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Understanding the Characteristics of Two Different Types of Cement in Relation to the Comparison of Concrete Compressive Strength

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Abstract

Cement is one of the main materials in construction that significantly affects the quality and compressive strength of mortar and concrete. Differences in cement characteristics, such as fineness, density, and bonding ability, may produce different compressive strength values even under the same mixture conditions. However, in practical construction work, cement selection is often based only on price and market availability without considering its technical performance. Therefore, this study aimed to compare the characteristics and compressive strength of mortar produced using Puger cement and Gresik cement under identical mixture proportions and curing conditions. This research employed an experimental quantitative method conducted in the Civil Engineering Laboratory. Mortar specimens were prepared using mixture proportions of 1:3, 1:4, 1:5, and 1:6 with Lumajang sand as fine aggregate. Compressive strength testing was performed at curing ages of 14, 21, and 28 days. The results showed that mortar compressive strength increased with curing age, while higher sand composition reduced strength performance. Gresik cement consistently produced higher compressive strength than Puger cement in all mixture variations. The highest compressive strength at 28 days was achieved by Gresik cement with a 1:3 mixture proportion at 197.13 Kg/cm^2. In conclusion, cement type significantly influences mortar compressive strength and should be carefully considered in construction material selection to achieve optimal structural quality and cost efficiency.

INTRODUCTION

Concrete and mortar are the main materials in the construction world whose quality is highly determined by the constituent materials, especially cement. Cement functions as a binding agent that reacts chemically with air through the hydration process so that it is able to bind aggregates into a strong unit. Differences in cement characteristics, both in terms of specific gravity, fineness, and chemical composition, will have a direct effect on the mechanical properties of the mortar or concrete produced, especially the compressive strength.

In practice in the field, people and construction executives often choose cement based on price or availability in the market, without considering its technical characteristics. This can cause differences in the quality of work results even though the proportion of mixture and the cement water factor used are the same. In other words, two cements of different brands or factory origin can produce different strong pressures of mortar even if used under the same mixing conditions.

This study aims to test the characteristics and compressive strength of two cement brands originating from the Puger and Gresik areas. The formulation of the problem posed is how the test results of the characteristics of the two different cement brands and how the results of the compressive strength of the mortar of both cements at the same proportion of mixture and water-cement factor (*fas*). This study has limitations, namely only comparing the characteristics and compressive strength of the two cement brands with mortar test objects that use fine aggregates from Lumajang sand. The proportions of the mixture used are 1:3, 1:4, 1:5, and 1:6 (cement:fine aggregate), with compressive strength testing performed on the 28th day after the manufacture of the test piece. Each proportion of the mixture involved 25 test objects, but this study did not examine the chemical elements of cement or calculate production costs. In Indonesia, cement remains a strategic construction material because residential, commercial, and infrastructure projects rely heavily on mortar and concrete. Recent industry information shows that Indonesia's cement production reached about 64.720 million tons in 2025, although this represented a decrease from 2024, indicating that the industry faces both demand pressure and efficiency challenges. These conditions make technical studies on cement performance increasingly relevant because construction actors need materials that are not only economical but also capable of meeting strength requirements.

The specific problem addressed in this research is the tendency of communities and construction practitioners to choose cement mainly based on price or market availability, while technical characteristics are often overlooked. The uploaded manuscript explains that two cement brands from different production origins may produce different mortar compressive strengths even when the mixture proportion, water-cement factor, aggregate source, curing age, and testing conditions are kept the same.

