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The Behavior of Non-Destructive Test for Different Grade of Concrete

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Abstract: Rebound hammer tests are generally preferred as a non-destructive testing method as compared to destructive testing methods such as compression tests. In this study, a general series of rebound hammer tests and destructive tests were carried on in a heavy concrete laboratory. A set of concrete cubes measuring 100 x 100 x 100 mm were cast and subjected to water curing for 7, 14 and 28 days to obtain the cube strength and rebound number. Three grades of concrete, namely M20, M25 and M30 were used in this experiment. At 28 days, the minimum target strength should be 30 MPa. The rebound hammer tests were conducted before the compression tests. The data obtained for each test was evaluated and tabulated in the findings of this study. It was found that the variation between predicted strength and experimental strength for the rebound hammer test was 0.18%. This indicates that the rebound hammer test is able to predict strength with acceptable accuracy.

Keywords: Rebound hammer, non-destructive test, prediction strength, compression test

1. Introduction

Concrete is a composite material which consists of cement, fine aggregate (as known as sand), coarse aggregate (gravel or granite) and water accordance to the prescribe mixes cement ratio [1]. The standard for formation of concrete obey to standard and JKR Standard Specifications for Building Works 2005.

It is the crucial key materials and unreplaceable for construction since it has a high compressive strength and withstand enormous loading and without failure. When all the mixture of concrete was blended, the cement and water will bind each other material to form a bond. This bond gained strength and stronger when cement and water have fully bind with others, the strength are known as compressive strength of the concrete. Ultimately, the harden mixture formed fresh concrete and ready to use. Most concrete was poured with reinforcing materials such as steel embedded to provide tensile strength yielding reinforced concrete since concrete has high compressive strength but weak in tensile strength. Concrete gave a huge contribution on civilization which widely used to build bridges, drainage, high-rise building, dam and so on. The advantages of the concrete are high compressive strength, economical, resistance to corrosion and weathering effect, high durable and so on. A concrete grade obtained by compressive strength of concrete after 28 days curing process [2]. The concrete grade of the concrete depends on the ratio of the mixture.

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The compressive strength of a concrete structure is considered as the most valuable information. It is defined as the maximum capacity of compressive load which concrete can bear before fracture and reduction in size [3]-[5]. There are two methods which can be used to determine the strength of concrete structures, namely destructive tests and non-destructive tests. Destructive tests are capable of determining the compressive strength of concrete accurately and effectively but at the same time they affect the durability and lifespan of concrete [4], [5]

Meanwhile, non-destructive test methods are defined as the inspection, testing, or evaluation of materials, components or assemblies without destroying the serviceability of parts or the system [6]-[9]. The important to test concrete structures after the concrete has solidified is to determine whether the structure is in the desire condition and suitable for its purpose without interrupt the properties. There were quite a number of parameters that determined by non-destructive test such as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. At the same time, non-destructive test also used for maintenance work on existing building structure such as detect voids, cracking and delamination.

Some others uses for non-destructive testing which consists of quality control of pre-cast component, such as column, slab, beam, investigate the workmanship involved in mixing, casting, compacting and curing process of harden concrete, determination of cracks, voids, honeycombing, leakage and similar defects within a concrete structure, determining the position, quantity or condition of reinforcement, increased the reliability of destructive tests, figured out the suspected failure of concrete resulted from such factors as overloading, fatigue, external or internal chemical attack or change, fire, explosion, environmental effects, estimation for durability of the concrete, monitoring long term changes in concrete properties and ageing management of concrete structure.

The rebound hammer test, also known as the surface hardness test, is able to estimate and predict concrete strength, regardless of concrete structure. It is one of the most useful and convenient techniques for evaluating the condition of concrete structures. It was invented in 1948 by a Swiss engineer called Ernst Schmidt [10]. Readings are required several times to ensure the accuracy of the rebound hammer test. The compressive strength of concrete can also be obtained through this method. Concrete with higher strength and stiffness will absorb less energy and yields a higher rebound value [11]. Therefore, this test was selected to be used in this research to determine the compressive strength of concrete samples.

