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ANALYSIS OF THE RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND BENDING STRENGTH OF CONCRETE WITH FC 30 MEGAPASCAL (MPA)

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ABSTRACT

With the rapid development in the field of construction, various material innovations are increasingly emerging, especially in concrete. Concrete is in high demand for its durability, resistance to pressure, and low maintenance costs. Made from a growing mix of cement, coarse aggregate (split), fine aggregate (sand), water, and additives, concrete is becoming a top choice in modern infrastructure. This study aims to explore the relationship between compressive strength and flexural strength in 30 MPa quality concrete. The method used was a laboratory experiment with cylindrical and block-shaped test pieces, which were tested at the ages of 7, 14, and 28 days. The main materials used include coarse and fine aggregates, water, fly ash, and Portland type I cement. The study measured the compressive strength values of concreate, and evaluated the formula $(fs = 0.62\sqrt{fc'})$ as stated in SNI 2847:2013 to test its relevance to this quality concrete. The results showed that the flexural strength increased with the age of the concrete, with the largest difference between compressive strength and flexural strength at 1.3%. These findings support a deeper understanding of the performance of concrete at a given age and the relevance of the standard formula for 30 MPa quality concrete.

Keywords: *Flexural strength, Compressive strength, Compressive test, Flexural test*

1. PRELIMINARY

Innovation in construction continues to grow, especially in the infrastructure sector, with concrete remaining the main widely used material. Concrete has various advantages, such as fire resistance, high compressive strength, long durability, and flexibility in forming according to design. Concrete mixtures consist of cement, aggregate, water, and additives to improve their quality, with proper design to ensure optimal compressive strength.

Concrete is also used as a rigid pavement in Indonesia because of its durability and low maintenance costs. In the construction of civil buildings, concrete must be able to withstand various forces, such as pressure and bending due to wind, earthquake, or vehicle loads. Therefore, the concrete structure must be stable and safe, meeting the specified strength standards.

Laboratory testing is needed to ensure the quality of concrete, including inspection of aggregates, mixtures, and compressive strength and flexure tests at certain ages. The purpose of this study is to determine the compressive strength value of 30 MPa quality concrete and to examine the flexural strength value using the formula fs = 0.62 $\sqrt{Fc}$, so as to obtain a comprehensive understanding of the performance of fc' 30 MPa concrete.

Classification of Concrete Based on Compressive Strength

Concrete is a construction material that has high compressive strength, which is measured at the age of 28 days after the mixing process. According to SNI 2847:2013, concrete is a mixture of portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additives (admixture). Over time, the concrete will harden and reach a planned strength (f′c) Based on its compressive strength, concrete is grouped into three categories: low-quality concrete (compressive strength less than 20 MPa), medium-quality concrete (compressive strength between 21–40 MPa), and high-quality concrete (compressive strength above 41 MPa).

Low-quality concrete is used for simple construction that does not bear large loads. Medium quality concrete, which is widely used in general structural elements such as beams and columns, offers adequate strength with cost efficiency. High-quality concrete, which requires strict quality control and is made with a lower cement water factor, is used for structures that require superior performance, such as skyscrapers and bridges. High-quality concrete is also able to achieve significant initial strength with optimal maintenance. (Suryani et al., 2018)

The compressive strength of concrete refers to the magnitude of the load per unit area that can cause the concrete to crumble when subjected to a certain compressive force generated by the pressure testing machine. Compressive strength is the most important property in determining the quality of concrete compared to other properties. The compressive strength of concrete is affected by the ratio between cement, coarse and fine aggregates, water, and a mixture of other materials (Dady et al., 2015).

Concreate Making Materials

a. Portland Cement
   Portland cement is a non-plastic material that is widely used in building construction and has been approved for a wide range of construction applications. This cement is easy to find in many material sales places in various regions (Fathonah et al., 2022).
b. Aggregate
   Aggregates are particles made up of crushed stone, gravel, sand, or other minerals, either of natural origin or synthetically produced. These aggregates can be solid minerals of various sizes, ranging from large to small, or in the form of fragments formed from natural or artificial processes (Adiarto & Riani, 2024)
c. Clean Water
   Clean water is a high-quality water resource that is often used by humans for various purposes, including in the process of making concrete materials. Good water quality is very important to ensure the quality of the concrete

produced, because the water plays a role in mixing and binding concrete materials appropriately (Kornita, 2020).

d. Additional Ingredients *(Admixture)*
Admixture is an additive that has a dual function, namely reducing the amount of water needed in the mixing process to produce concrete with the desired consistency, as well as speeding up the binding and hardening process of concrete. This material is often used to improve the quality of concrete in a variety of construction applications (Rahmat et al., 2016).

