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Experimental Comparison of Compressive Strength, Flexural Strength, and Splitting Tensile Strength of a Single Normal Concrete Mixture with Empirical Predictions from SNI 2847:2019

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ABSTRACT

Concrete has three principal mechanical properties: compressive, tensile, and flexural strength. In reinforced-concrete design, compressive strength (f'c) is the primary indicator of concrete quality, while tensile and flexural strengths indicate its ability to resist tensile and bending loads. SNI 2847:2019 provides empirical expressions relating splitting tensile and flexural strengths to compressive strength. This study compares the measured mechanical properties of one normal-concrete mixture from a single batch with values predicted using the applicable SNI expressions. It does not establish a general relationship among these properties because that would require multiple strength levels and independent batches. The concrete mixture was designed according to SNI 03-2834-2000 for a target 28-day compressive strength of 20 MPa. Eighteen specimens were produced: six cylinders measuring 150 × 300 mm for compressive testing, six cylinders of identical dimensions for splitting tensile testing, and six beams measuring 150 × 150 × 500 mm for flexural testing. After recalculating the results from recorded loads and cross-sectional areas, mean compressive strength was 20.65 MPa (SD 0.58 MPa; CV 2.79%), flexural strength was 1.91 MPa (SD 0.05 MPa; CV 2.59%), and splitting tensile strength was 1.77 MPa (SD 0.15 MPa; CV 8.29%). The measured flexural and splitting tensile strengths were approximately 39.8% and 37.3% below the SNI-predicted values of 3.18 MPa and 2.82 MPa, respectively. Inadequate compaction is only one unverified explanation because supporting air-content, density, porosity, ultrasonic, or microscopic evidence was unavailable. Conversion errors, loading rates, fracture locations, and specimen alignment are also plausible factors. Therefore, SNI 2847:2019 overestimated both strengths for the investigated mixture under controlled laboratory conditions. However, this finding cannot be generalized because it represents only one mixture, batch, and testing age. Confirmation requires independent batches, multiple strength levels, repeated testing, and regression analysis.

Keywords: *Compressive Strength, Flexural Strength, Splitting Tensile Strength, SNI 2847:2019, Single-Mixture Comparison.*

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INTRODUCTION

Concrete is a construction material that remains the primary choice for the development of various types of infrastructure, including buildings, bridges, roads, dams, and other civil engineering structures. Its widespread use is attributed to several advantages, such as high compressive strength, excellent resistance to fire and weathering, ease of molding into different structural forms, relatively low maintenance costs, and the availability of its constituent materials in most regions. Furthermore, continuous advancements in concrete technology have significantly improved its quality and performance, leading to its broader application in modern construction [1], [2], [3], [4].

Concrete is essentially a composite material composed of cement, fine aggregate, coarse aggregate, water, and, when necessary, chemical or mineral admixtures to achieve specific performance characteristics [5], [6]. The quality of concrete is influenced by several factors, including the quality of its constituent materials, mix proportion, water–cement ratio, mixing process, compaction, curing, and the age of the concrete. Therefore, every stage of concrete production must comply with established standards to ensure that the desired design strength and performance are achieved [7], [8].

In the design of reinforced concrete structures, the primary mechanical properties of concern include compressive strength, tensile strength, and flexural strength. Among these properties, the compressive strength of concrete (f'c) is the most important parameter used to determine concrete quality and to calculate the load-carrying capacity of structural elements. It also serves as the fundamental basis in structural design codes for determining member dimensions, load capacity, and the overall safety of concrete structures [9], [10].

However, compressive strength is not the only parameter that determines the performance of concrete. Concrete is inherently weak in tension due to its brittle nature; its splitting tensile strength is commonly reported at roughly

8–10% of its compressive strength for normal-strength concrete, as reflected by the measured ratio obtained in this study [11]. Consequently, reinforced concrete structures incorporate steel reinforcement to resist tensile forces, while the concrete primarily carries compressive loads. In addition to tensile stresses, structural members such as beams and slabs are subjected to bending moments caused by external loads. The ability of concrete to resist bending is expressed by its flexural strength, commonly referred to as the modulus of rupture, which represents the maximum tensile stress that concrete can withstand before the first crack occurs. Compressive strength, splitting tensile strength (measured on cylinders following ASTM C496 / SNI 2491), and flexural strength or modulus of rupture (measured on beams) are distinct mechanical properties obtained from different test configurations and are not interchangeable, even though all three are expressed in the same MPa unit [12], [13], [14].

