Vol 6 No 1 (Februari) pp. 1067 - 1079

COMPARATIVE ANALYSIS OF HAMMER TEST AND COMPRESSION TESTING MACHINE AGAINST NORMAL CONCRETE COMPRESSIVE STRENGTH TEST K300

Vicky Putra Anugrah Pratama[1], Retnowati Setioningsih[2], Marwanto[3]
[1,2,3]Teknik Sipil Institut Teknologi Nasional Yogyakarta
vickyputraanugrahpratama@gmail.com[1] , rsetioningsih@itny.ac.id[2] , marwanto@itny.ac.id[3]

ABSTRACT
The materials used in a concrete construction have a major impact on its strength. But a lot of other things also matter, like the cement-water ratio (FAS), temperature fluctuations, curing conditions, and lack of compaction. The purpose of this study is to evaluate the findings of compressive strength testing of K-300 quality concrete using two different approaches: the non-destructive Hammer Test (HT) and the destructive Compression Test Machine (CTM). Both techniques were used to examine ten cube-shaped concrete samples that were 15 cm x 15 cm x 15 cm. The two approaches differed significantly, according to the results. Compressive strength values from CTM were consistently higher than those from HT. Test specimen number 7 showed that CTM had the highest compressive strength at 507.92 kg/cm², while test specimen number 10 showed that HT had the highest compressive strength at 247kg/cm². These findings suggest that in order to get more accurate results, CTM should be used in concrete testing.

Keywords: *Compressive Strength Test, Compression Test Machine Hammer Test, K300 Concrete, Non-destructive*

1. INTRODUCTION

The strength of concrete structures is mainly influenced by the ingredients present in them. However, many other factors such as lack of compaction, curing conditions, temperature variations and water to cement ratio play a strong role. In modern concrete technology, different types of cement are used according to the oxide content (Kumavat, Chandak, & Patil, 2021). At the construction stage, structural concrete is not fully compacted, some parts of structural concrete are manually compacted and some parts are without compaction. The degree of compaction also varies with the type of structure and its location. The same phenomenon also occurs, seen from the curing conditions of structural concrete cured with water or only with air. When structural concrete is exposed to heat loads, it affects the hardness of the concrete and its micro-structural behavior.

Concrete compressive strength testing is one of the important aspects in assessing the quality of concrete in construction, because the strength of concrete directly affects the safety and durability of the structure. K300 quality concrete is generally used for structural construction, such as floors, columns and beams, which require reliable strength. In concrete testing, two methods that are often used are Compression Testing Machine and Hammer Test. Compression Testing Machine is a destructive method that directly measures the compressive strength of concrete by destroying the sample, providing more accurate results regarding the overall strength of the concrete (Indra et al., 2019). In contrast, Hammer Test is a non-destructive method that is faster and easier to do, but only measures the surface strength of the concrete, so it often does not reflect the overall internal strength of the concrete (Angga et al., 2018).

Among the mechanical properties, the structural performance of concrete has been assessed mostly through the determination of compressive strength, either by destructive or non-destructive tests (Saha & Amanat, 2021). Destructive testing involves the destruction of a cylindrical concrete specimen or through other semi-destructive tests such as extracting and testing cores from the actual structure. On the other hand, non-destructive testing techniques used to evaluate the strength of cast in concrete as well as its quality include rebound hammer test, ultrasonic pulse velocity test, electrical resistivity and others. The rebound hammer test is the simplest of these and was first developed by a Swiss engineer in the late 1940s. The rebound hammer determines the quality of concrete based on surface hardness. It is a common practice to correlate the rebound figure obtained from the hammer test and the compressive strength of concrete. This relationship is influenced by the type of concrete, the type of aggregate used in the concrete, the mix proportions, the type of hammer and the angle of impact of the hammer.

This research aims to compare the compressive strength results of K300-grade concrete using two methods: the compression test machine, a destructive method, and the hammer test, a non-destructive method. Ten cube-shaped concrete samples with dimensions of 15x15x15 cm were tested using both methods.