Previous studies have shown that compressive strength is a central indicator for evaluating cement-based materials. Yu et al. (2023), for example, emphasized that strength is a vital performance metric for assessing the durability of cement-based materials, particularly under environmental exposure. Other recent research on mortar also confirms that mixture composition, cement replacement, and aggregate characteristics can significantly influence compressive strength development (Neville & Brooks, 2010; Mehta & Monteiro, 2014). The hydration process of Portland cement, governed by the reaction of tricalcium silicate (C3S) and dicalcium silicate (C2S), is a primary determinant of mortar strength at different curing ages (Scrivener et al., 2019). Research by Rao (2021) confirmed that mechanical properties of cement mortar are primarily affected by the water-to-cement (w/c) ratio, cement-to-sand ratio, type of cementitious material, and properties of fine aggregate. Yousry et al. (2020) further demonstrated that manipulating mixing parameters in cementitious mortar can yield significant improvements in compressive strength performance. The influence of cement fineness on strength development is also well documented, with finer cement particles producing denser hydration products and higher early-age compressive strength (Lothenbach et al., 2011).

In the Indonesian context, studies comparing mortar or concrete performance have also highlighted that material source and composition affect compressive strength. Research comparing fine aggregates, for instance, reported different mortar strength values when Semen Gresik was combined with different sands, showing that local materials and cement type can influence final performance. This supports the relevance of examining cement brands and locally available aggregates in a controlled experimental setting. A study by Isaia et al. (2018) also confirmed that different brands of cement with varying chemical compositions can produce measurably different compressive strength outcomes under identical mixture conditions, demonstrating the need for empirical comparison before material selection. Moreover, Mindess et al. (2003) noted that aggregate characteristics, particularly gradation and mineralogy, can alter the interface between paste and aggregate, ultimately affecting the final compressive strength of the mortar (Asés-García et al., 2021).

Despite these contributions, a research gap remains in the direct comparison of locally used cement brands, particularly Puger and Gresik cement, under identical mortar mixture proportions and using Lumajang sand as fine aggregate. Many previous studies focus on supplementary cementitious materials, predictive modeling, or environmental durability (Deng et al., 2023; Visairo-Méndez et al., 2021), while fewer studies provide practical comparative evidence for local construction users who must choose between available cement brands for daily construction work. Studies by Tran et al. (2019) and Ibrahim et al. (2020) emphasized that practical cement-to-sand ratio comparisons remain important for local practitioners, particularly in developing construction economies where brand selection is often empirical rather than data-driven. Chen et al. (2025) similarly observed that the sand-to-binder ratio significantly affects compressive strength development in mortar, with lower ratios generally yielding higher strengths.

The urgency of this research lies in the need to provide empirical evidence for material selection in construction practice. If two cement brands produce different compressive strengths under the same mixture conditions, then choosing cement only based on lower price may create risks for structural quality, service life, and work reliability. At the same time, higher-cost cement must also be justified by measurable technical performance so that construction decisions can balance strength, cost, and suitability. This concern was similarly raised by Elseifi et al. (2022), who noted that construction quality can be compromised when material procurement is driven purely by cost considerations without proper technical assessment. The relationship between construction material cost and structural performance has been examined by several researchers, reinforcing the need for evidence-based material selection (Pilon et al., 2019).

The novelty of this study is its focused comparison of Puger and Gresik cement mortar using several cement-to-sand proportions, namely 1:3, 1:4, 1:5, and 1:6, with compressive strength testing at 28 days. The manuscript shows that Gresik cement produced higher 28-day compressive strength than Puger cement in all tested proportions, while Puger cement offered lower mortar production cost, creating an important technical-economic comparison for practical construction decisions.

Therefore, this research aims to identify the characteristics and compressive strength performance of two different cement brands under the same mixture conditions. The contribution of this study is to enrich applied construction material knowledge, especially for local cement selection, mortar proportioning, and cost-performance consideration. The expected benefit is that communities, contractors, and future researchers can use the findings as a reference for selecting cement according to construction needs and as a basis for further studies involving chemical composition, durability testing, alternative aggregates, or additional admixtures.