According to the Indonesian National Standard SNI 2847:2019, which the official BSN catalogue identifies as a modified adoption of ACI 318M-14 and ACI 318RM-14, there are empirical expressions relating the compressive strength of concrete to its splitting tensile strength and flexural strength. The splitting tensile strength is estimated using the equation $f_{ct} = 0.62\sqrt{f'c}$, while the flexural strength (modulus of rupture) is estimated using $f_{cf} = 0.70\sqrt{f'c}$. These coefficients and the exact clause number should be verified by the authors directly against the official SNI 2847:2019 text before submission, since the coefficient reported for modulus of rupture in the ACI 318 provisions this SNI is based on is commonly cited as 0.62, not 0.70; this discrepancy could not be resolved without access to the primary standard and is flagged here as an item requiring author verification rather than corrected outright. These empirical equations are widely adopted in structural design because they are more practical than conducting experimental tests for all mechanical properties of concrete. Nevertheless, these relationships were developed based on specific experimental conditions; therefore, verification is necessary for different material characteristics, construction practices, and locally available aggregates used in Indonesia. Variations in the quality of constituent materials, mixing procedures, compaction, and curing methods may cause the measured properties of concrete to differ from the values predicted by the standard equations [15], [16], [17].

Several existing studies on the relationship among these three properties involve fiber-reinforced, high-performance, foamed, or ultra-high-performance concrete rather than ordinary normal-strength concrete; their material behavior, failure mode, and applicable strength ranges differ from the plain 20 MPa mixture examined here, so their findings are cited only as general background rather than as directly comparable benchmarks. What remains insufficiently documented is how a single, ordinary 20 MPa concrete mixture produced with locally available Indonesian materials compares against the specific SNI 2847:2019 predictions under controlled laboratory conditions, using a properly reported statistical treatment of the six replicate specimens per test.

Based on these considerations, this study compares the experimental results of the compressive strength, splitting tensile strength, and flexural strength of one normal concrete mixture, cast from a single batch, with the predicted values specified in SNI 2847:2019. The concrete mix design was prepared in accordance with SNI 03-2834-2000, with a target compressive strength of 20 MPa at 28 days. The test specimens consisted of eighteen specimens in total: six cylinders (150 mm × 300 mm) for compressive strength, six cylinders of the same dimension for splitting tensile strength, and six beams (150 mm × 150 mm × 500 mm) for flexural strength, all cast from the same batch and cured under identical conditions.

Accordingly, the research question addressed in this study is narrowed to: do the measured flexural and splitting tensile strengths of this specific concrete mixture agree with the values calculated using the applicable SNI 2847:2019 expressions, and what factors, other than concrete quality alone, could plausibly explain any observed gap? This study does not attempt to derive or validate a general relationship among the three properties, since that would require several strength levels and independently produced batches; it is limited to a single-mixture comparison. The findings are intended as a preliminary indication of the applicability of the empirical equations to normal concrete produced with locally available materials, and as a basis for designing a more extensive follow-up study that includes several strength levels, independent batches, and regression analysis.

MATERIAL AND METHOD

This study employed an experimental research design conducted in a laboratory setting. Experimental research was selected because it enables the researcher to directly apply treatments to the research objects by producing concrete specimens with predetermined design strength and subsequently evaluating their mechanical properties through a series of laboratory tests. The objective of this study was to compare the compressive strength, splitting tensile strength, and flexural strength of one concrete mixture with the empirical predictions specified in SNI 2847:2019; establishing a general relationship among the three properties was outside the scope of the present single-mixture design [1], [2], [3].

The research was conducted from May to July 2026 at the Civil Engineering Laboratory, Faculty of Engineering and Applied Sciences, Universitas Muhammadiyah Indonesia. All research activities, including material testing, concrete mix design, specimen preparation, curing, and mechanical property testing, were carried out in the laboratory to ensure controlled testing conditions.