2. Materials and Methods

2.1 Preparation of materials

Ordinary Portland cement (OPC), aggregate, sand (fine aggregate) and tap water were required for production of concrete. According to JKR Standard Specification for Building Works [12], the nominal maximum size for aggregate is 20 mm where 5 mm is the nominal maximum size for sand. Therefore, sieve pans measuring 5 mm and 20 mm were required to obtain the desired size for aggregate and sand. In order to prepare materials of the desired size, sand was initially poured from the top of the 5mm sieve pan. Sand particles measuring less than or equal to 5 mm which passed through the sieve pan were then collected. The same applied to aggregates measuring lesser than or equal to 20 mm which were collected for casting purposes [13].

Fig. 1 shows the Ordinary Portland cement collected from the heavy concrete lab whereas Fig. 2 and Fig. 3 show the aggregate and sand after being sieved. Concrete mixing is a process where Ordinary Portland cement (OPC), aggregate, sand (fine aggregate) and water are mixed uniformly and allowed to harden to become concrete. Concrete grades M20, M25 and M30 were used in this research. According to JKR 20800 Standard Specification for Building Works [12], the concrete mixes of grade M20, M25 and M30 require a cement, sand and aggregate ratios of 1:2:4, 1:1.5 and 1:1:2, respectively. Fig. 4 to Fig. 6 shows the process from mixing, molding and compression test for concrete cubes which was done according to the standard BS EN 12390-3 (2019) [14]. Meanwhile, Table 1 shows the amount of raw materials used for different grades of concrete.

2.1 Rebound hammer

According to the JKR Standard, the rebound hammer test is done in accordance with the BS-1881-Part2-202-86 Standard [15]. A flat ground location was recommended to ensure no inclination angle for the rebound hammer equipment. The concrete test specimens were allowed to dry for 1 hour before the rebound hammer test began. This is because concrete test specimens with moisture on the surface are easily dented and this affects the rebound number. In Fig. 5, it can be observed that the plunger of the rebound hammer was pressed on the surface centre of concrete cube specimens and held vertically downwards at a right angle to the concrete specimens. The mechanical spring in the rebound hammer rebounds once it is fully pressed onto the concrete specimens. The penetrations of the rebound hammer were repeated on different surface centres of the concrete cube specimens to increase accuracy and to obtain an average rebound number. The rebound number was obtained from the graduated scale which is one of the important parameters [16], [17]. Fig. 7 and Fig. 8 shows the application of a rebound hammer on the surface at the centre of a concrete cube.

Fig. 1 - OPC

Fig. 2 - Aggregate

Fig. 3 - Sand (fine aggregate)

Table 1 - Raw materials used

Concrete grade	Amount of Raw Materials Required (kg)		
	Cement	Sand	Aggregate
M20	4.14	8.29	16.6
M25	5.27	7.90	15.8
M30	7.25	7.25	14.5

Fig. 4 - Mixing all materials

Fig. 5 - Casting and labelling the samples

Fig. 6 - Compression test

Fig. 7 - Rebound Hammer

Fig. 8 - Application on concrete surface

3. Results and Discussion

The rebound hammer test was carried out on grade M20, M25, M30 concrete test specimens with curing periods of 7, 14, 21, and 28 days. As a result, a list of rebound numbers was obtained and a calibration curve was developed with actual compressive strength with similar properties, respectively. From the calibration curve, predicted compressive strength can be obtained by substituting the rebound number in the calibration curve equation. The predicted compressive strength was then compared with the actual compressive strength of concrete obtained through the compression test.

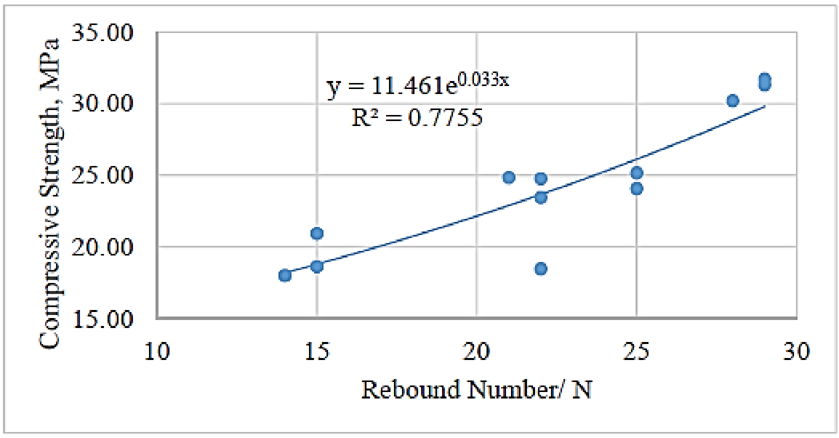

Fig. 9 - The calibration curve of the compressive strength of M20 test vs rebound number