METHOD

This research employed an experimental quantitative design to investigate the characteristics and compressive strength performance of mortar produced using two different cement brands, namely Puger cement and Gresik cement. The experimental approach was selected because the study aimed to identify the effect of cement type on mortar compressive strength under controlled laboratory conditions. The population of this research consisted of all mortar mixtures produced using varying cement-to-fine aggregate proportions with identical water-cement factors and curing conditions. The research samples included mortar specimens with mixture proportions of 1:3, 1:4, 1:5, and 1:6 using Lumajang sand as fine aggregate and two different cement brands. The sampling technique applied was purposive sampling because the cement types and mixture proportions were intentionally selected based on the objectives of the study. Each mixture composition involved several mortar specimens tested at curing ages of 14, 21, and 28 days to observe the development of compressive strength over time.

The research instruments consisted of laboratory testing equipment including weighing scales, mortar mixers, cube molds, measuring cylinders, curing tanks, compression testing machines, and supporting tools for material characterization. Material testing was conducted to identify the physical properties of cement and aggregates before specimen preparation. The validity of the instruments was ensured through calibration procedures based on Indonesian National Standards (SNI), while reliability was maintained by conducting repeated measurements and uniform testing procedures for all specimens. Data collection techniques were carried out through direct laboratory observation, compressive strength testing, material characterization testing, and documentation of all experimental results. The research procedure began with material preparation and testing, followed by mixture proportioning, specimen casting, curing process, and compressive strength testing according to predetermined curing ages. All specimens were treated under identical laboratory conditions to minimize external variables that could influence the results.

The data obtained from the laboratory tests were processed using descriptive quantitative analysis to compare the compressive strength values of mortar produced from both cement brands. Data analysis techniques included calculating average compressive strength, comparing strength development at different curing ages, evaluating the effect of mixture proportions, and interpreting the relationship between cement characteristics and mortar performance. The compressive strength data were presented in the form of tables, graphs, and comparative descriptions to facilitate interpretation of the findings. In addition, cost comparison analysis was conducted to evaluate the economic efficiency of each cement type in mortar production. The research utilized Microsoft Excel and SPSS software to organize, calculate, visualize, and analyze the experimental data systematically, thereby ensuring accuracy and consistency in the interpretation of the research findings.

RESULT AND DISCUSSION

Analysis of Mortar Compressive Strength Test Results

The results of mortar compressive strength testing in this study showed that the average compressive strength at the ages of 14, 21, and 28 days with composition experiments that have been determined as follows. The progressive increase in compressive strength over curing time is consistent with well-established principles of cement hydration, whereby the formation of calcium silicate hydrate (C-S-H) gel continues to densify the microstructure over time (Lothenbach et al., 2011). This pattern has also been reported in multiple experimental studies involving ordinary Portland cement mortars (Rao, 2021).

Table 1 Results of the compressive strength test of mortar

	AGE 14	AGE 21	AGE 28
1 : 3.	113,2	136,67	**154,71**
1 : 4.	94,89	116,52	**124,09**
1 : 5.	78,52	83,56	**85,8**
1 : 6.	**56,05**	**68,06**	**68,81**