2. LITERATURE REVIEW

Hammer Test(HT), also known as Schmidt Hammer, has long been used to test the surface quality of concrete without damaging the sample. Angga et al. (2018), the basic principle of the Hammer Test is to reflect the energy from the spring hammer blow to the concrete surface, then measure the rebound to estimate the compressive strength of the concrete. However, Baiq (2018) stated that the results of the Hammer Test are greatly influenced by the condition of the concrete surface, such as humidity, age of the concrete and the quality of the surface workmanship.

Compression Testing Machine (CTM) is a destructive testing method that is considered the international standard in concrete compressive strength testing (Baiq, 2018). This tool measures the strength of concrete by applying gradual pressure until the concrete is damaged or broken. The Compression Testing Machine provides very accurate results because it measures the overall internal strength of the concrete. This method is recognized for its high accuracy in providing an overview of the structural capabilities of concrete.

*Hammer Test*and Compression Testing Machine have their own advantages and disadvantages. Hammer Test is easier to use and does not damage the concrete sample, but the results are less accurate than Compression Testing Machine (Indra et al., 2018). Compression Testing Machine is considered more accurate because it calculates the material strength of the entire concrete, while Hammer Test only measures surface strength.

This study was conducted with cube concrete (15 cm x 15 cm x 15 cm). The compressive strength of each test object was tested with a hammer test referring to the compression test or with a compression test machine where the compressive strength value obtained from the hammer test cannot represent the actual compressive strength value of the concrete tested using CTM. Thus, an appropriate correlation value is needed between the compressive strength value of the concrete with the hammer test and the compression test. The above is in accordance with the provisions required in ASTM C 805 / C 805M-08, where in using the hammer test method to estimate the compressive strength value of a concrete, it is important to build a correlation / relationship between the rebound number from the hammer test and the compressive strength of the cube test object tested using CTM.

3. RESEARCH METHODOLOGY

Research Location

This research was conducted at the Sabo Research and Development Center, Sopalan, Denokan, Maguwoharjo, Depok, Sleman, Yogyakarta. The research was conducted from July 2024 to October 2024 during the Independent Learning Campus Independent Internship (MBKM) activity.

Data

This study used 10 samples of K-300 quality cube concrete with a cube sample size of 15 cm x 15 cm x 15 cm. Each sample was tested using a Hammer Test and Compression Testing Machine. The Hammer Test was carried out by measuring the rebound value at five points on the sample surface. The Compression Testing Machine was carried out by gradually applying a load until the concrete broke. The series of activities in this study include sample making, testing to data analysis which are made sequentially. The stages of implementation used in this study are:

a. Material Quality Testing Stage

The material quality testing stage includes several checks, namely checking the specific gravity of coarse and fine aggregates, checking the volume weight of coarse and fine aggregates, and checking the water content of coarse and fine aggregates. In addition, checking the mud content of fine aggregates, checking the modulus of fine aggregates, and checking the gradation of coarse and fine aggregates is also carried out.

Figure 1. Material Quality Testing

b. Concrete Mix Calculation Stage

At this stage, mix design is planned with concrete quality K-300 (26.4 MPa). Cube test objects are made as many as 10 pieces.

Table 1. Concrete Mix Planning K-300 (26.4 MPa)

No	Description	Mark
1	Indicated Compressive Strength	K300 (26.4 MPa)
2	Standard Deviation	7 MPa
3	Value Added (Margin)	11.48 MPa
4	Targeted average power	37.88 MPa
5	Types of Cement	Type 1 Regular
6	Types of Coarse Aggregate	Broken Stone
7	Types of Fine Aggregate	Experience
8	Free Water Cement Factor	0.5
9	Maximum Water Cement Factor	0.6
10	Slump	80mm
11	Maximum Aggregate Size	40mm
12	Free Water Content	205 kg/m3
13	Amount of Cement	410.20 kg/m3
14	Maximum Cement Amount	-
15	Minimum Cement Quantity	325 kg/m3
16	Adjusted water cement factor	410.20 kg/m3
17	Large Composition of Fine Aggregate Grains	Medium (Grade 2)
18	Percentage of Fine Aggregate	0.41
19	Relative Specific Gravity of Coarse Aggregate	2,678
20	Relative Specific Gravity of Fine Aggregate	2,505
21	Concrete Content Weight	2302.11 kg/m3
22	Combined Aggregate Content	1686.83 kg
23	Fine Aggregate Content	691.59 kg
24	Coarse Aggregate Content	995.21 kg

