Concrete Quality Analysis Based on Compressive and Splitting Tensile Strength Using Inferential Statistical Methods

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Abstract

This research analyzes the effect of Senoni and Palu coarse aggregates combined with silica sand on the compressive and split tensile strength of concrete across 7, 14, 21, and 28 days. Using 80 cylindrical specimens and independent sample T-tests, the study found that aggregate type significantly impacts compressive strength at all ages (Sig.<0.05), confirming that physical characteristics are a primary determinant of compressive capacity. In contrast, split tensile strength did not show statistically significant differences at all testing intervals, as some ages yielded significance values greater than 0.05. Furthermore, a correlation analysis revealed a moderately strong positive relationship between compressive and split tensile strength, although the intensity fluctuated based on the concrete's age. Ultimately, the study concludes that coarse aggregate selection plays a vital role in concrete performance, particularly regarding compressive loads, while its influence on indirect tensile forces appears less consistent throughout the curing process.

Keywords: *Compressive strength; Palu aggregate; Senoni aggregate; Silica sand; Splitting tensile strength*

1. Introduction

Concrete remains one of the most essential construction materials worldwide, particularly in Indonesia, due to its durability, strength, and versatility [1], [2]. Its widespread use across various structural applications demands careful selection of raw materials to ensure optimal performance. In addition to cost-efficiency and availability, concrete must exhibit high compressive strength and resistance to environmental conditions. Among its components, the quality of coarse and fine aggregates plays a critical role in determining the mechanical properties and overall durability of the final product [3].

In civil engineering, compressive strength and splitting tensile strength are the two primary indicators used to evaluate concrete performance. Compressive strength reflects the material's ability to withstand axial loads, while splitting tensile strength provides insight into its resistance to indirect tensile forces. These parameters are essential for structural design, quality assurance, and long-term serviceability [4].

Despite standardized testing procedures such as ASTM C39 and ASTM C496 [5], [6], variability in concrete strength results is inevitable due to material heterogeneity and operational factors. Therefore, inferential statistical methods are highly relevant for analyzing test data [7]. These methods allow for more accurate conclusions about population characteristics based on limited samples and help identify patterns, reliability, and consistency in concrete quality [8].

Recent studies have also explored the predictive relationship between compressive and flexural strength using local aggregates, reinforcing the importance of regional material characterization [9]. Furthermore, new experimental methods for tensile strength testing have improved detection accuracy and data efficiency, offering promising alternatives to conventional approaches [10].

This study investigates the mechanical performance of concrete produced using two types of coarse aggregates—Senoni and Palu stone—with silica sand as a fine aggregate replacement. A total of

80 cylindrical specimens were tested for compressive and splitting tensile strength at 7, 14, 21, and 28 days. The research applies independent T-tests and correlation analysis to evaluate strength differences and relationships between parameters. The findings aim to provide a systematic and statistically grounded approach to concrete quality evaluation, support the optimal use of local materials, and contribute to more reliable material selection in construction projects.

2. Method

This study employed an experimental and statistical approach to evaluate the compressive and splitting tensile strength of concrete using Senoni and Palu coarse aggregates with silica sand as a fine aggregate replacement. The process began with material preparation and testing for moisture content, clay content, specific gravity, gradation, and abrasion resistance. Concrete mix design was based on SNI 03-2847-2000 for f'c 25 MPa, and 80 cylindrical specimens were cast and cured at 7, 14, 21, and 28 days. Mechanical testing followed ASTM C39 and C496 standards. Strength data were analyzed using normality tests, parametric (T-test, Pearson) methods to assess differences and correlations, with final interpretation aligned to the research objectives.

3. Results and Discussion

3.1. Compressive and Splitting Tensile Strength Analysis

Compressive strength tests were conducted on concrete specimens using two types of coarse aggregates—Palu and Senoni—based on SNI 1974-2011. Each group consisted of 20 cylindrical specimens tested at 7, 14, 21, and 28 days. The results on Table 1 showed that concrete with Palu aggregate achieved higher strength across all curing ages, with an average 28-day strength of 29.10 MPa and an estimated strength of 27.34 MPa —exceeding the design strength of f'c 25 MPa. In contrast, concrete with Senoni aggregate had a lower 28-day average of 22.54 MPa and an estimated strength of 23.62 MPa. These findings indicate that aggregate type significantly influences compressive strength development. The underperformance of Senoni concrete is likely due to its higher clay and moisture content, typical of local aggregates, which can impair bonding and reduce strength development.

Table 1. Average Compressive Strength by Aggregate Type

Curing Age (Days)	Palu Aggregate (MPa)	Senoni Aggregate (MPa)
7	16.83	19.92
14	25.10	18.06
21	24.56	19.73
28	29.10	22.54
Estimated to 28 Days	**27.34**	**23.62**

Splitting tensile strength tests were conducted on concrete specimens using Palu and Senoni coarse aggregates, following SNI 1974-2011. Each group consisted of 20 cylindrical specimens tested at 7, 14, 21, and 28 days. Table 2 shows concrete with Palu aggregate consistently showed higher tensile strength across all ages, with a 28-day average of 2.93 MPa and an estimated strength of 2.84 MPa. Concrete with Senoni aggregate had lower values, averaging 2.44 MPa at 28 days and 2.35 MPa in estimated strength. These values align with the expected 8–12% ratio of tensile to compressive strength in concrete behavior. Palu concrete consistently falls within this range, indicating stronger aggregate–cement bonding and better resistance to indirect tensile stress. In contrast, Senoni concrete trends toward the lower bound, suggesting weaker internal cohesion and higher susceptibility to cracking.