Source: Puger Cement Mortar Press Test Results

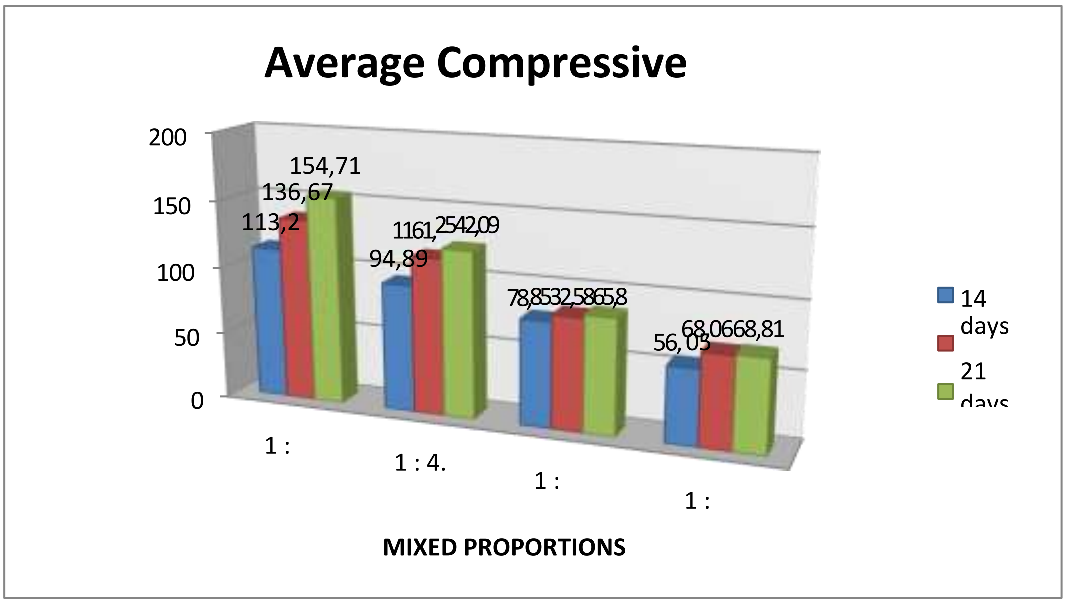


Figure 1 Graph Average compressive strength of cement mortar puger

Description:

The graph above explains that from various proportions, the mixture has a compressive strength that is increasing day by day, because the older the test specimen, the more compressive strength of the test specimen increases. It can be known that the compressive strength used as a reference is at the age of 28 days of 1:3 = 154.71; 1:4=124.09; 1:5=85.8 ; 1:6=68.81.

The more sand, the smaller the compressive strength, and vice versa, the less compressive sand the more compressive strength it gets. This is because a little sand can be perfectly bonded by cement. This finding aligns with Abrams' law, which establishes an inverse relationship between the aggregate-to-binder ratio and the resulting compressive strength of cementitious mortars (Rao, 2021). Torres et al. (2011) similarly reported that increasing the sand proportion in cement mortar reduces compressive and flexural strength values in hardened specimens.

Table 2 Average result of compressive strength of Gresik cement mortar

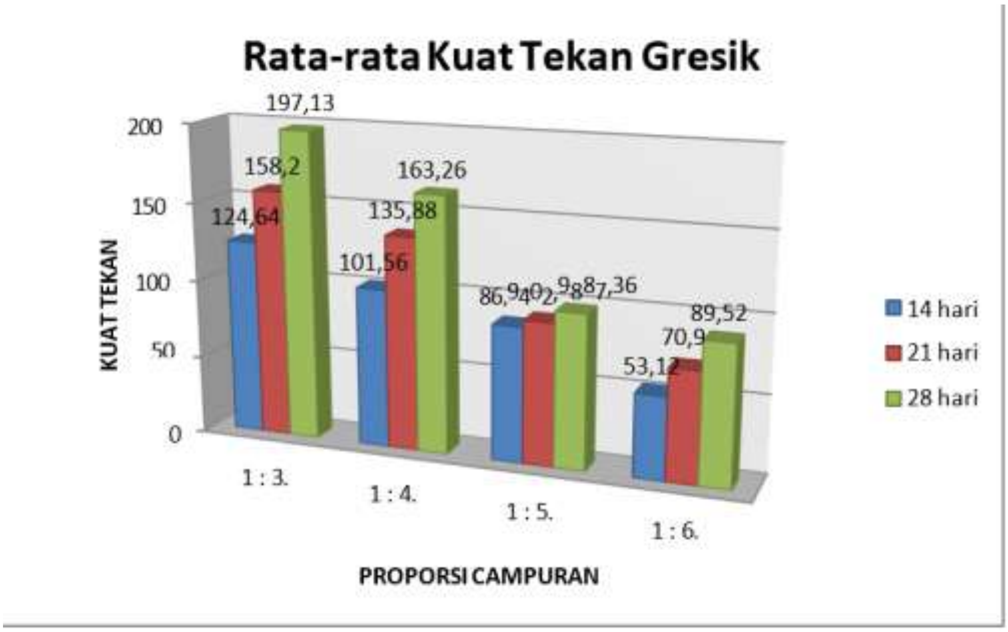
	14 days	21 days	28 days
1 : 3.	124,64	158,2	197,13
1 : 4.	101,56	135,88	163,26
1 : 5.	86,42	90,87	98,36
1 : 6.	53,12	70,9	89,52