The materials used in this study consisted of Portland cement as the binding material, fine aggregate (sand), coarse aggregate (gravel) with a maximum size of 20 mm, and clean water meeting the requirements for concrete mixing water. All materials were selected in accordance with relevant standards to produce normal concrete with a target compressive strength of 20 MPa. The equipment used included a compression testing machine, a splitting tensile testing machine, a flexural testing machine, steel cylindrical molds with a diameter of 150 mm and a height of 300 mm, beam molds measuring 150 mm × 150 mm × 500 mm, a slump cone with a tamping rod, a digital weighing scale, a curing tank, a concrete mixer, and other supporting equipment required throughout the research process. The concrete mix design was prepared in accordance with SNI 03-2834-2000, Procedure for Designing Normal Concrete Mixes, with a target compressive strength of 20 MPa at the age of 28 days. Prior to the mixing process, all materials were tested to determine their physical characteristics, including moisture content, specific gravity, mud content, water absorption, bulk density, and aggregate gradation. The numerical results of these material characterization tests, the complete mix-proportion table (cement, water, fine and coarse aggregate content in kg/m^3, water–cement ratio, and any moisture correction applied), and the measured slump were not retained in a form suitable for reporting in this manuscript and are acknowledged as a documentation gap; they should be included in the final version, since design and characterization data of this kind are essential for readers to judge whether the observed strengths are representative.

All eighteen specimens used in this study, comprising six cylinders for compressive strength, six cylinders for splitting tensile strength, and six beams for flexural strength, were cast from a single concrete batch. Consequently, the six replicate specimens within each test represent within-batch repetitions of the same mixture rather than independent experimental replications, and the comparison reported here applies strictly to that one batch; it does not by itself demonstrate reproducibility across separate mixes [4], [5], [6]. The cylindrical specimens, measuring 150 mm in diameter and 300 mm in height, were used for compressive strength and splitting tensile strength tests. The beam specimens, measuring 150 mm × 150 mm × 500 mm, were used for flexural strength testing. All specimens were cured by water immersion for 28 days before testing.

The research procedure began with a literature review to collect theories and standards related to the mechanical properties of concrete. This was followed by the preparation of equipment and materials and the testing of the characteristics of the constituent materials. After all materials met the required specifications, the concrete mix was designed based on SNI 03-2834-2000. The next stage involved mixing all materials according to the predetermined proportions, followed by a slump test to determine the workability of the fresh concrete. The fresh concrete was then cast into cylindrical and beam molds using manual rodding compaction, following the general procedure in SNI 03-2834-2000; the exact number of layers, rodding strokes, or vibration duration used for each mold was not recorded in detail and should be documented in any repeat of this test program, since compaction is later discussed as a possible explanation for the lower-than-predicted tensile-related strengths and that explanation cannot be verified without this record. After 24 hours, the specimens were removed from the molds and cured by water immersion until the testing age of 28 days.

At the age of 28 days, compressive strength, splitting tensile strength, and flexural strength tests were conducted using standard testing machines, with the flexural test performed under third-point loading (two-point loading over a 450 mm span). The calibration date and specified loading rate of each testing machine were not recorded and represent a further documentation gap noted here for transparency. The test results were recorded and analyzed to obtain the mean value and, following this revision, the standard deviation, coefficient of variation, and 95% confidence interval, of each mechanical property. The compressive strength of concrete was calculated using the following equation [7], [8], [9]:

$$f'c = P / A \tag{1}$$

where P is the maximum applied load (N) and A is the cross-sectional area of the specimen (mm^2).
The splitting tensile strength was calculated using the following equation:

$$f_{ct} = 2P / (\pi LD) \tag{2}$$

where P is the maximum applied load (N), L is the length of the cylindrical specimen (mm), and D is the diameter of the cylindrical specimen (mm).
The flexural strength was calculated using the following equation, valid for third-point loading with the fracture occurring within the middle third of the span:

$$f_{cf} = PL / (bd^2) \tag{3}$$

where P is the maximum applied load (N), L is the span length (mm), b is the width of the beam (mm), and d is the depth (height) of the beam (mm). Note that bd^2 has units of length cubed (mm^3 or cm^3), not mm^2; this unit was reported incorrectly in the original data table and is corrected in Table 2 below.