Previous Research Review

Previous research on the relationship between compressive strength and bending strength of concrete has been done to explore the correlation between the two at various qualities. These studies show that these two characteristics of concrete are influenced by key factors such as the type and quality of the material (cement, fine aggregate, coarse aggregate, as well as water), as well as manufacturing procedures, including the curing process and the age of the concrete during testing.

For example, research (Pratama et al., 2023) with fc' 25 MPa quality concrete, there was a variation in the yield of bending strength compared to the standard prediction of SNI 2847:2013, especially in the formula $fs = 0.62\sqrt{fc'}$ for 28-day-old concrete. Some studies have even shown that the relationship between compressive strength and bending does not always fit the formula, so further evaluation is needed to determine if the existing formula needs to be adjusted or if there are other factors that affect the manufacture of high-quality concrete.

Previous research involved various experimental tests with variations in materials, treatment methods, and test conditions to achieve optimal results. These studies make an important contribution to the construction industry in determining the right composition of concrete to meet compressive strength and flexural requirements.

My research will use 30 MPa concrete quality, with the hope of producing higher compressive strength and bending. The main focus is to examine the relationship between these two parameters on concrete quality and to test whether the SNI formula ($fs = 0.62\sqrt{fc'}$) remains relevant or requires adjustment for a quality higher than 25 MPa.

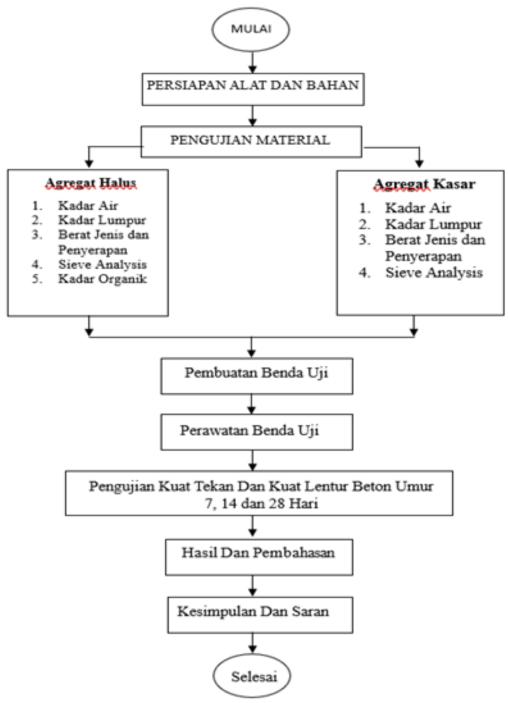
Research Objectives

a. Identifying the average compressive strength value obtained from the results of this study.
b. Identify the average value of bending strength obtained from the results of this study.
c. Determine the difference between the bending strength value and the compressive strength of the concrete obtained, based on the formula $0.62\sqrt{fc'}$.

2. RESEARCH METHODE

This research focuses on the experiment of a 30 MPa quality concrete mixture which was carried out from September to December 2023 at the Independent Laboratory of PT Adhimix RMC Indonesia, Plant Kasablanka. The research stages include designing concrete mixtures, testing on 28-day-old concrete, as well as the implementation of application design and final testing. The data used consisted of secondary and primary data. Secondary data includes journals related to the compressive strength and bending of concrete as a reference for research methods and reports, as well as literature reviews from SNI and ASTM which contain material standards, mixing processes, manufacturing and maintenance of test pieces, and testing methods. Primary data was obtained from the results of material testing at PT Adhimix RMC Indonesia's laboratory and compressive strength and flexure tests at PT Mixindo Abadi Karya Laboratory.

The experimental method was used to compare the compressive strength and bending results of f'c 30 MPa quality concrete at the age of 7, 14, and 28 days of concrete. Materials used include coarse and fine aggregate, water, fly ash from the Suralaya PLTU in Cilegon, and Portland cement type I. The equipment used is concrete laboratory standards, including ASTM filters, ovens, measuring cups, precision scales, Los Angeles machines for abrasion tests, mixers, and concrete compressive strength and bending testing equipment. Cylindrical and beam specimens with 3 samples for each test, using an additional 25% fly ash on 7, 14, and 28-day-old concrete.



Picture 1. Flow Chart Research Methods

Material Test Results

This research was conducted at PT Adhimix Precast Indonesia using high-quality materials, such as OPC Type I cement, premium sand from Bangka Belitung, and splits obtained from the Rumpin area at the Adhimix Kasablanka Plant. OPC Type I cement was chosen because it is the most commonly used type of cement in general construction that does not require special strength, while the Bangka Belitung sand used has gone through a filtration and washing process to ensure optimal quality, while the split from Rumpin was chosen because it has characteristics that are in accordance with the standard of precast concrete requirements.

