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Correlation of Concrete Compressive Strength Using the Hammer Test, Ultrasonic Pulse Velocity and Compressioin Test Methods

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---*ABSTRACT*---

Concrete is still widely used for structural purposes as a building material. Testing the compressive strength of concrete is the most essential aspect of determining the quality of the concrete. This research was conducted to ascertain the correlation value of the compressive strength test results of concrete conducted in the laboratory with a compression strength machine (destructive test), a hammer test, and an ultrasonic pulse velocity (non-destructive test). Cylindrical specimens with 15 MPa, 20 MPa, and 25 MPa concrete strength were subjected to testing. Based on the results of the upv test and compression test, the regression equation for the relationship between wave velocity and concrete compressive strength is determined to be y = 8.61e-00003x with a coefficient of determination of 89.88%. As a consequence of the hammer test and compression test, the regression equation y = 6.12e0.0580x with a coefficient of determination of 98.18 % was determined. On the basis of this correlation value, it is anticipated to be possible to increase the application of the non-destructive testing method if the destructive testing method cannot be performed.

Keywords: *concrete compressive strength, ultrasonic pulse velocity test, hammer test, compression test*

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I. Introduction

Concrete consists of cement, fine aggregate, coarse aggregate, and water, with or without the addition of additives [1]. Because of its many benefits, concrete is one of the most vital materials in the construction industry. In addition to being designed to support burdens, concrete is designed to withstand natural environmental influences and the effects of its use [2]. According to research, the compressive strength of cured concrete will be greater than that of uncured concrete [3]. The properties of concrete are generally influenced by the grade of the material used, the technique of manufacturing, and the treatment method used.

The compressive strength of concrete must be evaluated in order to determine the material's quality. All concrete testing methods include non-destructive,semi-destructive,and destructive procedures. Nondestructive test is a compressive strength test that does not harm the test object, whereas destructive test is a test procedure that harms the test object's entire component. Existence of situations such as readings of compressive strength on extant concrete structures will increase the use of non-destructive testing techniques.

However, these results do not reflect the actual outcomes; therefore, a correlation with the destructive test method is required. In non-destructive testing, the hammer test and ultrasonic pulse velocity (UPV) test are common methodologies. The hammer test identifies the quality of concrete using the principle of an ultrasonic wave approach to concrete, whereas the UPV test identifies the quality of concrete using the principle of an ultrasonic wave approach to concrete. This research was conducted on a variety of concrete samples with varying qualities so that more precise results could be obtained. This correlation value can be used to determine the compressive strength of concrete in the absence of a destructive test, thereby expanding the applicability of non-destructive testing.

Ultrasonic Pulse Velocity Test

Using longitudinal wave propagation in concrete, this test method is used to determine the uniformity of concrete quality, detect voids/cracks, and evaluate the effectiveness of crack repair [4]. The contact between the concrete surface and the transducer with the coupling agent will generate waves and convert them into electrical signals. The voltage produced by the receiving transducer will then determine the speed of wave propagation.

Using the UPV tool depicted in Figure 1, the following [4] methods are possible:

1. Direct transmission, in which the transmitter and receiver are positioned opposite one another so that the resulting waves are perpendicular to the transducer's surface. This method will yield the best results because the obtained transmission of wave energy is the largest and most equitably dispersed..
2. Semi-direct transmission, in which the two transducers are affixed on opposing sides of the test object and do not face one another.
3. Indirect or surface transmission, meaning that both transducers are parallel to the same side. If only one side of the concrete is accessible, this method is utilized. This technique yields less-than-optimal results due to the fact that the signal received represents only a portion of the tested surface.