Source: Research Calculations 2024

Table 2. Planning Requirements for Testing Concrete Mixture Samples K-300 (26.4 MPa)

Concrete Mix Planning Requirements 1 m3 K300 (26.4 MPa)		
1	Cement requirement 1 m3	410.20 kg

Vol 6 No 1 (Februari) pp. 1067 - 1079
© 2025Jurnal Teknik Sipil Cendekia

No	Description	Mark
2	Water requirement 1 m3	195.52 kg
3	Fine Ag Requirement 1 m3	707.42 kg
4	Coarse Ag Requirement 1 m3	988.85 kg
	Concrete Mix Planning Requirements 1 Cube Sample K-300 (26.4 MPa)	
1	Cement Requirement Sample cube 15 cm x 15 cm x 15 cm	0.66 kg
2	Water Requirement Sample 15 cm x 15 cm x 15 cm	1.3 kg
3	Fine Ag Requirement Sample Cube 15 cm x 15 cm x 15 cm	2.39 kg
4	Coarse Ag Requirement Sample Cube 15 cm x 15 cm x 15 cm	3.34 kg
	Concrete Mix Planning Requirements 10 K-300 Cube Samples (26.4 MPa)	
1	Cement Requirement Sample cube 15 x 15 x 15 cm	6.60 kg
2	Water Requirement Sample 15 x 15 cm x 15 cm	13.86 kg
3	Fine Ag Requirement Sample Cube 15 x 15 cm x 15 cm	23.91 kg
4	Coarse Ag Requirement Sample Cube 15 x 15 cm x 15 cm	33.42 kg

Source: Research Calculations 2024

c. Test Object Manufacturing Stage

The stage of making test objects for compressive strength testing and Hammer Test using cubes with dimensions of 15 cm x 15 cm x 15 cm, where 10 test objects are prepared. At this stage, all materials needed for making test objects, such as cement, water, coarse aggregate and fine aggregate, are mixed evenly to form test objects that meet the test specifications.

Figure 2. Making Test Objects

d. Concrete Curing/Soaking Stage.

After the concrete is finished from the casting stage, the concrete is left for one day, the concrete is removed from the mold after the concrete dries. After that, it is soaked in a tub filled with water which functions to keep the concrete temperature stable.

Figure 3. Concrete Damping

e. Testing of Test Objects

Testing of cube-shaped test objects to measure compressive strength was carried out at the age of 28 days using the Compression Test Machine (CTM) and the Hammer Test method. Both methods are used to evaluate the strength of concrete at its optimal age, with CTM as a destructive method and Hammer Test as a non-destructive method.

1) Testing with Hammer test

Concrete compressive strength testing with Hammer using Hammer Test based on ASTM C 805/C 805M-08.

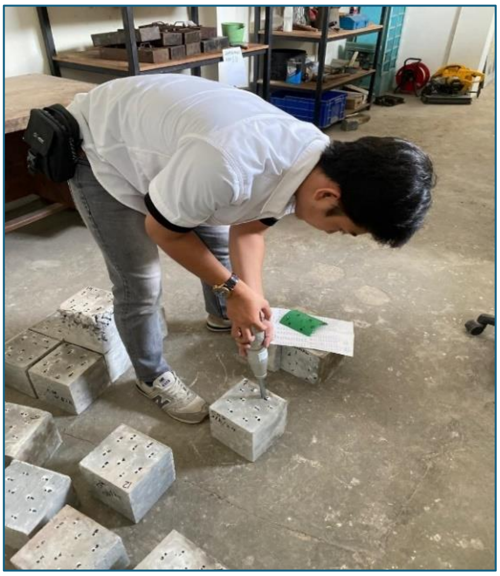

Figure 4. Hammer Test

Data is obtained from pressure to the surface of the test object that produces a spring value (R) at each test point that must be recorded and the average value calculated. Reading values that differ by more than 5 units from the average value should not be taken into account, then calculate the average of the remaining values to determine the estimated compressive strength value using the correlation curve that can be seen in the following:

Vol 6 No 1 (Februari) pp. 1067 - 1079

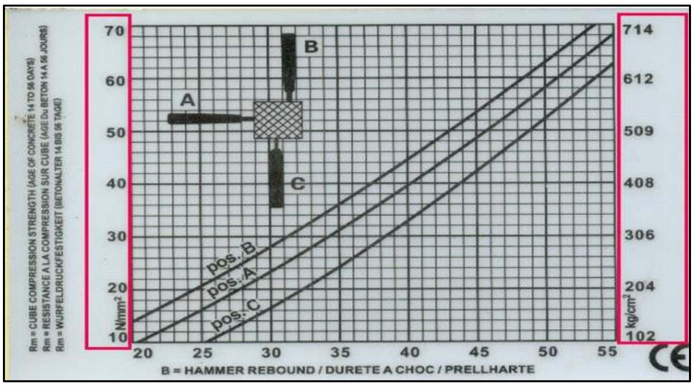

Figure 5. Correlation Curve

2) Compression Test Machine (CTM) Testing

The concrete compressive strength value is obtained through the ASTM C-192 standard testing procedure, namely the concrete compressive strength test is carried out using a CTM tool by placing a concrete cube sample and providing a graduated compressive load at a speed of 0.15 MPa/second to 0.34 MPa/second until the test object is destroyed. Before testing, the compressive surface of the test object must be flat so that the stress is evenly distributed on the cross-section of the test object.

Data were obtained through laboratory compression testing using a compression testing machine for all test objects. The results are in the form of force (P) that occurs when the test object is destroyed. Based on the compression force data and the cube cross-sectional area, the concrete compressive strength can be calculated using the formula:

$$f_c' = \frac{P}{A}$$

Where:

f_c'= Compressive strength (kg/cm2)

P = Compressive force (kg)

A = Cross-sectional area of the cube (cm2)


Figure 6. Compression Test Machine (CTM) testing

f. Correlation Test

Correlation test is a way to find out the relationship between two or more variables, using the correlation coefficient measure (Ghozali, 2015: 68). This correlation coefficient describes the closeness of the relationship between the research variables. If the significance value is less than 0.05 then it is correlated, conversely, if the significance value is more than 0.05 then it is not correlated. Pearson Correlation value 0.00 - 0.20 then there is no correlation, Pearson Correlation value 0.21 - 0.40 then the correlation is weak, Pearson Correlation value 0.41 - 0.60 then the correlation is moderate, Pearson Correlation value 0.61 - 0.80 then the correlation is strong, Pearson Correlation value 0.81 - 1.00 then the correlation is perfect.

g. Independent Sample t-test analysis.

The analysis technique used in this study is by using independent sample t-test analysis. This independent sample t-test difference test is used to determine whether two unrelated samples have different average values (Ghozali, 2015: 64). In this study, independent sample t-test analysis is used to determine whether there is a difference in the results of the normal K300 concrete compressive strength test on the Hammer Test and Compression Testing Machine.

4. ANALYSIS AND DISCUSSION

a. Hammer Compressive Strength Test

Based on the results of the compressive strength using the Hammer Test on the concrete cube test specimen samples, the results obtained can be seen in Table 3 below:

Table 3. Hammer Test Compressive Strength

Number Test Object	P	L	Surface Area	Reflection Number (r)	Compressive Strength	
	cm	cm	cm²	Σr	kg/cm²	MPa
1	15.22	15.33	233	22.44	224	21.97
2	14.09	15.18	214	20.00	204	20.01
3	15.26	15.21	232	25.00	250	24.52
4	15.25	15.18	232	20.40	204	20.01
5	15.26	15.34	234	23.50	235	23.05
6	15.08	15.32	231	20.30	203	19.91
7	14.83	15.34	227	23.20	232	22.75
8	15.15	15.12	225	21.89	218	21.38
9	15.01	15.29	230	22.44	224	21.97
10	15.42	15.19	234	24.70	247	24.22

Source: Research Calculations 2024

Based on the concrete compressive strength test data using the Hammer Test contained in the table, 10 test objects were tested with rebound number results (r) varying between 20 and 25. The compressive strength produced by the Hammer Test ranged from 203 kg/cm² to 250 kg/cm², or equivalent to 19.91 MPa to 24.52 MPa.

The test object with the highest rebound number, namely 25 (test object number 3), showed a compressive strength of 250 kg/cm² or 24.52 MPa, while the test object with the lowest rebound number, 20 (test object number 2), had a compressive strength of 204 kg/cm² or 20.01 MPa.