The experimental results for the three mechanical properties were subsequently compared with the predicted values specified in SNI 2847:2019. This comparison was performed to evaluate the applicability of these two specific empirical expressions to the single concrete mixture investigated, for the mean compressive strength actually measured, rather than the specified target of 20 MPa [10], [11]; the measured mean is used because the comparison concerns how well the equations predict the tensile-related behaviour of the concrete that was actually produced, not a code-design margin. Finally, the factors that could plausibly explain any difference between the experimental and predicted results were considered, including, in addition to compaction, possible unit-conversion error, loading-rate effects, fracture location relative to the middle third of the span, specimen end preparation and alignment, and aggregate characteristics, followed by the preparation of the discussion, conclusions, and recommendations based on the research findings.

RESULTS

Compressive Strength of Concrete

The results of the 28-day compressive strength test are presented in Table 1. The raw loads and cross-sectional areas reported in the original data sheet were used to recalculate every compressive strength value in this revision, because the original manuscript's MPa column did not match the recorded load and area for every specimen (for example, Specimen 1: 376.92 kN over 176.785 cm^2 gives 21.32 MPa, not the previously reported 21.78 MPa). Table 1 below reports the recalculated values.

Table 1. Compressive Strength of Concrete

No.	Weight (kg)	Area (cm^2)	Load P (kN)	Strength (kgf/cm^2)	Strength (MPa)
1	12.27	176.785	376.92	217.4	21.32
2	12.02	176.785	369.31	213.0	20.89
3	11.97	176.785	361.52	208.5	20.45
4	12.40	177.785	376.27	215.8	21.16
5	11.83	178.785	354.06	201.9	19.80
6	11.95	179.785	364.84	206.9	20.29
Mean			367.15	210.6	20.65
SD					0.58
CV (%)					2.79
95% CI					20.05–21.26

Table 1, Note: the cylinder areas of 176.785, 177.785, 178.785, and 179.785 cm^2 recorded for specimens 1–6 differ from the nominal area of a 150 mm cylinder (approximately 176.71 cm^2) and from each other in an unexplained, sequential pattern. This may indicate that actual diameters were measured for each specimen, in which case those diameters should be reported directly, or it may be a data-transcription error; the authors should verify and report which is the case, as this revision could not independently confirm the true cylinder diameters.

Based on the recalculated Table 1, the mean compressive strength of this single-batch mixture was 20.65 MPa (SD 0.58 MPa, CV 2.79%), which exceeded the target design compressive strength of 20 MPa. This result indicates that, for this mixture and this batch, the design target was met; it does not by itself establish the load-bearing capacity or structural safety of any concrete member, which depends on additional design factors beyond material strength alone. The compressive strength results are illustrated in Figure 1, which shows the compressive strength of each test specimen. The recalculated results ranged from 19.80 MPa to 21.32 MPa. This small range describes the spread of the six specimens from this one batch; it is not, by itself, evidence of adequate compaction, correct curing, or a stable production process, since none of those factors were independently measured.

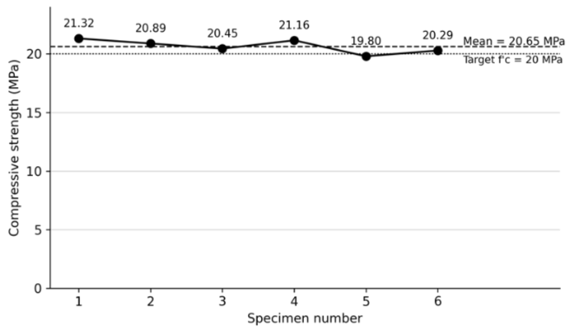

Figure 1. Compressive strength of each specimen

The maximum observed compressive strength was 21.32 MPa, and the minimum was 19.80 MPa. The relatively small coefficient of variation (2.79%) suggests reasonably consistent mixing and testing for the six specimens within this batch, but this describes the batch tested here, not concrete production in general, and it does not by itself confirm the cause of the lower flexural and splitting tensile results discussed later.