Table 2. Average Splitting Tensile Strength by Aggregate Type

Curing Age (Days)	Palu Aggregate (MPa)	Senoni Aggregate (MPa)
7	1.95	1.76
14	2.38	1.88
21	2.57	2.02
28	2.93	2.44
Estimated to 28 Days	**2.84**	**2.35**

3.2. Inferential Statistical Analysis

3.2.1. Normality Testing

Before conducting further statistical analysis, the compressive and splitting tensile strength data were tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk methods. These tests determine whether the data distribution meets the assumptions required for parametric analysis. The results are summarized in the table below:

Table 3. Normality Test Results for Compressive Strength

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	**Sig**	**Distribution**	**Statistic**	**Sig**	**Distribution**
Senoni7	0.295	0.180	Normal	0.848	0.190	Normal
Palu7	0.209	0.200	Normal	0.969	0.868	Normal
Senoni14	0.419	0.004	Not Normal	0.682	0.006	Not Normal
Palu14	0.221	0.200	Normal	0.878	0.302	Normal
Senoni21	0.144	0.200	Normal	0.996	0.995	Normal
Palu21	0.304	0.147	Normal	0.839	0.163	Normal
Senoni28	0.284	0.200	Normal	0.885	0.332	Normal
Palu28	0.214	0.200	Normal	0.940	0.667	Normal

Table 3 display normality testing using Kolmogorov-Smirnov and Shapiro-Wilk methods showed that most compressive strength datasets were normally distributed (Sig. > 0.05), except for Senoni aggregate at 14 days, which exhibited significant deviation (Sig. < 0.05). This anomaly likely stems from curing inconsistencies or aggregate heterogeneity, reflecting the less stable quality of Senoni concrete. In contrast, Palu concrete consistently displayed normal distribution, indicating more homogeneous data.

Table 4. Normality Test Results for Splitting Tensile Strength

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	**Sig**	**Distribution**	**Statistic**	**Sig**	**Distribution**
Senoni7	0.220	0.200	Normal	0.944	0.695	Normal
Palu7	0.235	0.200	Normal	0.898	0.401	Normal
Senoni14	0.186	0.200	Normal	0.980	0.937	Normal
Palu14	0.148	0.200	Normal	0.983	0.948	Normal
Senoni21	0.251	0.200	Normal	0.866	0.249	Normal
Palu21	0.244	0.200	Normal	0.845	0.179	Normal
Senoni28	0.349	0.46	Normal	0.797	0.76	Normal
Palu28	0.285	0.200	Normal	0.832	0.144	Normal

Table 4 shows all splitting tensile strength datasets for both Senoni and Palu aggregates across all curing ages showed Sig. > 0.05, indicating normal distribution. This validates the use of parametric statistical methods such as the Independent T-test for further analysis.

3.2.2. T-Test Analysis

An Independent-Samples T-test was conducted to determine whether there were significant differences in compressive strength between concrete made with Senoni and Palu aggregates across four curing ages. The results (Table 5) showed that for all ages—7, 14, 21, and 28 days—the significance values (Sig.) were consistently below 0.05, and the t-values exceeded the critical threshold (t-table = 2.306), confirming statistically significant differences.

Table 5. T-Test Results – Compressive Strength

Comparison	t-value	df	Sig. (p-value)	Significance
Senoni vs Palu (7 days)	-2.456	8	0.040	Significant
Senoni vs Palu (14 days)	-3.873	8	0.005	Significant
Senoni vs Palu (21 days)	-4.442	8	0.002	Significant
Senoni vs Palu (28 days)	-10.249	8	0.000	Significant

The hypothesis test rejected H_0 and accepted H_1 in all cases, confirming that the type of coarse aggregate significantly affects compressive strength. Palu aggregate consistently produced higher strength due to its superior physical characteristics—such as angular shape, rough texture, and lower clay content—which enhance bonding with cement paste. In contrast, Senoni aggregate, being more rounded and containing more fines, resulted in weaker interfacial adhesion and lower strength development. These findings validate the importance of aggregate selection in achieving target concrete performance.

