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| RESEARCH ARTICLE

Correlation between Compressive Strength of Concrete and Flexural Strength of Concrete Using Local Aggregates

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| ABSTRACT

Compressive strength and flexural strength are two important parameters in the concrete job mix formula. Both parameters are strongly influenced by the characteristics of the constituent aggregates. This study aims to obtain the relationship between the compressive strength and flexural strength of concrete mixtures using local aggregates for construction projects around the province of South Kalimantan. The experimental mechanism was carried out by examining aggregates and designing concrete proportions using type V Portland cement with an initial setting time of 80 minutes and a final setting time of 150 minutes. Meanwhile, coarse aggregate from Katunun and fine aggregate from Barito are used in the concrete job mix formula. In this case, the results of the analysis show that there is a correlation value (K) for f'c 30 MPa and f'c 35 MPa, which are 0.84 and 0.78, respectively.

| KEYWORDS

Concrete, compressive, flexural, aggregate

| ARTICLE INFORMATION

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1. Introduction

Flexible strength testing on concrete mixtures that are often used in the design of Rigid Pavement construction. In this case, the relationship between the value of the compressive strength and the strength becomes crucial in the concrete mix. Consequently, it may be a possibility of cracks in the rigid pavement layer as a reaction to the stress distribution acting on the edges or corners of the concrete slab. The purpose of this study was to obtain a relationship between the compressive strength value and the flexural strength of the concrete mixture, as indicated by the correlation number using local aggregates. In this case, the concrete mix material in question is coarse and fine aggregates. Meanwhile, the Rigid Pavement design model using the AASHTO method (1993) was used to predict the flexural strength of concrete based on its compressive strength.

2. Literature Review

The brief picture of the flexural strength criteria of the concrete mixture has been arranged carefully in the AASHTO method (1993) for the design of Rigid Pavement construction. Furthermore, a number of studies have been conducted on the relationship between these two parameters [Hardiyatmo, 2019][Dipohosodo 1999][Fwa, 2006][DoT, 2001][McCormac, 2003]. Here, the nature of the concrete mixture is highly dependent on the characteristics of the constituent aggregates. Therefore, the characteristics of the aggregate in each region will vary depending on the process of formation of the aggregate [Suryani 2018][Handayani, 2019][Dady 2015].

3. Methodology

3.1 Material Constituents

Material constituents used in the concrete job mix formula were: (i) coarse aggregate of crushed stone from the cotton village of Tanah Laut district; (ii) fine aggregates originate from the river Barito; (iii) Portland cement type V Gresik (PPC); and (iv) clean water from Banjarmasin drinking water companies (PDAM). The aggregate examination is carried out in the Laboratory of Material and Rock Test Structure at Banjarmasin State Polytechnic, including physical property testing such as Sieve Analysis, Specific Gravity Examination, Water Content Examination, Sludge Content, Organic Content, and Fill Weight, as well as mechanical properties testing in the form of Hardness (Impact Test) or Abrasion with Los Angeles Machines. The tests were done following the Indonesian National Standard (SNI) for aggregate testing, as shown in Table 1.

Table 1. Aggregate testing method

Test Type	SNI Number
Sieve Analysis	1969-2008
Specific Gravity and Fine Aggregate Water Absorption	1970-2008
Specific Gravity and Coarse Aggregate Water Absorption	1969-2008
Abrasion with Los Angeles Machine	2417-2008
Water content examination	03-1971-2011
Sludge levels	03-4142-1996
Volume weight	03-1973-1990
Roughness (Impact Test)	03-4426-1997
Fine Aggregate Organic Content	03-2816-1992

3.2 Specimen Treatment & Procedure

The design of the concrete materials proportion refers to the SNI 03-2834-2000 through two variations of the fc' compressive strength of 30 MPa and 35 MPa. There were 15-cylinder specimens with a diameter of 150 mm and a height of 300 mm for each variation of compressive strength. Meanwhile, for flexural testing, six beam specimens measuring 150 mm x 150 mm x 600 mm were made. In this case, all specimens had been Slump Tested on the mortar before molding the specimens in order to determine the level of flexibility. Meanwhile, the measurement test used a Hydraulic Compression and Flexural Concrete Beam Testing Machine, type of PP 24-1269-C with a Console frame, Compression machine frame and Flexural beam test frame (Figure 1). Here, the treatment of the test object (curing) was carried out by immersing it for up to one day before testing.