Description:

From the data above, it can be seen that the difference in compressive strength from day to day, because the compressive strength will change with the increase in the life of the test piece, the more sand makes the compressive strength lower and vice versa, the less sand the greater the compressive strength. The compressive strength used by the reference is the 28th day, the results of the compressive test from the smallest to the largest are as follows:

1. 1:6 is 89.52 Kg/cm2
2. 1:5 is 98.36 Kg/cm2
3. 1:4 is 163.36 Kg/cm2
4. 1:3 is 197.13 Kg/cm2

Results of the Concrete Mortar Press Test Results Gresik



Sumber: Hasil Perhitungan (2025)

Figure 2 graph Average compressive strength of Gresik cement mortar

Description:

The graph above explains that from various proportions, the mixture has a compressive strength that is increasing day by day, because the older the test specimen, the more compressive strength of the test specimen increases. It can be known that the compressive strength used as a reference is at the age of 28 days of 1:3 = 197.13; 1:4=163.26; 1:5=98.36; 1:6=89.52. The more sand, the smaller the compressive strength, and vice versa, the less compressive sand the more compressive strength it gets. This is because a small amount of sand can be perfectly bonded by cement, while the more sand, the more difficult it is for cement to bind because cement in comparison is only one. This strength progression over time reflects the ongoing hydration of cement compounds, particularly C3S and C2S, which continue to form C-S-H gel up to and beyond 28 days (Scrivener et al., 2019). Several experimental studies have confirmed that the 28-day compressive strength serves as the standard design reference for mortar and concrete due to the high degree of hydration achieved at that age (Yousry et al., 2020). The observed strength hierarchy across mixture proportions is also consistent with research by Chen et al. (2025), who found that the compressive strength of mortar decreases progressively as the sand-to-binder ratio increases.

Comparison of Compressive Strength of Puger Cement and Gresik Cement

Table 3 Average Yield of Compressive Strength of Gresik Cement Mortar and Puger Cement

AGE 28	Gresik	Puger
1 : 3.	197,13	154,71
1 : 4.	163,26	124,09
1 : 5.	98,36	85,8
1 : 6.	89,52	68,81

Description:

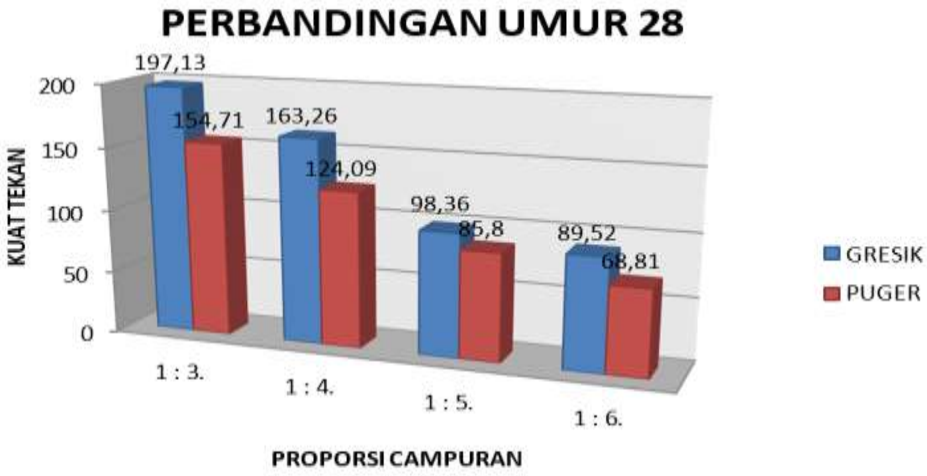
Looking at the results of the table compressive strength comparison, it is really the result of the strength of the cement. Because from material treatment to water needs, they are made the same. The test day is also made the same which distinguishes only the cement brand. It is known that the results are.

