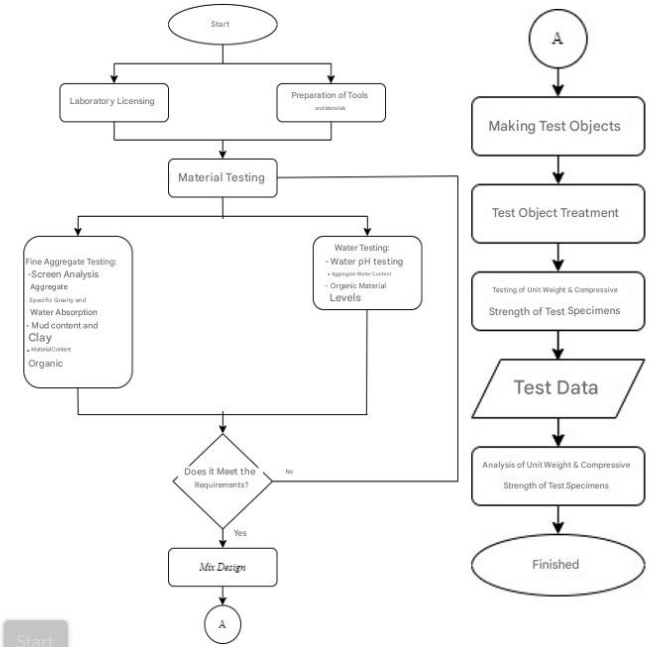

Figure 1. Research Flow-Chart

Source: Flow chart of mortar experimental research with concrete waste substitution (compiled by authors, 2025)

The materials used consist of Portland cement, fine aggregate (natural sand), water, and crushed concrete waste from the rest of the hard concrete test piece. Initial material characterization was carried out on fine aggregates (filter analysis, specific gravity, water absorption, sludge content, and organic content) and water (pH, odor, taste, color) according to relevant SNI standards to ensure their quality and suitability.

The composition of the basic mortar mixture is designed with a cement:sand ratio = 1:3 and a water-cement factor (FAS) = 0.5. Mix design calculations are carried out to determine the material needs of each variation (cement, sand, water and substitution concrete waste) per 5x5x5 cm cube mold. Concrete waste is added by replacing the weight of cement based on a predetermined percentage.

The manufacture of test specimens includes material mixing, molding, and curing by immersion in water until maturation life. Compressive strength testing was performed at 7, 14, 21, and 28 days of age using the Compression Testing Machine (CTM). The compressive strength data obtained will be analyzed descriptively and comparatively to see the trend of substitution influence and determination of the optimum percentage of compressive strength on mortar with concrete waste mixture.

RESULT AND DISCUSSION

Mix Design Mortar

Mix design is carried out to determine the proportion of each mixture of materials that make up the mortar. In this study, 7 variations of the mixture were made test specimens where the mixture refers to the normal mortar mix design. In the calculation of the mix design, several data data are needed, including:

- S/P=1:3
- FAS = 0.5
- Water Unit Weight = 1000kg/m3
- Cement Unit Weight = 1250 kg/m3
- Unit Weight of Sand = 1500 kg/m3.

From the reference of the design mix, the volume is then converted according to the needs of the planned test specimen, as listed in the table below:

Table 1. Mix Design table cube size 5x5x5 cm

NO.	MIXTURE	Cement/g	Sand/g	Water/g	Waste/g
1	0%	820	2945	401	0
2	5%	779	2945	401	41
3	10%	738	2945	401	82
4	15%	697	2945	401	123
5	20%	656	2945	401	164
6	25%	615	2945	401	205
7	30%	574	2945	401	246

Source: Calculation of mix design based on the proportions of 1PC:3PS and FAS 0.5 (processed by the author, 2025)

2. Mix Design table cube size 5x5x5 cm.

Weight of Mortar Volume

The average weight value of the mortar content is used as a preliminary reference for the weight comparison of normal mortar with other mixed variations, following is a recap of the mortar weight of each mixture variation:

Table 2. Weight table on mortar mixture

No.	Mixed variations	Contents weight (Kg)			
		7 days	14 days	21 days	28 days
1	0% concrete waste	0.281	0.294	0.291	0.288
2	5% concrete waste	0.328	0.303	0.314	0.299
3	10% concrete waste	0.323	0.348	0.318	0.308
4	15% concrete waste	0,296	0,339	0,299	0,313
5	20% concrete waste	0,308	0,324	0,313	0,326
6	25% concrete waste	0,358	0,359	0,351	0,350
7	30% concrete waste	0,353	0,350	0,360	0,325

Source: Mortar weight data from laboratory measurements by PT. SACNA - MINARTA JO (2025)

3. Weight table on mortar mixture

The weight value of the contents obtained from each addition of concrete waste did not get significant results. This is because concrete waste as a partial substitution of cement is used with a small amount and concrete waste has a specific gravity that is almost equal to the weight of cement. The compaction process on the test piece has an important role in the test weight result.

Compressive Yield

The compressive strength of the mortar is tested with a tool Compression Testing Machine (CMT) After the test piece enters the age of 7, 14, 21 and 28 days, pressure is carried out until the mortar test piece collapses.