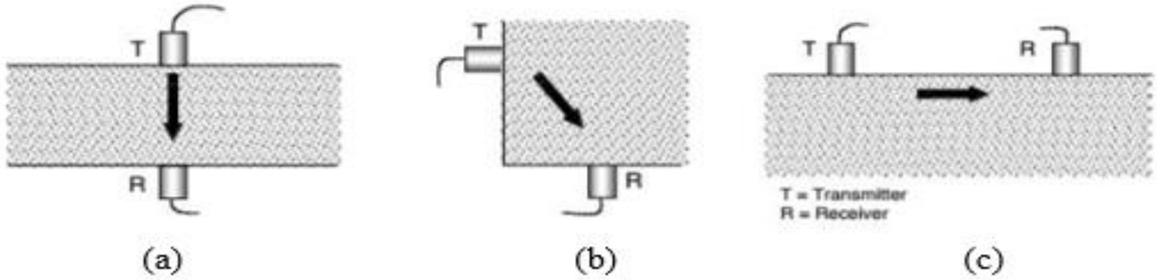


Figure 1. Configuration for UPV Tests (a) Direct Method (b) Semi-direct Method (c) Indirect Method
Source: V.M Malhotra & N.J Carino, 2004

Hammer Test

This method estimates the compressive strength of concrete based on its surface hardness. The working principle is to apply a collision impact to the surface of the concrete, which will produce reflections. Stability or rigidity of the test object affects the results of the anvil test [5]. The anvil test is conducted as described below [6].

1. Hold the instrument with the tip of the mallet perpendicular to the concrete's surface.
2. Press the instrument's handle gently against the specimen's surface until the rebounding hammer contacts the hammer's head.
3. Press the handle on the tool's side to secure the position of the mallet head.
4. Read and make a note of the bounce numbers. At a minimum distance of 25 mm, take 10 point readings in each test area.

Compression Test

This method of testing is regarded as having the utmost degree of dependability. The principle is to subject the test object to a progressive compressive load until it's completely destroyed. Using the following equation [7], the compressive strength of concrete can be determined:

$$\text{Compressive Stre } (\text{fc}') = \frac{P}{A} \qquad 1$$

Where:
fc' = compressive strength of concrete expressed in MPa,
P = axial compressive force expressed in Newtons,
A = cross-sectional area of the specimen expressed in mm^2.

II. Research Method

This research is conducted through laboratory experiments. The research flowchart is depicted in Figure 2 below. A cylindrical specimen measuring 15 cm in diameter and 30 cm in height was utilized for the test. The quality of the used concrete is 15, 20, and 25 MPa. At least five portions of each mélange must be collected as test specimens [8]. In total, 15 specimens must be created. Utilizing the anvil test, the UPV test, and the compression test, tests were conducted.

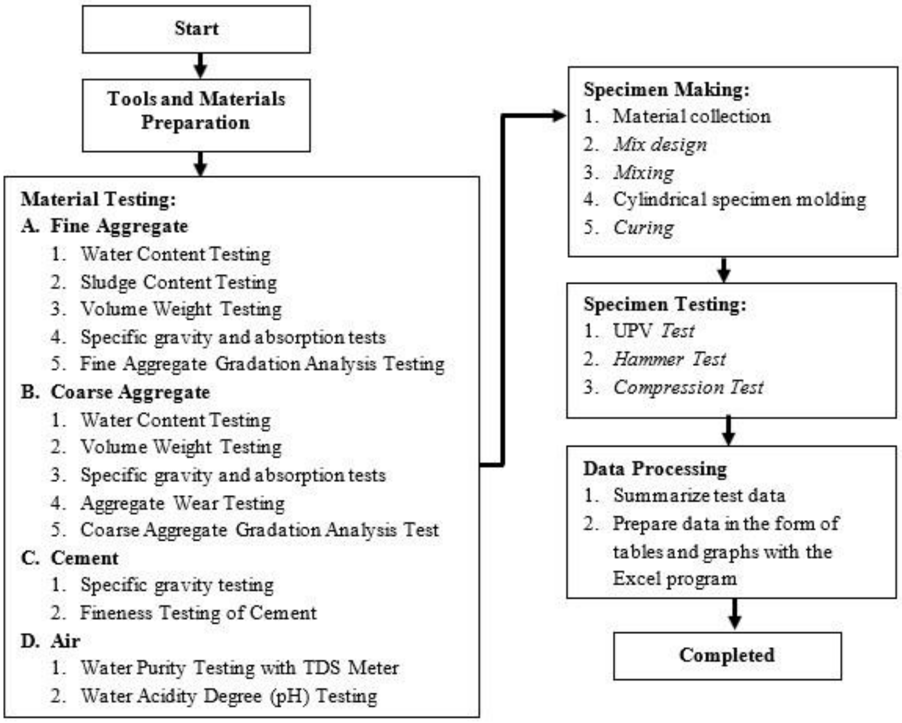


Figure 2. Research Flowchart

Method of Collecting Data

The necessary compressive strength data is acquired from the performed testing. The ultrasonic pulse velocity measurement will generate wave velocity data, which will be compared to the actual compressive strength value. The mallet test will yield data in the form of reflection numbers and compressive strength values for concrete. While the compression test will yield data in the form of the maximal load, which will be converted into concrete compressive strength, the test will also produce data in the form of the concrete's compressive strength.