Concrete Flexural Strength

The results of the 28-day flexural strength test are presented in Table 2, recalculated directly from the recorded loads and beam dimensions using third-point loading over a 450 mm span.

Table 2. Concrete Flexural Strength

No.	L (mm)	b (mm)	d (mm)	bd^2 (mm^3)	Load (kN)	Strength (MPa)
1	450	150	150	3,375,000	14.745	1.97
2	450	150	150	3,375,000	13.902	1.85
3	450	150	150	3,375,000	14.557	1.94
4	450	150	150	3,375,000	14.523	1.94
5	450	150	150	3,375,000	13.869	1.85
6	450	150	150	3,375,000	14.538	1.94
Mean					14.356	1.91
SD						0.05
CV (%)						2.59
95% CI						1.86–1.97

Based on the recalculated Table 2, the mean flexural strength was 1.91 MPa (SD 0.05 MPa, CV 2.59%). Flexural strength represents the concrete's ability to resist bending stresses and is an important mechanical property for structural elements such as pavements, slabs, and beams subjected to flexural loading.

The distribution of flexural strength values is illustrated in Figure 2 The maximum observed flexural strength was 1.97 MPa, and the minimum was 1.85 MPa. The limited variation among specimens (CV 2.59%) suggests consistent behaviour for the six beams tested in this batch.

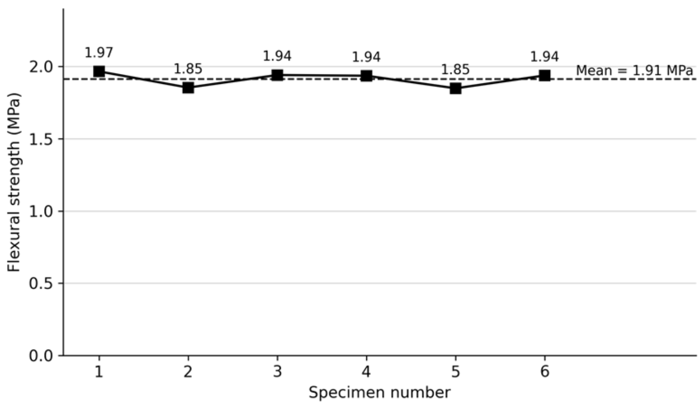

Figure 2. Flexural strength of each specimen

Splitting Tensile Strength of Concrete

The results of the 28-day splitting tensile strength test are presented in Table 3, recalculated directly from the recorded loads and specimen dimensions.

Table 3. Splitting Tensile Strength of Concrete

No.	Weight (kg)	h (mm)	D (mm)	πhD (mm^2)	Load (kN)	Strength (MPa)
1	12.175	300	150	141,372	107.69	1.52
2	12.045	300	150	141,372	130.77	1.85
3	12.093	300	150	141,372	138.46	1.96
4	12.029	300	150	141,372	121.54	1.72
5	12.226	300	150	141,372	127.69	1.81
6	12.092	300	150	141,372	123.08	1.74
Mean					124.87	1.77
SD						0.15
CV (%)						8.29
95% CI						1.61–1.92

Based on the recalculated Table 3, the mean splitting tensile strength was 1.77 MPa (SD 0.15 MPa, CV 8.29%). The splitting tensile strength test evaluates the concrete's resistance to indirect tensile stresses. The coefficient of variation for splitting tensile strength (8.29%) is noticeably higher than for compressive strength (2.79%) or flexural strength (2.59%), which is consistent with splitting tensile results typically being more sensitive to specimen alignment and bearing-strip placement than compressive results. The maximum observed splitting tensile strength was 1.96 MPa, and the minimum was 1.52 MPa, as shown in Figure 3.