The rebound number was obtained through the penetration of the rebound hammer on 3 different surfaces of the concrete test specimens. The range of rebound numbers for grade M20 test specimens after a curing period of 28 days was 15 to 28 N. Fig. 9 showed a positive gradient as it increased with compressive strength and curing period. In addition, a calibration equation, y=11.461e0.033x and R^2=77.55% were obtained where y represents compressive strength and x represents rebound number. The coefficient of determination, R^2, is the indicator of how well the data fits the curve. This means that the higher the coefficient of determination, the more accurate the predicted strength. In order to obtain the predicted strength for the rebound hammer test, the rebound number was used to substitute x in the equation and the outcome y showed the predicted strength for the rebound number. All the predicted compressive strength values by rebound number for M20 concrete test specimens ranged between 18.8 MPa to 29.84 MPa. According to Standard Specification for Building Work (JKR Standard 2005), the strength of concrete achieved for grade M20 is 14 MPa in the first 7 days and 20 MPa after 28 days. An approximate difference of 9.5 MPa was found compared to the standards mentioned.

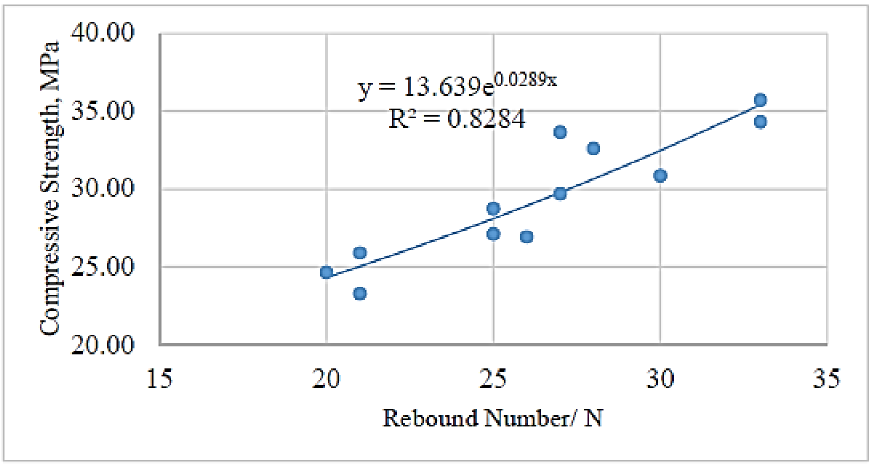

Fig. 10 - The calibration curve of compressive strength of M25 test vs rebound number

From Fig. 10, a calibration equation, y=13.639e0.0289x with R^2=82.84 were obtained. The range of rebound numbers for grade M25 test specimens in 28 days was 20 to 33N which is slightly higher than that of M20 test specimens. This is due to the higher strength observed in grade M25 test specimens. Also, Fig. 7 showed a positive gradient as it increased with compressive strength and curing period. The range of predicted strength for M25 specimens was 24.30 MPa to 35.40 MPa which is a lower difference of 3MPa compared to M20 specimens. According to Standard Specification for Building Work (JKR Standard 2005), the strength of grade M25 concrete obtained is 17 MPa in the first 7 days and 25 MPa in 28 days. An approximate difference of 8.2 MPa was found compared to the standard mentioned.