Table 4. Correlation of Hammer Test and Compressive Strength Values

Correlations			
		Hammer Test	Compressive Strength Value
Hammer Test	*Pearson Correlation*	1	.124
	Sig. (2-tailed)		.733
	N	10	10
Compressive Strength Value	*Pearson Correlation*	.124	1
	Sig. (2-tailed)	.733	
	N	10	10

Source: Research Calculations 2024

Based on the results of the IBM SPPS Statistic Version 25 test, it shows that the significance value is 0.733, this indicates that there is no correlation between the hammer test and the compressive strength value. When viewed from the Pearson correlation value, it shows a value of 0.124 which means there is no correlation between the hammer test and the compressive strength value.

b. Compression Test Machine Compressive Strength

Based on the results of compressive strength using the Compression Test Machine on concrete cube test specimen samples, the following results were obtained:

Table 5. Compressive Strength of Compression Test Machine

Number Test Object	Surface Area cm²	Heavy kg	Burden Maximum kgf	Compressive Strength kg/cm²	Compressive Strength MPa
1	223	7.77	100000	447.87	43.92
2	204	7.75	71000	348.16	34.14
3	222	7.79	86000	387.47	38.00
4	222	7.67	101600	458.57	44.97
5	224	8.27	104000	464.32	45.54
6	221	7.79	105200	476.09	46.69
7	217	7.77	110400	507.92	49.81
8	219	7.74	102000	465.74	45.67
9	220	7.51	91000	414.43	40.64
10	224	8.1	97000	432.56	42.42

Source: Research Calculations 2024

Based on the data in the table, the compressive strength of concrete was tested on 10 test objects with variations in cross-sectional area and maximum load. The cross-sectional area in the Compression Test Machine test was reduced because in the Hammer Test test the concrete sample experienced surface damage due to the Hammer Test impact load of up todepth± 30mm with an average surface damage of 15 mm for one test point. The highest compressive strength was achieved by test specimen number 7, with a value of 507.92 kg/cm² or 49.81 MPa, at a cross-sectional area of 217 cm² and a weight of 7.77 kg. In contrast, test specimen number 2 showed the lowest compressive strength, which was 348.16 kg/cm² or 34.14 MPa, with a cross-sectional area of 204 cm² and a weight of 7.75 kg. In general, the compressive strength ranged from 34.14 MPa to 49.81 MPa, with most test specimens showing compressive strength values above 40 MPa. Test specimens with larger areas tended to have higher compressive strengths, as seen in test specimens number 6, 7 and 8, which recorded compressive strengths above 44 MPa.

Table 6. Correlation of Compression Test Machine and Compressive Strength Values

Correlations			
		Compression Test Machine	Compressive Strength Value
Compression Test Machine	*Pearson Correlation*	1	.984
	Sig. (2-tailed)		.000
	N	10	10
Compressive Strength Value	*Pearson Correlation*	.984	1
	Sig. (2-tailed)	.000	
	N	10	10

Source: Research Calculations 2024

Based on the results of the IBM SPPS Statistic Version 25 test, it shows that the significance value is 0.000, this indicates that there is a correlation between the Compression Test Machine and the compressive strength value. When viewed from the Pearson correlation value, it shows a value of 0.984 which means that there is a strong correlation between the Compression Test Machine and the compressive strength value.

c. Comparison of Hammer Test and Compression Test Machine Results

Table 7. Independent Samples Test

		Levene's Test for Equality of Variances		*t-test for Equality of Means*						
		F	*Sig.*	*t*	*df*	*Sig. (2-tailed)*	*Mean Difference*	*Std. Error Difference*	*95% Confidence Interval of the Difference*	
									Lower	*Upper*
Results	*Equal variances assumed*	6,663	.019	8.56	18	.000	37726.1	4407.299	28466.71	46985.49
	Equal variances not assumed			8.56	9.	.000	37726.1	4407.299	27756.10	47696.10

Source: Research Calculations 2024

Vol 6 No 1 (Februari) pp. 1067 - 1079

Based on the results of the Independent sample t-test on the compressive strength of concrete using the Hammer Test and Compression Test Machine, there is a significant difference between the two methods, this is because the sig. (2-tailed) or 0.000 <0.05. The test results show that the Compression Test Machine consistently provides higher compressive strength values than the Hammer Test. The results of this test are reinforced by the results of the correlation test or the relationship between the hammer test and the compressive strength value. The results of the correlation test show that the significance value is 0.733, indicating that there is no correlation between the hammer test and the compressive strength value.