Methods For Processing Data

In the form of a mathematical equation, the relationship between variables will be derived from the results of the regression analysis. This investigation employed a straightforward exponential regression analysis. Exponential regression is a non-linear regression in which the dependent variable has an exponential distribution; it is the evolution of linear regression through the use of logarithmic functions [9]. Following is the form of the equation that will be derived from the results of simple exponential regression analysis:

$$Y = ae^{bx} \qquad 2$$

Where:
Y = dependent variable
x = independent variable
a = regression constant
b = regression coefficient

Test Deviation

Calculating the test deviation is required in order to determine the percentage difference between the nondestructive test and compression test values for concrete compressive strength. The following equation expresses the deviation in percentage of concrete's compressive strength value:

$$\text{Persentase Deviasi} = \left|\frac{x_1 - x_2}{x_1}\right| \times 100\% \qquad 3$$

Where:

x1 = concrete compressive strength value from compression test results,
x2 = value of concrete compressive strength as a result of non-destructive testing.

III. RESULTS AND DISCUSSION

The constituent materials of concrete consist of cement, fine aggregate, coarse aggregate, and water, each of which will be subject to material analysis in accordance with SNI (Indonesian National Standard) standards. The aggregate inspection results are shown in Tables 1 and 2, while the cement inspection results are shown in Table 3. Figures 3 and 4 depict the results of the water examination. The water obtained a TDS of 31 mg/L and a pH close to 7, meeting the requirements. The outcomes of these tests serve as parameters for the design of concrete formulations (mix design). Table 4 outlines the composition of each variant of the mixture..

Table 1. Inspection of Fine Aggregate

Examination	Results	Unit
Water Content	1,356	%
Mud Content	0,610	%
Volume Weight	1,500	kg/L
Specific gravity (SSD)	2,605	g/mL
Absorption	1,031	%
Aggregate Gradation	Zona III	-

Table 2. Inspection of Coarse Aggregate

Examination	Results	Unit
Water Content	0,411	%
Volume Weight	1,452	kg/L
Specific gravity (SSD)	2,676	g/mL
Absorption	0,301	%
Aggregate Wearing	15,10	%
Aggregate Gradation	Zona III (40 mm)	-

Table 3. Cement Examination

Examination	Results	Unit
Specific gravity	2,98	g/mL
Fineness of Cement	83,503	%

Figure 3. Water Purity Test

Figure 4. Water pH Testing

Table 4. Composition of the Test Object Mixture

Compressive Strength (MPa)	**Needs**			
	Cement (kg)	Water (kg)	Sand (kg)	Gravel (kg)
15	16,273	10,494	57,667	63,183
20	18,398	10,500	55,787	63,183
25	21,684	10,509	52,924	63,183
Total	56,355	31,503	166,378	189,549

When the compressive strength test was conducted at the Materials and Construction Laboratory of Tanjungpura University's Department of Civil Engineering, the specimens had been in existence for 28 days. Using the direct method, UPV testing was performed, and measurement results in the form of wave propagation velocity were obtained. The hammer test was conducted with a discharge angle of 90 degrees and yielded measurement results in the form of the rebound number and compressive strength of the concrete.