Figure 1. Testing Machine

The compressive strength test was measured at the age of 7 days, 14 days, 21 days and 28 days. The specimen to be tested must be removed from the soaking bath the day before the test and left at room temperature for 24 hours. Parallelly, the flexural strength test was carried out at the age of 28 days and 56 days, referring to the experimental stages as shown in Figure 2. In this case, the procedure for the manufacture and maintenance of concrete test objects in the laboratory refers to SNI 2493-2011. For the moment, the slump test, compressive strength and flexural strength of concrete refer to the SNI as listed in Table 2.

Table 2. Concrete Testing Method

Test Type	SNI Number
Concrete Slump Test	1972-2008
Concrete Compressive Strength Test	1974-2008
Concrete Bending Strength Test	03-4154-1996

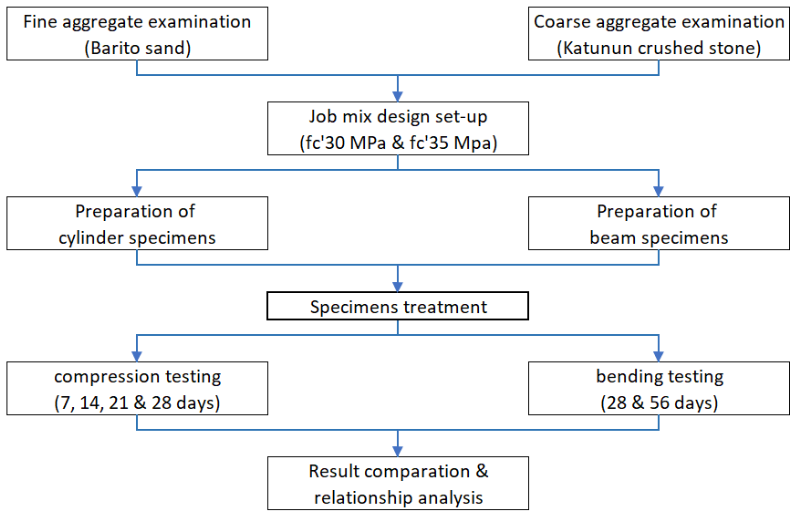

Figure 2. Experimental stages

4. Results and Discussion

4.1 Concrete Mix Design

Based on the results of the combined gradation planning, analytically, it can be determined that the proportion of fine aggregate is 38%, coarse aggregate 2-3 is 27% and coarse aggregate 1-2 is 35% with a maximum grain size of 40 mm (Figure 3). In accordance with the planning of the concrete mix according to SNI 03-2834-2000, which uses mixed ingredients: water, Gresik cement, the fine aggregate used is Barito sand, coarse aggregate crushed stone 1-2 and 2-3 originating from Katunun, the proportion of the concrete mix varies fc' 30 MPa and fc' 35 MPa, the results of mixed concrete mixtures are shown in Table 3.

Table 3. The proportion of the concrete mix

Mixed proportions	Portland cement (Kg)	Additives (Liter)	Water (Kg/Liter)	Surface Dry Saturated		
				Fine aggregate	Coarse aggregate	
				Barito sand	1 – 2	2 – 3
f'c 30 MPa						
Each m³	447.4		170	702.1	646.7	498.9
Each cylinder specimen	42.67		16.21	66.96	61.68	47.58
Each beam specimen	42.28		16.07	66.35	61.11	47.14
Overall specimens	89.45		32.38	133.31	122.79	94.72
f'c 35 MPa						
Each m³	500.0	2.5	170	682.1	628.3	484.7
Each cylinder specimen	47.69	0.24	16.21	65.06	59.92	46.22
Overall specimens	94.94	0.47	32.38	129.52	119.29	92.02