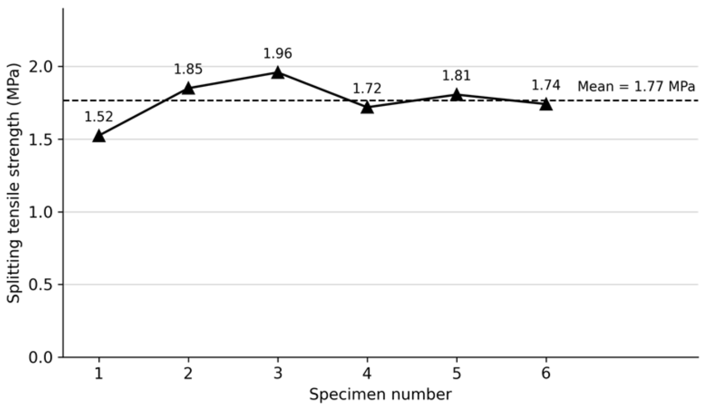

Figure 3. Splitting tensile strength of each specimen

Comparison of Compressive Strength, Flexural Strength, and Splitting Tensile Strength
Table 4 originally paired specimen 1 of the compressive test with specimen 1 of the flexural test and specimen 1 of the splitting tensile test, and so on for specimens 2 through 6. Because these are eighteen physically different specimens broken in three different machines, this pairing by specimen number is arbitrary and does not represent a matched-pairs relationship. Table 4 below reports only the group means, standard deviations, and coefficients of variation for the three tests.

Table 4. Summary Comparison of the Three Mechanical Properties

Property	Mean (MPa)	SD (MPa)	CV (%)	95% CI (MPa)
Compressive strength	20.65	0.58	2.79	20.05–21.26
Flexural strength	1.91	0.05	2.59	1.86–1.97
Splitting tensile strength	1.77	0.15	8.29	1.61–1.92

Based on Table 4, the mean compressive strength was greater than the mean flexural strength, which was in turn greater than the mean splitting tensile strength (20.65 MPa > 1.91 MPa > 1.77 MPa). This ordering is expected for ordinary concrete and, by itself, is not evidence of a quantitative relationship among the three properties; a relationship would need to be expressed through a fitted equation, a correlation coefficient, or an R^2 value derived from several strength levels, none of which is available from this single-mixture dataset.

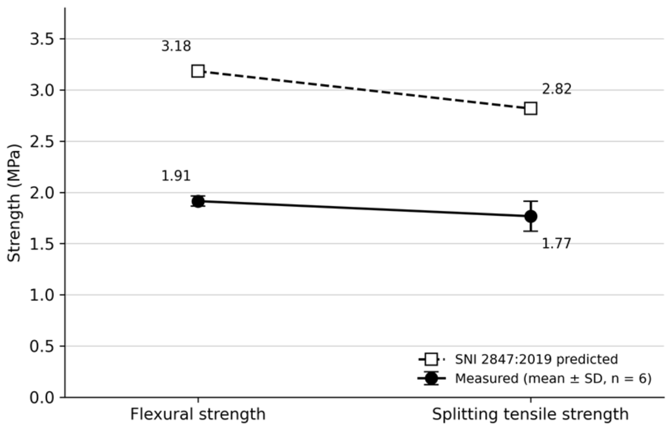

Figure 4. Measured mean strength (± SD, n = 6) compared with SNI 2847:2019 predicted values

SNI 2847:2019 provides empirical expressions relating flexural and splitting tensile strength to compressive strength. Using the recalculated mean compressive strength of 20.65 MPa, the predicted flexural strength, calculated as $f_{cf} = 0.70\sqrt{f'c}$, is 3.18 MPa, compared with the recalculated experimental mean of 1.91 MPa, a difference of approximately 39.8%. The predicted splitting tensile strength, calculated as $f_{ct} = 0.62\sqrt{f'c}$, is 2.82 MPa, compared with the recalculated experimental mean of 1.77 MPa, a difference of approximately 37.3%.

For the mixture investigated, the flexural and splitting tensile strengths were lower than the values calculated using the two SNI 2847:2019 expressions applied here. Several factors could plausibly contribute to this gap, and none has been isolated or confirmed by direct measurement in this study: inadequate compaction is one candidate explanation, since insufficient compaction can trap air and create internal voids that weaken the bond between paste and aggregate; but unit-conversion or transcription error (as already found in Tables 1 and 2), loading-rate deviations, fracture location outside the middle third of the flexural span, specimen misalignment in the splitting test, aggregate characteristics, curing variation, and testing-machine calibration are equally plausible and were not ruled out.