I. 1 : 3. 197.13 Kg/cm2: 154.71 Kg/cm2
II. 1 : 4. 163,26 Kg/cm2 : 124,09 Kg/cm2
III. 1 : 5. 98,36 Kg/cm2 : 85,8 Kg/cm2
IV. 1 : 6. 89,52 Kg/cm2 : 68,81 Kg/cm2

Description:

Looking at the results of the table compressive strength comparison, it is really the result of the strength of the cement. Because from material treatment to water needs, they are made the same. The test day is also made the same which distinguishes only the cement brand. It is known that the results are

V. 1 : 3. 197.13 Kg/cm2: 154.71 Kg/cm2
VI. 1 : 4. 163,26 Kg/cm2 : 124,09 Kg/cm2
VII. 1 : 5. 98,36 Kg/cm2 : 85,8 Kg/cm2
VIII. 1 : 6. 89,52 Kg/cm2 : 68,81 Kg/cm



Sumber: Hasil Perhitungan (2025)

Description:

Judging from the graph, there is indeed a difference in strength between gresik cement and puger cement. Gresik cement has a higher compressive strength than puger cement. Both have the highest compressive strength value in a mixture ratio of 1:3 cement: sand, with puger strength = 154.71 Kg/cm2, gresik = 197.13 Kg/cm2. The observed difference in compressive strength between the two cement brands under identical mixture conditions can be attributed to differences in cement characteristics such as fineness, specific surface area, and clinker mineral composition, particularly the proportion of C3S (alite), which is primarily responsible for early and medium-term strength development (Scrivener et al., 2019). Research by Loa et al. (2020) also showed that cement brands from different manufacturing origins can yield statistically significant differences in 28-day mortar compressive strength, even when tested under standardized laboratory conditions. The findings in this study are further supported by Asés-García et al. (2021), who demonstrated that the mineralogical composition of the aggregate and the paste-aggregate interface zone both contribute to the final strength of hardened mortar. Additionally, Deng et al. (2023) confirmed that the mix design and the quality of cementitious components are interdependent factors governing mortar compressive strength outcomes.

Comparison Calculation Cost for Making Puger Cement Mortar and Gresik Cement

Table 4 Results of Cost Calculation of Puger Cement Mortar

Installing 1 m2 Mortar 1 PC: 3 PP

1.1	Ingredients					
	Quantity	Sat	Name	Price (Rp)	Quantity	
	7,776	kg	Semen	1.200,00	Rp	9.331,20
	0,023	m3	Pasir	118.000,00	Rp	2.714,00
	1,200	ltr	Air	350,00	Rp	420,00
1.2	Tenaga			**Quantity (I)**	**Rp**	**12.465,20**
	0,300	OH	Employees	40.000,00	Rp	12.000,00
	0,150	OH	Masons	55.000,00	Rp	8.250,00
	0,015	OH	Head builder	60.000,00	Rp	900,00
	0,010	OH	Mandor	70.000,00	Rp	700,00
Quantity (II)					**Rp**	**21.850,00**
Unit price of work					**Rp**	**34.315,20**
Price after rounding					**Rp**	**34.310,00**
2	**Installing 1 m2 Mortar 1 PC : 4 PP**					
2.1	Ingredients					
	Quantity	Sat	Name	Price (Rp)	Quantity	
	6,240	kg	Semen	1.200,00	Rp	7.488,00
	0,024	m3	Sand tide	118.000,00	Rp	2.832,00
	1,400	ltr	Air	350,00	Rp	490,00
2.2	Tenaga			**Quantity (I)**	**Rp**	**10.810,00**
	0,300	O	Employees	40.000,00	Rp	12.000,