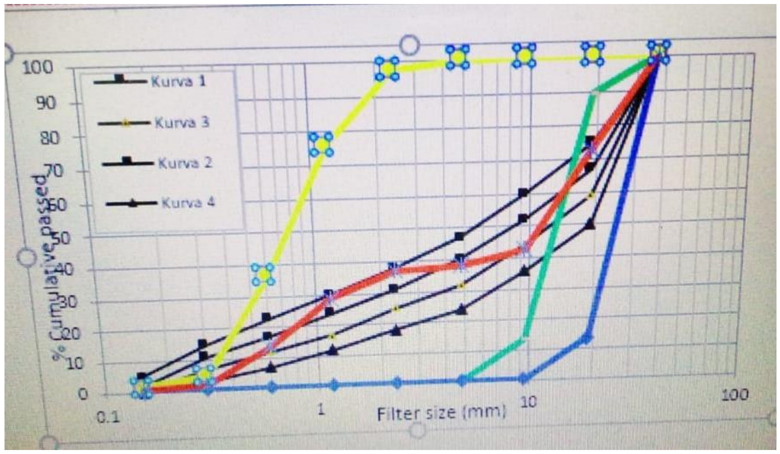

Figure 3. Combined Normal Concrete Gradation (Maximum Grain: 40 mm)

4.2 Compressive and Flexural Strength

According to SNI 1974-2011, there were 15 cylindrical specimens for testing the compressive strength of the job mix design for 1 variation of concrete quality, which was divided into 5 ages, namely 7, 14, 21, 28, and 56 days. The results of testing the compressive strength, as shown in Table 4. Variations in concrete compressive strength values are shown in Figure 4. The values for ages 7, 14, 21, 28, and 56 days are quite normal. For f'c 30 MPa category, there is a consistent increase in values between test ages, by 5.74, 0.98, 1.75 and 0.53 MPa, respectively, then 6.67 MPa, 1.13 MPa, 1.34 MPa, and 3.77 MPa, respectively for f'c 35 MPa category. There is a significant increase in amounts at the age of 14 days for both od f'c 30 MPa and 35 MPa categories; however, the curves are slightly smooth from day 28 for f'c 35 MPa category.

Table 4 Specimen’s test result for Compressive strength

Sample number	Pressure measurement on (Kg/cm2)														
	7th day			14th day			21st day			28th day			56th day		
	actual	comparison value: 28th day	corrected	actual	comparison value: 28th day	corrected	actual	comparison value: 28th day	corrected	actual	comparison value: 28th day	corrected	actual	comparison value: 28th day	corrected
f'c 30 MPa for cylinder specimens															
1a-C	23,98	34,26	23,36												
2a-C	24,78	35,39	24,93												
3a-C	25,12	35,88	25,62												
4a-C				30,21	34,33	30,06									
5a-C				30,77	34,97	31,19									
6a-C				30,09	34,20	29,83									
7a-C							29,87	31,11	28,47						
8a-C							33,26	34,65	35,30						
9a-C							30,88	32,17	30,43						
10a-C										32,13	32,13	31,20			
11a-C										33,26	33,26	33,43			
12a-C										33,88	33,88	34,69			
13a-C													33,69	31,05	33,76
14a-C													33,81	31,16	34,00
15a-C													33,37	30,75	33,12
average	24,63	35,18	24,64	30,36	34,50	30,36	31,34	32,64	31,40	33,09	33,09	33,11	33,62	30,99	33,62
f'c 35 MPa for cylinder specimens															
1b-C	29,87	42,67	30,53												
2b-C	29,07	41,54	28,92												
3b-C	28,74	41,05	28,26												
4b-C				37,45	42,55	39,06									
5b-C				36,20	41,14	36,50									
6b-C				34,05	38,70	32,30									
7b-C							38,35	39,95	39,72						
8b-C							36,09	37,59	35,17						
9b-C							36,65	38,18	36,28						
10b-C										35,86	35,86	33,51			
11b-C										38,75	38,75	39,13			
12b-C										40,5	40,5	42,75			
13b-C													38,69	35,65	35,52
14b-C													44,40	40,91	46,78
15b-C													43,33	39,92	44,55
average	29,23	41,75	29,23	35,90	40,80	35,95	37,03	38,57	37,05	38,37	38,37	38,47	42,14	38,83	42,29