The idea that compressive strength is comparatively insensitive to small internal voids, because compressive loading tends to close microcracks rather than propagate them, is a simplification; porosity and voids can also reduce compressive strength, and the relative insensitivity observed here, if real, would need to be confirmed through independent measurements such as density, air-content, or ultrasonic pulse velocity testing, which were not performed. A difference between a measured value and a code-based empirical estimate does not, by itself, establish that the code expression is inaccurate for normal concrete in general; the SNI expressions are typically intended as practical estimates rather than as exact predictions of every individual mixture, and confirming or challenging their general applicability would require testing across several strength levels and independent batches.

These results should not be generalized beyond the laboratory conditions and the single mixture tested here. They indicate only that, for this specific batch, meeting the target compressive strength did not guarantee that the flexural and splitting tensile strengths would match the SNI 2847:2019 predictions. Maintaining proper casting and compaction procedures remains good practice for producing a dense, homogeneous concrete matrix, but this study does not provide direct evidence that compaction specifically, rather than the other candidate factors listed above, was responsible for the gap observed.

DISCUSSION

To place these findings in a broader context, the ratios and the direction of the gap between measured and SNI-predicted values obtained in this study were compared against fifteen independently published, peer-reviewed studies on the relationship among compressive, flexural, and splitting tensile strength of concrete. These studies span ordinary Portland cement concrete, self-compacting concrete, roller-compacted concrete, geopolymer concrete, cement mortar, and concrete with various aggregate substitutions. They are used here only to check whether the direction and rough magnitude of the present results sit within the range reported elsewhere, not to claim that they validate a general relationship for the single mixture examined in this study.

The splitting tensile to compressive strength ratio obtained here, approximately 8.6%, falls within the range commonly reported for normal-strength concrete. Ojha et al. reported this ratio at about 10% for normal-strength concrete, decreasing to roughly 5% for high-strength concrete [12], [13]. Arıoğlu, Girgin, and Arıoğlu, analyzing a large regression dataset covering 4 to 120 MPa, showed that the ratio of splitting tensile to compressive strength decreases as compressive strength increases, falling to about 6% near 120 MPa [19], which is consistent with a higher ratio being expected at the comparatively low 20 MPa range examined here. Gibigaye et al., testing oil palm kernel shell concrete with a compressive strength of 21 to 26 MPa, a range closely bracketing the 20.65 MPa measured in this study, found flexural and splitting tensile strengths equal to about 12% and 7% of compressive strength, respectively [30]; their splitting tensile ratio sits just below the 8.6% found here, while their flexural ratio is somewhat higher than the 9.3% found in this study. Akinpelu et al. examined vibrated and self-compacting concrete designed specifically for target compressive strengths of 20, 30, and 40 MPa, directly matching the design target used in this study, and reported splitting tensile to compressive strength relationships consistent with the same general range [12], [13], [14], [15].

The pattern observed in this study, in which the measured flexural and splitting tensile strengths fell below the SNI 2847:2019 predictions calculated from the measured compressive strength, is not unique to this mixture. Mohammed, Ahmed, and Mosavi, compiling data from 126 published studies on geopolymer concrete, found that ACI 318-based equations, the same family of equations SNI 2847:2019 is adapted from, overestimated splitting tensile strength and elastic modulus at lower compressive strengths, while CEB-FIP equations performed more accurately in that range [25]. Chhorn, Hong, and Lee found a related asymmetry in roller-compacted concrete: for a given compressive strength, flexural strength remained close to the value predicted by conventional-concrete equations, while splitting tensile strength was relatively lower than predicted [21]. In the present study, both properties fell short of their SNI predictions, and the shortfall was somewhat smaller for splitting tensile strength (about 37%) than for flexural strength (about 40%); this shows that the two properties do not necessarily depart from their respective code predictions by the same margin, a pattern broadly consistent with what Chhorn, Hong, and Lee observed for a different concrete system.