		OH				00
	0,150	OH	Masons	55.000,00	Rp	8.250,00
	0,015	OH	Head builder	60.000,00	Rp	900,00
	0,010	OH	Mandor	70.000,00	Rp	700,00
Quantity (II)					**Rp**	**21.850,00**
Unit price of work					**Rp**	**32.660,00**
Price after rounding					**Rp**	**32.660,00**
3.	**Installing 1 m2 Mortar 1 PC : 5 PP**					
3.1	Ingredients					
	Quantity	Sat	Name	Price (Rp)	Quantity	
	5,184	kg	Semen	1.200,00	Rp	6.220,80
	0,026	m3	Sand tide	118.000,00	Rp	3.068,00
	1,600	ltr	Air	350,00	Rp	560,00
3.2	Tenaga			**Quantity (I)**	**Rp**	**10.221,92**
	0,300	OH	Employees	40.000,00	Rp	12.000,00
	0,150	OH	Masons	55.000,00	Rp	8.250,00
	0,015	OH	Head builder	60.000,00	Rp	900,00
	0,010	OH	Mandor	70.000,00	Rp	700,00
Quantity (II)					**Rp**	**21.850,00**
Unit price of work					**Rp**	**32.071,92**
Price after rounding					**Rp**	**32.070,00**
4	**Installing 1 m2 Mortar 1 PC : 6 PP**					
4.1	Ingredients					

	Quantity	Sat	Name	Price (Rp)	Quantity	
	4,416	kg	Semen	1.200,00	Rp	5.299,20
	0,027	m3	Sand tide	118.000,00	Rp	3.186,00
	1,800	ltr	Air	350,00	Rp	630,00
4.2	Tenaga			**Quantity (I)**	**Rp**	**9.280,08**
	0,300	OH	Employees	40.000,00	Rp	12.000,00
	0,150	OH	Masons	55.000,00	Rp	8.250,00
	0,015	OH	Head builder	60.000,00	Rp	900,00
	0,015	OH	Mandor	70.000,00	Rp	1.050,00
Quantity (II)					**Rp**	**22.200,00**
Unit price of work					**Rp**	**31.480,08**

Table 5 Results of Cost Calculation of Gresik Cement Mortar Installing 1 m2 Mortar 1 PC : 3 PP

1.1	Ingredients					
	Quantity	Sat	Name	Price (Rp)	Quantity	
	7,776	kg	Semen	1.500,00	Rp	11.664,00
	0,023	m3	Pasir	118.000,00	Rp	2.714,00
	1,200	ltr	Air	350,00	Rp	420,00
1.2	Tenaga			**Quantity (I)**	**IDR**	**14,798,00**
	0,300	OH	Employees	40.000,00	Rp	12.000,00
	0,150	OH	Masons	55.000,00	Rp	8.250,00
	0,015	OH	Head builder	60.000,00	Rp	900,00
	0,010	OH	Mandor	70.000,00	Rp	700,00
Quantity (II)					**Rp**	**21.850,00**
Unit price of work					**Rp**	**36.648,00**

Price after rounding				**Rp**	**36.640,00**
2	**Installing 1 m2 Mortar 1 PC : 4 PP**				
2.1	Ingredients				
	Quantity	Sat	Name	Price (Rp)	Quantity
	6,240	kg	Semen	1.500,00	Rp 9.360,00
	0,024	m3	Sand tide	118.000,00	Rp 2.832,00
	1,400	ltr	Air	350,00	Rp 490,00
2.2	Tenaga			**Quantity (I)**	**IDR 12,682.00**
	0,300	OH	Employees	40.000,00	Rp 12.000,00
	0,150	OH	Masons	55.000,00	Rp 8.250,00
	0,015	OH	Head builder	60.000,00	Rp 900,00
	0,010	OH	Mandor	70.000,00	Rp 700,00
Quantity (II)				**Rp**	**21.850,00**
Unit price of work				**Rp**	**34.532,00**
3.1	Ingredients				
	Quantity	Sat	Name	Price (Rp)	Quantity
	5,184	kg	Semen	1.500,00	Rp 7.776,00
	0,026	m3	Sand tide	118.000,00	Rp 3.068,00
	1,600	ltr	Air	350,00	Rp 560,00
3.2	Tenaga			**Quantity (I)**	**Rp 11.404,00**
	0,300	OH	Employees	40.000,00	Rp 12.000,00
	0,150	OH	Masons	55.000,00	Rp 8.250,00
	0,015	OH	Head builder	60.000,00	Rp 900,00
	0,010	OH	Mandor	70.000,00	Rp 700,00
Quantity (II)				**Rp**	**21.850,00**
Unit price of work				**Rp**	**33.254,00**
Price after rounding				**Rp**	**33.250,00**
4	**Installing 1 m2 Mortar 1 PC : 6 PP**				
4.1	Ingredients				