When viewed from the Pearson correlation value, it shows a value of 0.124 which means there is no correlation between the hammer test and the compressive strength value. Likewise, the results of the correlation test or relationship between the Compression Test Machine and the compressive strength value. The results of the correlation test show that the significance value is 0.000 which indicates that there is a correlation between the Compression Test Machine and the compressive strength value. When viewed from the Pearson correlation value, it shows a value of 0.984 which means there is a strong correlation between the Compression Test Machine and the compressive strength value. With this statistical test, it shows that testing using the Compression Test Machine is better than the hammer test. For example, on test object number 1, the Compression Test produces a compressive strength of 447 kg/cm², while the Hammer Test only produces 224 kg/cm². In addition, on test object number 7, which has the highest compressive strength based on the Compression Test test of 507.92 kg/cm², testing with the Hammer Test only reaches 232 kg/cm².

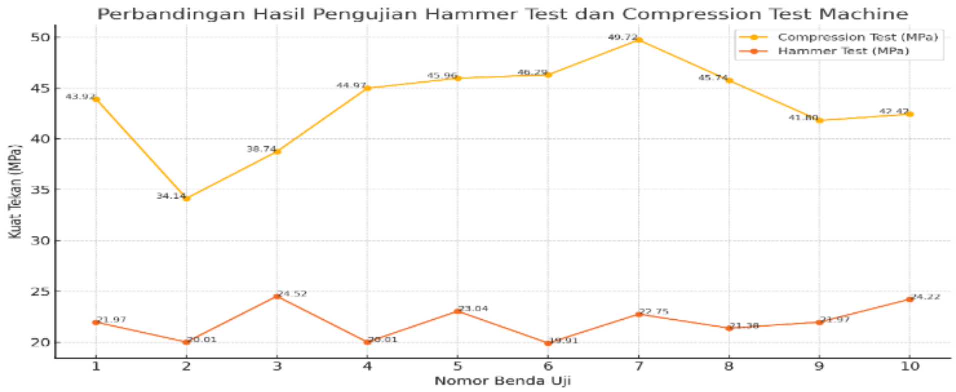

Figure 7. Comparison Chart of Hammer Test and Compression Test Machine Results

The difference in compressive strength between the Hammer Test and the Compression Test at the age of 28 days showed that the compressive strength of the Hammer Test was lower than the Compression Test with a difference of 182.23 kg/cm².

Based on the graph, it can be seen that the compressive strength values of the Compression Test results tend to be in a higher range (between 348.16 kg/cm² to 507.92 kg/cm²), while the Hammer Test produces lower values, with a range between 203 kg/cm² to 250 kg/cm². The results of this test indicate that the method using the Compression Test Machine is superior to the Hammer Test. By using the Compression Test Machine in testing the quality of concrete, researchers can measure the ability of concrete to withstand compressive loads; obtain data on the compressive strength of concrete and its mechanical properties; provide information on the weight of the integrity and safety of the material; can help manufacturing companies ensure the quality of their products. In addition, the benefits obtained by using the Compression Test Machine method are being able to determine the quality and thickness of a material (concrete) being tested, so that the data produced can be used as material evaluation data; can determine the condition of a material that is feasible and of good quality based on established standards; obtain accurate and standardized test results, so that the test results can be useful in the long term. Testing using the Hammer Test has several weaknesses, including measurement results can be influenced by external factors such as temperature, humidity and surface texture of the material which can cause the test results to be inconsistent or inaccurate; Hammer Test can only measure the strength of the material on the tested surface; Hammer Test has limitations in penetration depth which means that it can only measure the strength of the material on the tested surface and does not provide information about the strength of the material in the concrete structure. When conducting testing using the Hammer Test method, several factors must be considered that can affect the measurement results. Some of them are the size of the concrete surface being tested, the measurement position and the influence of environmental vibrations.