An Independent-Samples T-test was conducted to assess whether concrete made with Senoni and Palu aggregates showed significant differences in splitting tensile strength across curing ages. The results are summarized below:

Table 6. T-Test Results – Splitting Tensile Strength

Comparison	t-value	df	Sig. (p-value)	Significance
Senoni vs Palu (7 days)	-2.127	8	0.066	Not Significant
Senoni vs Palu (14 days)	-3.194	8	0.013	Significant
Senoni vs Palu (21 days)	-6.253	8	0.000	Significant
Senoni vs Palu (28 days)	-6.505	8	0.000	Significant

The T-test results (Table 6) indicate that splitting tensile strength differences between Senoni and Palu aggregates were statistically significant at 14, 21, and 28 days ($p < 0.05$), but not at 7 days ($p = 0.066$). This suggests that early-age tensile strength is less sensitive to aggregate type, likely due to incomplete bond development and internal curing variability. As curing progresses, Palu aggregate consistently yields higher tensile strength, reflecting better interfacial bonding and reduced microcracking. These findings highlight that aggregate selection becomes increasingly critical for tensile performance as concrete matures.

Overall, the T-test results indicate that at the early age of 7 days, the difference in compressive strength was not yet significant, while the difference in splitting tensile strength was already significant. From 14 to 28 days, nearly all tests showed statistically significant differences, except for the 7-day splitting tensile strength, which was not significant. These findings confirm that concrete made with Palu aggregate consistently outperforms Senoni, especially at the target age of 28 days, where the strength difference is highly significant statistically.

3.2.3. Pearson Correlation Analysis

Pearson correlation testing was used to evaluate the direction, strength, and statistical significance of the linear relationship between compressive strength and splitting tensile strength in concrete specimens using Senoni and Palu aggregates. The results reveal contrasting patterns between the two aggregate types.

Table 7. Pearson Correlation – Senoni Aggregate

Age (Days)	Correlation Coefficient (r)	Direction	Strength	Sig. (p-value)	Significance
7	-0.788	Negative	Strong	0.113	Not Significant
14	-0.779	Negative	Strong	0.120	Not Significant
21	-0.683	Negative	Strong	0.204	Not Significant
28	-0.650	Negative	Strong	0.235	Not Significant

Table 7 depict all correlation coefficients fall within the range of strong relationships (0.60–0.799), but they are negative, indicating that as compressive strength increases, splitting tensile strength tends to decrease—contrary to typical concrete behavior. This anomaly may be attributed to the heterogeneous nature of Senoni aggregate, such as high clay content or inconsistent particle bonding, which disrupts the expected parallel development of compressive and tensile strength.

Despite the strong correlation values, none of the results are statistically significant ($p > 0.05$), meaning there is insufficient evidence to confirm a consistent linear relationship between the two strength parameters. Therefore, the null hypothesis (H_0) is accepted for all ages: there is no significant linear correlation between compressive and splitting tensile strength in concrete using Senoni aggregate.

Table 8. Pearson Correlation – Senoni Aggregate

Age (Days)	Correlation Coefficient (r)	Direction	Strength	Sig. (p-value)	Significance
7	-0.035	Negative	Very Weak	0.956	Not Significant
14	0.616	Positive	Strong	0.269	Not Significant
21	0.949	Positive	Very Strong	0.014	Significant
28	-0.507	Negative	Moderate	0.383	Not Significant

It can be seen from Table 8 that at 21 days, the correlation between compressive and tensile strength was very strong and statistically significant ($r = 0.949$, $p < 0.05$), indicating a clear linear relationship where increases in compressive strength were matched by increases in tensile strength. At 7, 14, and 28 days, although some correlations were moderate to strong, none were statistically significant ($p > 0.05$), meaning the relationship could not be confidently generalized. The presence of negative correlations at 7 and 28 days suggests inconsistent strength development, possibly due to aggregate variability or microstructural factors affecting tensile performance independently of compressive strength.

These findings imply that while Palu aggregate generally supports strong bonding, the linear relationship between compressive and tensile strength is most reliable at 21 days, and less predictable at other ages.

The correlation analysis highlights that Palu aggregate exhibits more favourable and predictable strength development, particularly at 21 days, where the material properties significantly influence both compressive and tensile performance. In contrast, Senoni aggregate lacks consistent linear behavior, reinforcing its lower reliability in structural applications. These insights support the selection of Palu aggregate for concrete requiring balanced strength characteristics.

4. Conclussion

Based on the experimental results and inferential statistical analysis of concrete compressive and splitting tensile strength using Palu and Senoni coarse aggregates with silica sand, the following conclusions can be drawn: Concrete made with Palu aggregate achieved an average compressive strength of 27.34 MPa and a splitting tensile strength of 2.84 MPa, outperforming Senoni aggregate, which yielded 23.62 MPa and 2.35 MPa respectively.

The most appropriate statistical method for analyzing the strength data was the Independent Samples T-Test, which effectively compared the two aggregate groups and confirmed significant differences in performance.

Pearson correlation analysis revealed that Senoni aggregate consistently showed a negative relationship between compressive and tensile strength across all curing ages, with no statistically significant linear correlation ($p > 0.05$). In contrast, Palu aggregate exhibited mixed correlation directions, with only the 21-day age showing a significant positive relationship ($p < 0.05$). Overall, the statistical relationship between the two strength parameters was inconsistent, indicating that aggregate characteristics do not uniformly influence both compressive and tensile strength outcomes.

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