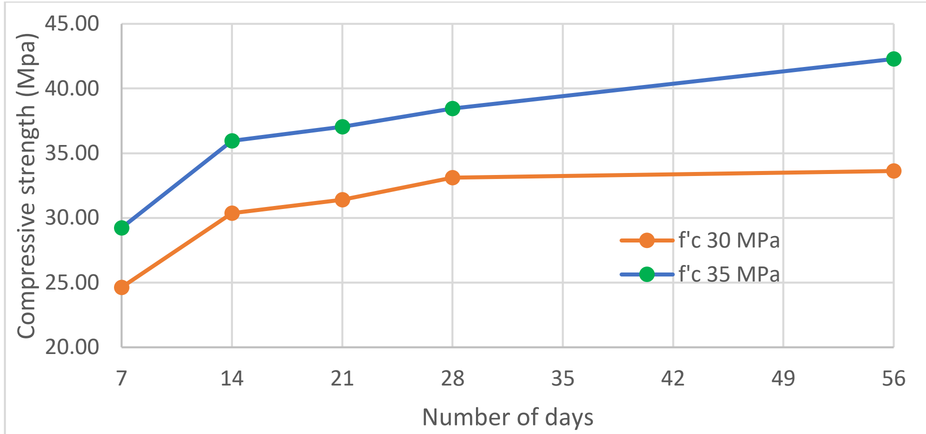

Figure 4. Graph of Average Compressive Strength Value

Meanwhile, there were 5 beam specimens for flexural strength testing in 1 variation of concrete quality on day 28 based on SNI 03-4154-1996. Variations in concrete flexural strength values are shown in Table 5 and Figure 5. Here, it can be seen that the variations that occur in the flexural strength test of concrete for f'c 30 MPa and f'c 35 MPa, respectively, produce an average flexural strength of fs of 5.44 MPa and 5.39 MPa. This has met the requirements of the General Specifications for Indonesian Highways 2010 Division 5, which at least needs the flexural strength of concrete to be f's = 4.7 MPa.

Table 5 Specimen's test result for Flexural strength

Sample number	Maximum load (Kg)	Pressure measurement on (Kg/cm2)					
		28^{th} day			56^{th} day		
		actual	comparison value: 28^{th} day	corrected	actual	comparison value: 28^{th} day	corrected
f'c 30 MPa for beam specimens							
1a-B	2164,36	4809,70	4809,70	4249,68			
2a-B	2583,27	5740,60	5740,60	6053,89			
3a-B	2687,99	5973,30	5973,30	6554,64			
4a-B	2827,63	5655,30	5186,90	5388,70			
5a-B	3002,17	6004,30	5507,10	6074,43			
6a-B	2386,82				5304,06	4809,70	4686,48
7a-B	2796,03				6213,41	5740,60	6552,51
8a-B	2864,26				6365,01	5973,30	6984,48
9a-B	2745,30				5490,64	5186,90	5231,80
10a-B	2954,00				5907,95	5507,10	5976,95
	average	5636,64	5443,52	5664,27	5856,21	5443,52	5886,44
f'c 35 MPa for beam specimens							
1b-B	2443,63	4887,30	4887,30	4426,74			
2b-B	2862,54	5725,10	5725,10	6074,52			
3b-B	2932,36	5864,70	5864,70	6374,37			
4b-B	2757,81	5515,60	5058,80	5171,14			
5b-B	2967,27	5934,50	5443,00	5986,43			
6b-B	2609,30				5218,64	4887,30	4726,85
7b-B	3114,36				6228,75	5725,10	6608,91
8b-B	3240,66				6481,30	5864,70	7044,56
9b-B	2814,22				5628,43	5058,80	5276,92
10b-B	2988,18				5976,32	5443,00	6028,62
	average	5585,44	5395,78	5606,64	5906,69	5395,78	5937,17