Figure 2. Compressive Strength Testing Pictures

Source: Documentation of mortar compressive strength testing in the laboratory of PT. SACNA - MINARTA JO (2025)

1. Compressive Strength Testing Pictures

Then the compressive strength value is taken for further analysis in comparison, the following are the results of the mortar compressive strength test from each variation of the concrete waste mixture on cement substitution:

Table 3. Compressive strength table

No.	Mixed Variations	Average Compressive Strength of Mortar (Mpa)			
		7 Days	14 Days	21 Days	28 Days
1	**0%**	24,67	26,00	28,00	30,67
2	**5%**	23,33	24,67	25,33	28,00
3	**10%**	24,67	26,67	27,33	28,67
4	**15%**	26,67	27,33	28,00	29,33
5	**20%**	21,33	20,67	23,33	29,33
6	**25%**	21,33	20,67	22,67	24,67
7	**30%**	22,00	22,67	24,67	25,33

Source: Results of mortar compressive strength testing using Compression Testing Machine (CTM) (processed by the author, 2025)

1. *Compressive strength table*

In another form, to make the comparison look clearer, the author makes a comparison with the following graph:

1. *Compressive strength graph*

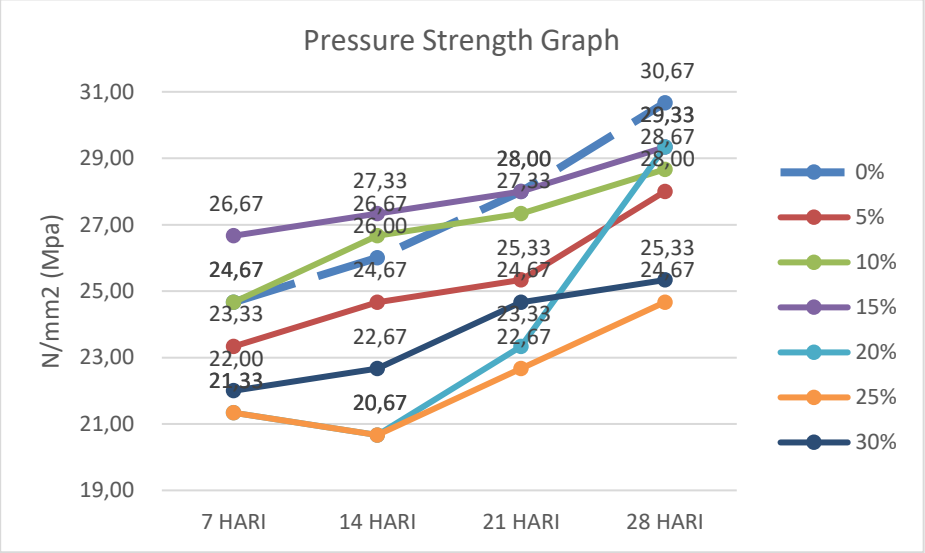

Figure 3. Compressive strength graph

Source: Mortar compressive strength comparison chart based on substitution variation and maintenance life (author's process, 2025)

Results Analysis

The results of the study on compressive strength testing for all mixture variations at different ages are presented in Table 4. The compressive strength of normal mortar (0%) at the age of 28 days is 30.67 MPa, which is a comparative reference. All variations of the mixture showed increased compressive strength with age, indicating that the cement hydration process and the potential pozolanic reaction of the concrete waste are ongoing.

In general, the higher the percentage of concrete waste substitution (above 15%), the lower the compressive strength produced, especially at a young age (7-21 days). This is due to the reduced amount of activated cement that is responsible for the main hydration reaction that forms power. The 10% and 15% mixture variations showed the best performance among mixtures with substitutions, the compressive strength value was close to normal even at 7 days of age for a mixture 15% higher than normal mortar (24.67Mpa versus 26.67Mpa). At 28 days of age, the compressive strength of a 15% mixture is only about 4.3% lower than normal mortar with a value of 29.33Mpa.

The substitution of 25%, and 30% led to a significant decrease in compressive strength, particularly at the age of 7-21 days. At 25% of the mixture, the 28-day compressive strength is only 24.67 MPa, or a decrease of 19.6% compared to normal mortar. This decrease occurs because the reduction of cement is too large and the substitution material, namely concrete waste, is randomly entered into the aggregate, so that the hydration product is not enough to bind all aggregate particles and fillers optimally. The porosity increases and the mortar structure becomes weaker.

CONCLUSION

This study on using concrete waste as a cement substitute in mortar revealed variations in compressive strength depending on substitution levels and curing age, with the control (0%) reaching 30.67 MPa at 28 days. Higher substitutions above 15% reduced strength, notably 25% (24.67 MPa; 19.5% decrease) and 30% (25.33 MPa; 17.4% decrease), while 5%, 10%, 15%, and 20% yielded 28.00 MPa, 28.67 MPa, 29.33 MPa, and 29.33 MPa (4.36%–8.7% decreases), respectively—none exceeding the control. Overall, concrete waste substitution diminished technical performance, rendering it currently unfeasible for maintaining mortar compressive strength, though 10% and 15% variants showed minimal, consistent declines with development potential. For future research, in-depth analyses of the physical and chemical properties of fine aggregates (sand and waste), including classifications by concrete quality/type and finer substitution increments, alongside testing various cement brands/types, could optimize feasibility and identify viable formulations.

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