Figure 5. Testing the ultrasonic pulse velocity test method

Figure 6. Testing the hammer test method

Figure 7. Testing the compression test method

Relationship between Ultrasonic Pulse Velocity Test and Compression Test

The test results were analyzed utilizing exponential regression analysis. Using Microsoft Office Excel, the subsequent graph and regression equation between the upv test and compression test are as follows:

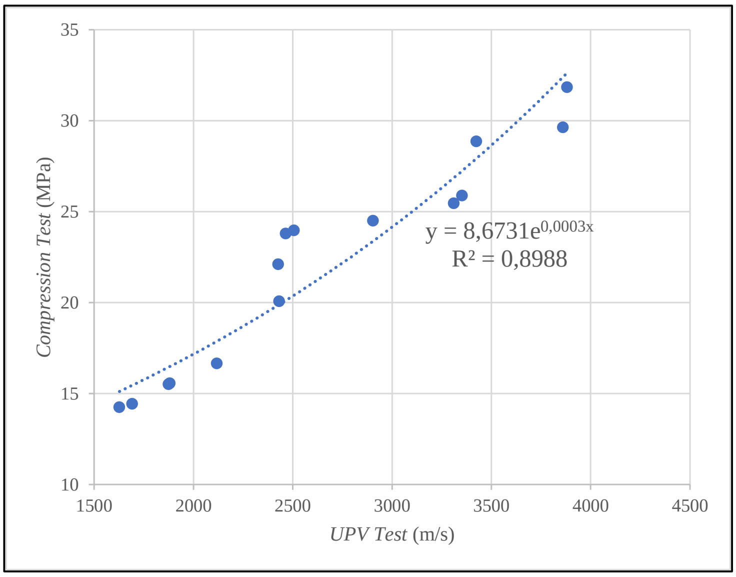


Figure8. Graph of the Relationship Between Wave Velocity and Concrete Compressive Strength

Using Microsoft Excel, the above graph's regression equation for the relationship between the UPV test and the compression test is y = 8.67e-00003x, with a coefficient of determination of 89.88%. Using data from hesa.co.id and test results, the following graph illustrates the relationship between wave velocity and concrete compressive strength.

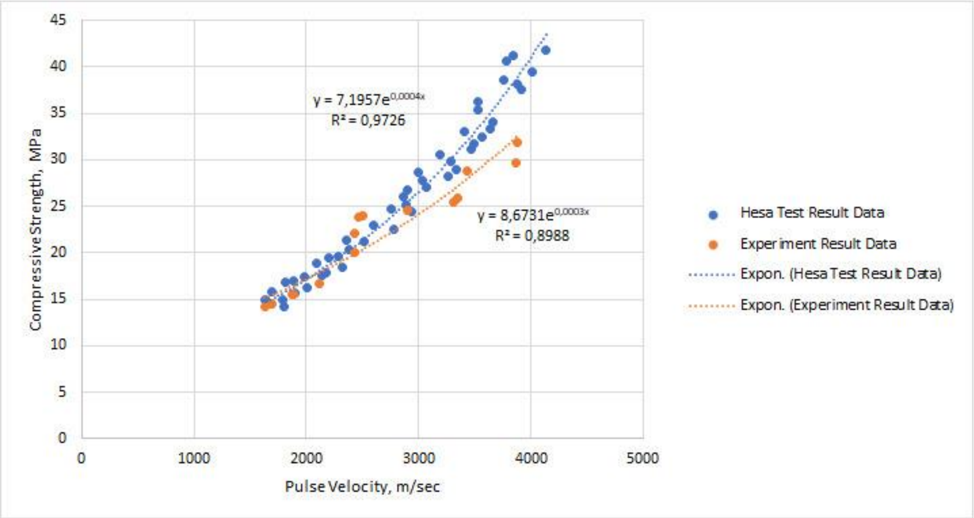


Figure 9. Graph of the Relationship Between Wave Velocity and Concrete Compressive Strength

On the basis of these graphs, it is possible to conclude that the graph and regression equation between the hesa.co.id data and the research data exhibit a minor deviation. This is due to disparities in the tools, test methodologies, and test objects employed.