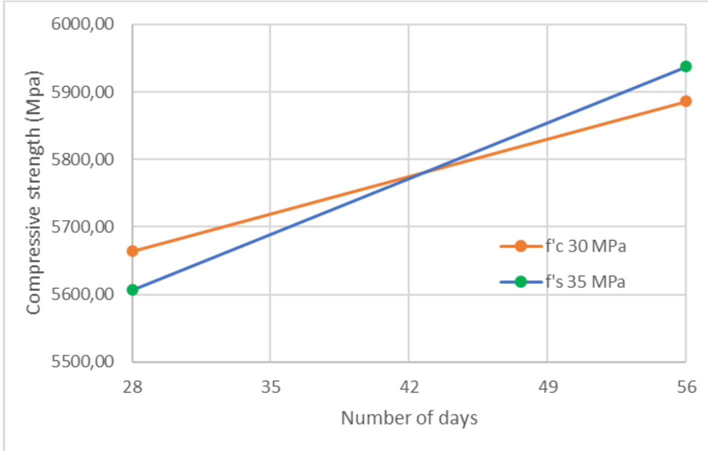

Figure 5. Graph of Average Flexural Strength Value

4.3 Statistical Parameters and Relationship Value

In these terms, the variations in the compressive strength and flexural strength of concrete in this study were considered to have followed a normal distribution based on the Gauss distribution law, with calculations of characteristic strength, average strength, and standard deviation, following equations (1), (2) and (3). In this case, there are 30 specimens for the characteristic compressive strength test and 10 specimens for the characteristic flexural strength test. Table 6 presents data on the compressive strength and tensile strength test results for concrete quality f'c 30 MPa and f'c 35 MPa.

$$\overline{x} = \frac{\sum_{i=1}^{n} xi}{n} \quad (1)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(xi - \overline{x})^2}{n-1}} \quad (2)$$

$$f'c = \overline{x} - 1{,}64.\, s \quad (3)$$

Table 6. Gaussian distribution parameters

Test Type	f'c 30 MPa	f'c 35 MPa
Compressive Strength		
average ($\overline{x}$)	33,806	39,664
Standard deviation (s)	1,610	2,175
Concrete ($f'c$)	31,166	36,098
Flexible Strength		
average ($\overline{x}$)	5,444	5,396
Standard deviation (s)	0,458	0,419
Concrete (fs)	4,700	4,708

The results of variations in compressive strength and flexural strength of concrete can be seen in Table 7. These results for the ratio f's/√f'c are in accordance with SNI 03-2847-2002 factor 0.7 for safe concrete deflection. Furthermore, it can be seen in Figure 6 that there is an inverse relationship between the compressive strength and flexural strength values following equations (4), while the correlation value (K) for f'c 30 MPa and f'c 35 MPa are 0.84 and 0.78, respectively.

$$y = -0{,}0106\, x + 1{,}166 \quad (4)$$

Table 7. Comparison of compressive and flexural strength of concrete

Characteristic design f'c (MPa)	Average compressive strength f'c (MPa)	Average Flexural Strength fs (MPa)	Comparison	
			√f'c	fs/√f'c
30	31.17	4.7	5.58	0.84
35	36.10	4.71	6.01	0.78

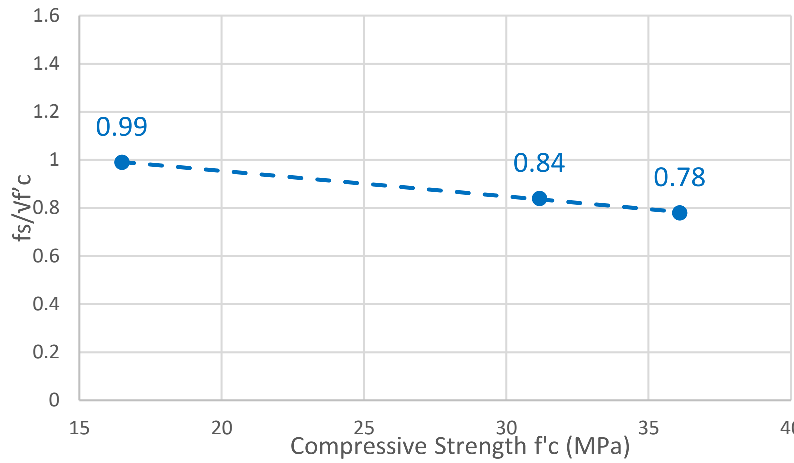

Figure 6. Graph of Comparison of Compressive Strength & Flexural Strength of Concrete

5. Conclusion

The formulation for a relationship between the compressive strength value and the flexural strength of the concrete mixture by using crushed stone from the Tanah Laut district and fine aggregates from Barito River is presented. The results of variations in concrete compressive-flexural strength for this research are in accordance with SNI 03-2847-2002 factor 0.7 for safe concrete deflection. In this case, there is an inverse relationship between compressive strength and flexural strength. Hopefully, this study can be referenced to minimize the potential for concrete slab cracking, especially for local concrete mix material use in the South Borneo area; however, further research is needed regarding variations in other local concrete mix materials to provide varied references.

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Conflicts of Interest: The authors declare no conflict of interest.

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