Aggregate Examination Results

This examination aims to determine the distribution of grain size and percentage in fine and coarse aggregates.

a. Tools and Materials :
Scales with 0.2% accuracy, a set of strainers (size 37.5 mm to No. 200), ovens up to 110 °C, and a sieve shaking machine.

b. Fine Aggregate Testing :
Measuring organic substance content, specific gravity, absorption, fine modulus, and content weight. The results of the fine aggregate test (Table 4.1) show that all parameters meet the specifications, such as the material passing the No. 200 sieve of 2.71% (maximum 3%), the specific gravity of SSD 2.59 (min. 2.55), and the absorption of 2.03% (maximum 4%).

Table 1. Fine Aggregate Test Results

Types of Testing	Result	Tolerance	Conclusion
Material Passes Sieve No.200 (%)	2.71	3% Maximum	Eligible
Sieve Specific Gravity SSD	2.59	2.55 Minimum	Eligible
Absorption (%)	2.03	4% Maximum	Eligible
Fine Modulus	2.65	2.3 – 3.1	Eligible
Contents Weight	1.487	1.2 Maximum	Eligible
Organic Content	3	3% Maximum	Eligible

c. Coarse Aggregate Testing
Includes gradation and inspection of materials with results (Table 4.2) that meet the specified tolerances, such as material passing No. 200 sieve of 0.9%

(maximum 1%) and SSD specific gravity of 2.58 (min. 2.55).

Table 2. Coarse Aggregate Test Results

Types of Testing	Result	Tolerance	Conclusion
Material Passes Sieve No.200 (%)	0.9	1% Maximum	Eligible
Sieve Spesific Gravity SSD	2.58	2.55 Minimum	Eligible
Absorption (%)	2.47	2.5% Maximum	Eligible
Fine Modulus	7.55	5.5 – 8.5	Eligible
Contents Weight	1.382	1.2 Minimum	Eligible
Over Size	0.29	10% Maximum	Eligible

Slump Test Method

Concrete slump is a test to measure the viscosity of fresh concrete, ensuring ease of flow and compaction in the mold. The test was carried out with an Abrams cone, where the height of the concrete was measured after the cone was lifted, providing a slump value that indicated the workability of the concrete.

a. Test Equipment : The slump test was carried out using a metal cone that has a bottom diameter of 203 mm, an upper diameter of 102 mm, amd height of 305 mm. In addition, a stuffing stick, metal plate, spoon, and measuring bar are also needed to measure the height of the slump.
b. Testing Procedure: The testing process begins by filling the metal cone with fresh concrete in three layers. Each layer of concrete is compacted by piercing it 25 times using a compacting stick. Once the cone is fully filled, the tool is carefully lifted, and the spilled concrete will indicate the height of the slump. Slump is measured by calculating the difference between the height of the mold and the height of the concrete that collapses after the cone is lifted.

Slump Test Results

Picture 2. Casting Concrete Mix

The slump test test produced a concrete mix value of 12 ± 2 cm, with a recorded slump height of 12 cm, meeting the minimum tolerance of 10 cm and a maximum of 14 cm.

Picture 3. Concrete Slump Test

Compressive Strength Test Results

The compressive strength test of concrete with Fly Ash substitution of 25% on FC 30 concrete was carried out to evaluate the performance of this material under predetermined conditions. The concrete sample used is cylindrical with a diameter of 15 cm and a height of 30 cm, resulting in a cross-sectional area of 176.71 cm^2. The mixing and casting process was carried out on October 23, 2023, where before testing, the sample was soaked in a control bath for one day to ensure optimal treatment. After that, the sample is left for another day to allow the surface water to evaporate, which is important to obtain accurate test results.

Compressive strength tests were carried out at the Mixindo Abadi Karya Laboratory at the age of 7, 14, and 28 days. This test follows a standard procedure that aims to determine the compressive strength of concrete at the initial and late stages of the testing period. At each testing period, concrete samples are weighed to record their initial weight. This weight recording is an additional variable that can affect the compressive strength results. Next, the sample is tested using a compression testing machine to measure the maximum load (in kN) that the concrete cylinder can withstand. The results of this test will show the compressive strength in MPa. In addition, the cracking pattern that occurs in the concrete cylinder is also observed to understand the cracking behavior due to the maximum pressure applied. Observation of crack patterns is very important because it can provide information about the durability and bearing capacity of the concrete structure under load.