Relatioship between Hammer Test and Compression Test

The test results were analyzed utilizing exponential regression analysis. Using Microsoft Office Excel, the resulting graph and regression equation between the impact test and compression test are as follows:

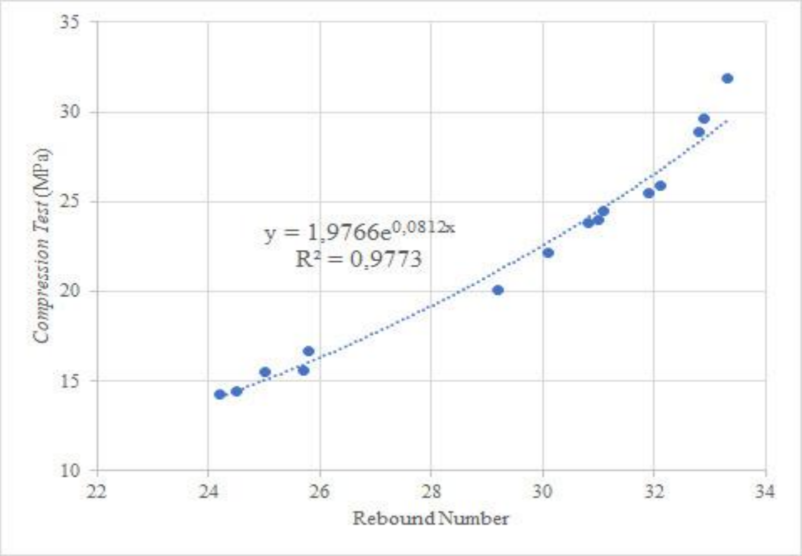


Figure 10. Graph of the Relationship Between Reflection Number and Compression Test

The relationship between the reflectance number of the Hammer test results and the compressive strength of the compression test results is depicted in the graph above. The relationship between the two experiments yielded the regression equation y = 1.98e0.0812x with a coefficient of determination of 97.73%.

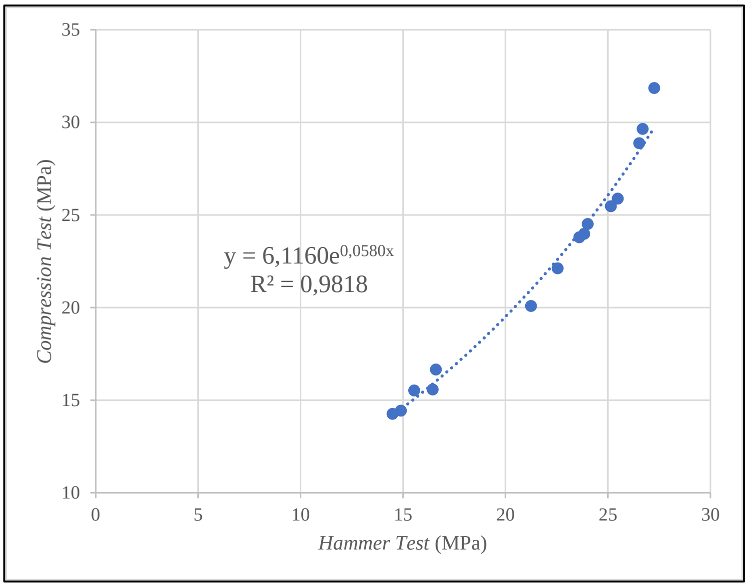
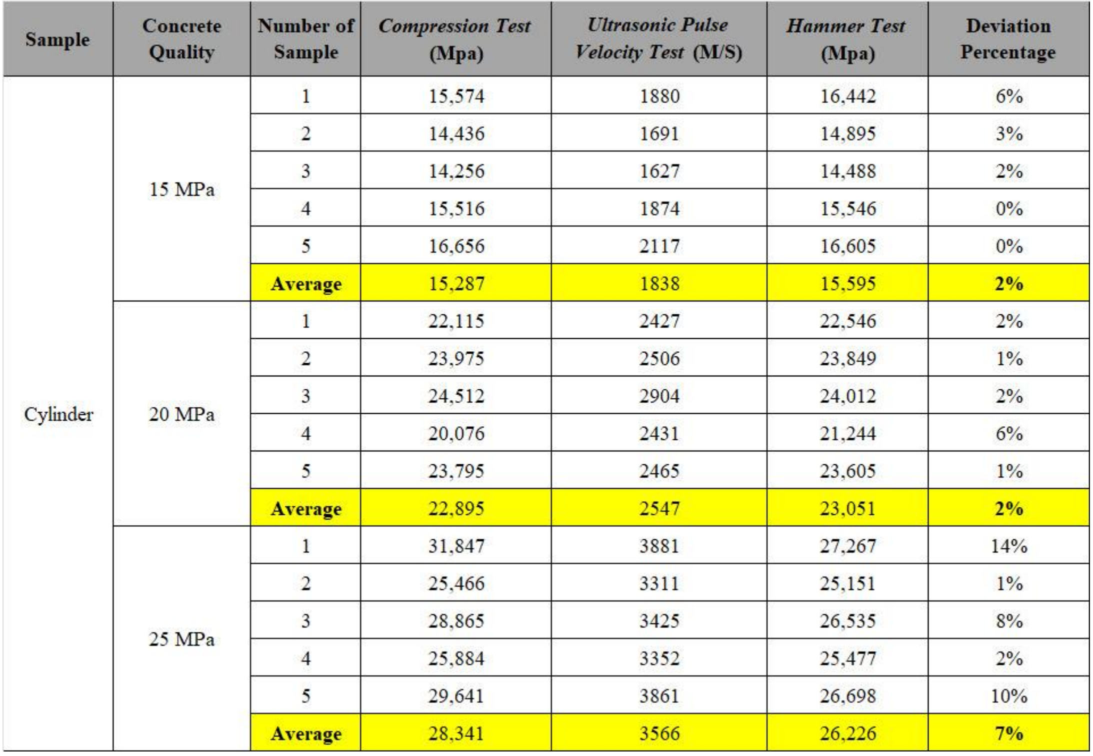