	Quantity	Sat	Name	Price (Rp)	Quantity
	4,416	kg	Semen	1.500,00	Rp 6.624,00
	0,027	m3	Sand tide	118.000,00	Rp 3.186,00
	1,800	ltr	Air	350,00	Rp 630,00
4.2	Tenaga			**Quantity (I)**	**IDR 10,440.00**
	0,300	OH	Employees	40.000,00	Rp 12.000,00
	0,150	OH	Masons	55.000,00	Rp 8.250,00
	0,015	OH	Head builder	60.000,00	Rp 900,00
	0,015	OH	Mandor	70.000,00	Rp 1.050,00
Quantity (II)					**Rp 22.200,00**
Unit price of work					**Rp 32.640,00**
Price after rounding					**Rp 32.640,00**

From the two cements, it can be seen that the cost to make 1 m2 of mortar using puger cement is Rp 34,310.00. The cost of this amount is lower than the cost of making mortar using gresik cement, which is Rp 36,640.00. There was a cost reduction of IDR 2,330.00 or a cost savings of 7.6%. This cost is a significant number, especially with the volume of work in a project usually quite large. This trade-off between cost and technical performance is a critical consideration in practical construction decision-making. Research by Pilon et al. (2019) emphasized that construction material selection should be evaluated based on both structural performance and economic efficiency, particularly in projects with large material volumes where small unit cost differences accumulate significantly. Furthermore, Visairo-Méndez et al. (2021) noted that the durability and long-term performance of repair and construction mortars should also be considered alongside initial material costs, as lower-strength materials may incur higher maintenance and remediation expenses over the service life of the structure.

Sumber: Hasil Perhitungan (2025)

Figure 3 Comparison diagram of Price Analysis of the two cements

COCLUSION

The results of this study indicate that the type of cement significantly influences the compressive strength performance of mortar under identical mixture proportions and curing conditions. Mortar produced using Gresik cement consistently demonstrated higher compressive strength values compared to mortar made with Puger cement across all mixture proportions of 1:3, 1:4, 1:5, and 1:6. The highest compressive strength was achieved in the 1:3 mixture proportion at the age of 28 days, where Gresik cement reached 197.13 Kg/cm², while Puger cement achieved 154.71 Kg/cm². In addition, the study found that increasing the proportion of sand reduced mortar compressive strength because the bonding capacity of cement became less effective with larger aggregate composition. Despite its lower strength performance, Puger cement provided a lower production cost than Gresik cement, indicating that cement selection in construction practice should consider both technical performance and economic efficiency according to project requirements. Based on these findings, future research is recommended to expand the scope of investigation by analyzing the chemical composition and microstructure characteristics of different cement brands to better understand the factors influencing mortar strength development. Further studies should also examine the durability performance of mortar under environmental exposure such as water absorption, sulfate attack, temperature variation, and long-term aging conditions. In addition, future researchers are encouraged to utilize alternative aggregates, supplementary cementitious materials, or environmentally friendly additives to improve mortar performance and sustainability. The application of advanced statistical analysis and digital modeling software is also recommended to obtain more comprehensive predictive models regarding mortar behavior and material efficiency in construction engineering.

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