The following table summarizes the results of concrete compressive strength testing at each age period:

Table 3. Compressive Strength Test Calculation Results

No.	Code	Age (day)	Heavy (kg)	Burden (kN)	Compressive Strength (MPa)
1	FC 30 FA 25	7	11.68	400	22.64
2	FC 30 FA 25	7	11.67	380	21.50
3	FC 30 FA 25	7	11.63	365	20.66
4	FC 30 FA 25	14	11.73	500	28.29
5	FC 30 FA 25	14	11.83	495	28.01
6	FC 30 FA 25	14	12.01	520	29.43
7	FC 30 FA 25	28	11.72	590	33.39
8	FC 30 FA 25	28	11.74	560	31.69
9	FC 30 FA 25	28	11.78	555	31.41

Flexural Strength Test Results

Testing of flexural strength on concrete blocks measuring 15 x 15 x 45 cm was carried out at the age of 7, 14, and 28 days with 3 samples per stage. The load in kilonewtons is used to calculate the bending moment, which is then converted into bending stress in megapascals (MPa). The results were compared with the compressive strength of concrete to understand the relationship between the two mechanical properties as the concrete ages.

Picture 4. Block Sample Mold

Formula - formula Used

a. Bending Load Volume (W)

$$W = \frac{1}{6} \times 15 \times (15)^2 = \frac{1}{6} \times 15 \times 225 = 562.5$$

b. Flexural Moment (M)

$$M = \frac{1}{6} \times P \times L$$

c. Flexural Stress (σ)

$$\sigma = \frac{M}{W}$$

d. Convert to Mpa

$$f_c' = \sigma \times 0.0980665$$

e. Relationship Proving Formula f_s dan f_c'

$$\frac{f_s}{\sqrt{f_c'}} = 0.62$$

Table 4. Results of Calculation of Beam Flexural Strength Test

No.	Age (days)	Burden P (kN)	Flexural Moment M (kg.cm)	Flexural Stress σ (MPa
1	7	22.1	16,901.69	2.95
2	7	21.6	16,519.30	2.88
3	7	21.2	16,213.39	2.83
4	14	24.7	18,890.13	3.29
5	14	24.6	18,813.65	3.28
6	14	25.2	19,272.52	3.36
7	28	28.2	21,566.87	3.61
8	28	28.1	21,490.39	3.51
9	28	26.1	19,960.82	3.48

Table 5. Results of Comparison of Compressive Strength and Flexural Strength

No.	Age(day)	Compressive Strength f_c' (MPa)	Flexural Stress σ (MPa)	Deviation (%)
1	7	22.64	2.95	0.9
2	7	21.50	2.88	1.2
3	7	20.66	2.83	1.3
4	14	28.29	3.29	0.1
5	14	28.01	3.28	0.4
6	14	29.43	3.36	0.3
7	28	33.39	3.61	1.1
8	28	31.69	3.51	0.7
9	28	31.41	3.48	0.8

The results of tthe calculation show that the bending strength of concreate increases with the age of concreate. The bending stress converted to MPa has been verified using the formula $\frac{f_s}{\sqrt{f_c'}} = 0.62$

Standard Deviation Calculation of Compressive Strength and Flexural Strength

This test aims to determine the quality of concrete quality through the calculation of standard deviations. The smaller the standard deviation, the better the quality of implementation, which indicates a more uniform strength of the concrete. Testing was performed at 7, 14, and 28 days of age with 3 samples per age for compressive strength and flexural strength.

Table 6. Concrete Compressive Strength and Standard Deviation

No.	Age(day)	Average Compressive Strength (MPa)	Standard Deviation (MPa)
1	7	21.6	0.99
2	14	28.58	0.75
3	28	32.16	1.07

Table 7. Strong Concrete Bending and Standard Deviation

No.	Age(day)	Average Flexural Strength (MPa)	Standar Deviation (MPa)
1	7	2.89	0.06
2	14	3.31	0.043
3	28	3.53	0.063

Based on the calculation results, a small standard deviation was obtained, indicating good implementation quality. This indicates that the strength of concrete both in compression and bending is quite uniform, strengthening the validity of the results of the tests and research conducted.

3. CONCLUSION

Based on the results of the calculations and analysis carried out, the conclusions that can be drawn are as follows:

1. The average compressive strength of the three cylinder samples tested at 28 days of age was 32.163 MPa, with individual values of 33.39 MPa, 31.69 MPa, and 31.41 MPa, respectively.
2. The average flexural strength of the three beams tested was 3.53 MPa, with individual values of 3.61 MPa, 3.51 MPa, and 3.48 MPa, respectively.
3. The proof of the formula used in the calculation shows the number 0.62. By weighting in the form of percentages, the comparison between compressive strength and flexural strength results in the largest difference of 1.3%, which indicates the consistency and suitability of the calculation results.

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