5. CONCLUSION AND SUGGESTIONS

Based on the results of concrete compressive strength testing using the Hammer Test and Compression Test Machine:

a. It was found that the two methods produced significant differences in compressive strength measurements. The Compression Test Machine consistently provided higher compressive strength values than the Hammer Test. Compression Test, as a destructive method, is able to measure the overall strength of concrete more accurately. Conversely, the Hammer Test, which is a non-destructive method, tends to measure the surface strength of concrete, so the results are lower
b. For example, test object number 1 shows a significant difference, with a compressive strength result of 447.87 kg/cm² from the Compression Test and only 224 kg/cm² from the Hammer Test. Test object number 7, which has the highest compressive strength in the Compression Test of 507.92 kg/cm², in the Hammer Test only reached 232 kg/cm². The large difference between the two methods shows that the Compression Test is more effective in measuring the actual strength of concrete.
c. Overall, the Compression Test Machine produces more precise measurements to determine the overall strength of the concrete, while the Hammer Test is more suitable for initial estimation or testing of the concrete surface.
d. It is recommended to perform additional testing using other methods such as Ultrasonic Pulse Velocity (UPV), to enrich the data and obtain a more holistic measurement of the concrete condition.

BIBLIOGRAPHY

[1] Angga, Ronny & Steenie. (2018).Comparison of Compressive Strength Using Hammer Test on Reinforced Concrete Portal Test Objects and Using Compressive Strength Test Machine on Cube Test Objects. Sam Ratulangi University

[2] Anonymous. (2004). SNI 15-2049-2004 *Portland Cement. Standardization Agency*National

[3] ASTM C 805 (North American Standard). Standard Test Method for Rebound Number of Hardened Concrete. USA: ASTM International

[4] Bai, Y., et al. (2024). Rail Pad Damping Characteristics in Track Vibration Reduction Evaluated Through Hammer Tests and Theoretical Analysis. Measurement 239, 1-18

[5] Baiq. (2018). Analysis of Influence *Humidity of Test Objects on Strength Concrete Splitting Tensile Strength and Compression High Quality with Method Destructive and Non Destructive Tests (Compression Testing Machine and Hammer Test). University of Mataram*

[6] Brencich, A., et al. (2021). Compressive Strength of Solid Clay Brickwork of Masonry Bridges: Estimate Through Schmidt Hammer Tests. Construction and Building Materials 306, 1-8

[7] El-Mir, A., et al. (2023). Machine Learning Prediction of Concrete Compressive Strength Using Rebound Hammer Test. Journal of Building Engineering 64, 1-21

[8] Ghozali, I. (2015). Multivariate Analysis Application with SPSS Program. Semarang: Diponegoro University Publishing Agency

[9] Indra, Lestyowati & Gatot. (2019). Study *Concrete Compressive Strength After Burning Using Compression Test and Hammer Test. University*Tanjungpura

[10] Jozef, Z., et al. (2018). Hardness Testing of Polymer Concrete Castings by Schmidt Hammer. 2018 2nd International Conference on Nanomaterials and Biomaterials, 293-299

[11] Kazemi, M., et al. (2019). Compressive Strength Assessment of Recycled Aggregate Concrete Using Schmidt Rebound Hammer and Core Testing. Construction and Building Materials 224, 630-638

[12] Kumavat, H.R., Chandak, NR, & Patil, I.T. (2021). Factors Influencing the Performance of Rebound Hammer Used For Non-Destructive Testing of Cencrete Members: a Review. Case Studies in Construction Materials 14, 1-12

[13] Mulyono, T. (2004). Concrete Technology.Yogyakarta: Andi Publisher

[14] Saha, AS, & Amanat, KM (2021). Rebound Hammer Test to Predict in-Situ Strength of Concrete Using Recycled Concrete Aggregates, Brick Chips and Stone Chips. Construction and Building Materials 268, 1-15

[15] Wang, M., & Wan, W. (2019). A New Emperical Formula For Evaluating Uniaxial Compressive Strength Using The Schmidt Hammer Test. International Journal of Rock Mechanies and Mining Sciences 123, 1-11

[16] Xu, X., et al. (2024). Experimental and Numerical Study of Drop Hammer Test on Honeycomb Sandwich Panel Resistant to Rock Burst in Coal Mine Roadway. Structures 65, 1-17