Figure 11. Graph of the Relationship Between the Hammer Test and the Compression Test

In the graph above, the relationship between the results of the hammer test and the compression test is used to determine the compressive strength. The regression equation derived from the relationship between the two exams has a coefficient of determination of 98.18 % and reads y = 6.12e-0.0580x. The percentage deviation of the hammer test value is computed relative to the compressive strength of the compression test results, which are deemed close to the actual value.

Table 5. Percentage of Test Object Deviation



Sample	Concrete Quality	Number of Sample	*Compression Test* (Mpa)	*Ultrasonic Pulse Velocity Test* (M/S)	*Hammer Test* (Mpa)	Deviation Percentage
Cylinder	15 MPa	1	15,574	1880	16,442	6%
		2	14,436	1691	14,895	3%
		3	14,256	1627	14,488	2%
		4	15,516	1874	15,546	0%
		5	16,656	2117	16,605	0%
		Average	15,287	1838	15,595	**2%**
	20 MPa	1	22,115	2427	22,546	2%
		2	23,975	2506	23,849	1%
		3	24,512	2904	24,012	2%
		4	20,076	2431	21,244	6%
		5	23,795	2465	23,605	1%
		Average	22,895	2547	23,051	**2%**
	25 MPa	1	31,847	3881	27,267	14%
		2	25,466	3311	25,151	1%
		3	28,865	3425	26,535	8%
		4	25,884	3352	25,477	2%
		5	29,641	3861	26,698	10%
		Average	28,341	3566	26,226	**7%**

According to the table, the largest average percentage deviation is 7% for the quality variation of 25 MPa, while the smallest average percentage deviation is 2% for the quality variation of 15 MPa and 20 MPa. On the basis of the results of the preceding analysis, graphs and regression equations are obtained that can be used as a guide for determining the compressive strength of concrete when the hammer test and UPV test are employed.

IV. Conclusion

The following conclusions are reached based on the findings of the research and the outcomes of the data analysis:

1. The regression equation derived from the relationship between the wave velocity from the UPV test results and the compressive strength from the compression test results is y = 8.67e-00003x with a coefficient of determination of 89.88%, according to the research.
2. The regression equation obtained from the relationship between the reflectance number of the hammer test results and the compressive strength of the compression test results is y = 1.98e0.0812x, with a coefficient of determination of 97.73%. While the relationship between compressive strength and the results of the hammer test and compression test yielded the regression equation y = 6.12e0.0580x with a coefficient of determination of 98.18 %, the relationship between compressive strength and the results of the hammer test and compression test produced the regression equation y = 6.
3. Based on the findings of this study, it can be concluded that the hammer test has a value near to the compression test, which is considered to be closest to the actual compressive strength, with a maximum deviation of 7% and a minimum deviation of 2%.

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