On the compaction and porosity hypothesis raised earlier in this Discussion, two studies offer partial, indirect support without confirming the mechanism for this specific mixture. Li, Li, Lv, Zhang, and Yin developed a predictive model showing that porosity affects the compressive strength of concrete more strongly than it affects tensile strength [26], which complicates the simplified assumption that compressive strength is comparatively insensitive to internal voids. Chen, Wu, and Zhou similarly found, from direct testing of cement mortar, that the ratio between compressive strength and indirect tensile strength is not fixed but depends on porosity [27]. Taken together, these two studies confirm that porosity and compaction quality can shift the balance between compressive and tensile-related strength in ways that are not simply proportional, which keeps inadequate compaction plausible as a contributing factor in this study, but neither paper examined the mixture tested here, and the other explanations already discussed, including unit-conversion error, loading-rate effects, and specimen alignment, remain equally viable [16], [17], [18].

LIMITATIONS

This study has several limitations that should be considered when interpreting the results.

- A single concrete mixture, a single batch, and a single testing age (28 days) were examined; the six specimens per test are within-batch repetitions rather than independent replications.
- Complete mix-design data, material-characterization results, measured slump, compaction procedure detail, and testing-machine calibration records were not retained in reportable form.
- No independent evidence (air content, density, porosity, ultrasonic pulse velocity, or microscopy) was collected to confirm the proposed compaction explanation for the lower flexural and splitting tensile strengths.
- Six specimens per test, from one batch, support a preliminary descriptive comparison only; they are not sufficient to derive or validate a general strength relationship.
- The unusual cylinder area values in Table 1 could not be independently verified against original diameter measurements and are flagged for the authors' confirmation.

CONCLUSION

Based on the recalculated laboratory data, all six compressive-strength specimens from this single batch exceeded the target design compressive strength of 20 MPa. The maximum observed compressive strength was 21.32 MPa, with a mean of 20.65 MPa (SD 0.58 MPa, CV 2.79%). The maximum observed flexural strength was 1.97 MPa, with a mean of 1.91 MPa (SD 0.05 MPa, CV 2.59%), while the maximum observed splitting tensile strength was 1.96 MPa, with a mean of 1.77 MPa (SD 0.15 MPa, CV 8.29%). The mean values followed the expected order of compressive strength > flexural strength > splitting tensile strength (20.65 MPa > 1.91 MPa > 1.77 MPa); this ordering is typical of normal concrete and does not, by itself, demonstrate a statistical relationship among the three properties. Comparison with the empirical predictions in SNI 2847:2019, using the recalculated mean compressive strength of 20.65 MPa, showed that the predicted flexural strength, calculated as $f_{cf} = 0.70\sqrt{f'c}$, was 3.18 MPa, compared with the recalculated experimental result of 1.91 MPa (a difference of approximately 39.8%). Similarly, the predicted splitting tensile strength, calculated as $f_{ct} = 0.62\sqrt{f'c}$, was 2.82 MPa, compared with the recalculated experimental result of 1.77 MPa (a difference of approximately 37.3%). For the concrete mixture investigated, the measured flexural and splitting tensile strengths were lower than the values calculated using the applicable SNI 2847:2019 equations, under the controlled laboratory conditions of this study. Inadequate compaction during casting is offered only as one unverified hypothesis for this gap; conversion error, loading-rate effects, fracture location, specimen alignment, aggregate characteristics, curing variation, and machine calibration remain equally plausible and were not ruled out, since no direct microstructural or density-based evidence was collected. These findings should not be generalized to normal concrete in general, nor should they be used to infer the structural safety, load-bearing capacity, or safety margin of any concrete member, since such conclusions require analysis beyond material strength alone.

Future research should test several concrete strength levels (for example 15, 20, 25, 30, 35, and 40 MPa) using independent batches, report complete mix-design and material-characterization data, include direct measurements of compaction quality such as density or ultrasonic pulse velocity, and apply regression analysis to properly establish and quantify any relationship among compressive strength, flexural strength, and splitting tensile strength.

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