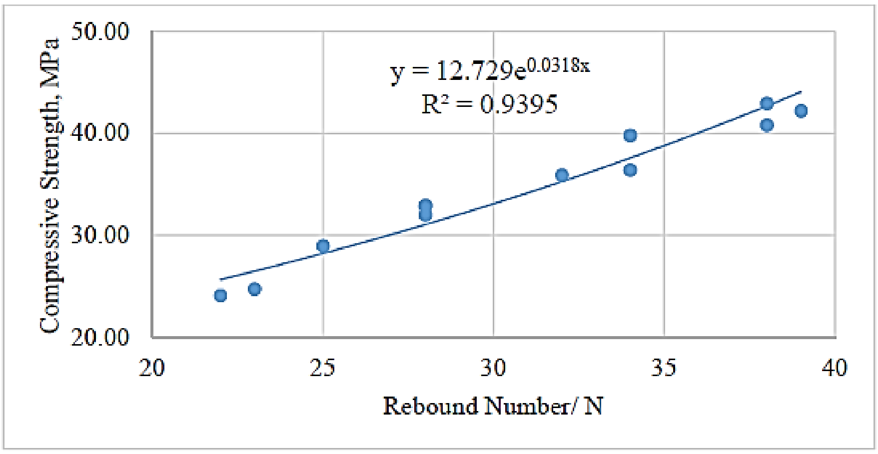

Fig. 11 - The calibration curve of compressive strength of M30 test vs rebound number

From Fig. 11, a calibration equation, y=12.729e0.0318x with R^2=93.95% were obtained. The range of rebound numbers for grade M30 test specimens in 28 days was 22 to 40 N which is the highest among M20 and M25 test specimens. This is due to higher strength observed in grade M25 test specimens. Fig. 8 also shows a positive gradient where compressive strength increases along with curing period. The range of predicted strength for M30 was 25.62 MPa to 44.0 MPa which is a difference of 9 MPa and 12 MPa compared to M25 specimens and M20 specimens, respectively. According to Standard Specification for Building Work (JKR Standard 2005), the strength of concrete for grade M30 obtained in the first 7 days is 20 MPa and 30 MPa in 28 days. An approximate difference of 12.0 MPa was found compared to the standard mentioned.

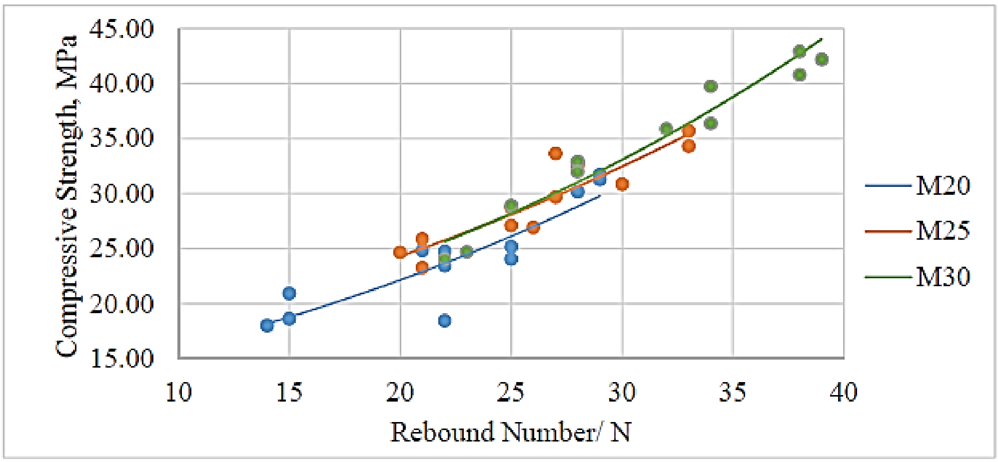

Fig. 12 - Combined calibration curve of compressive strength of M20, M25 and M30 test against rebound number

The range of rebound numbers for grade M30 test specimens in 28 days was 22 to 40 N which is the highest among M20 and M25 test specimens. From Fig.12, grade M30 concrete test specimens obtained the highest overall rebound number which is 44.0 N. This is because the concrete mix design M30 has a ratio of 1:1:2 which has a higher quantity of coarse aggregate compared to M20 and M25. The higher quantity of coarse aggregate results in higher strength and a higher rebound number. The 3- calibration curve showed a positive gradient with a range of 77.35% to 93.95% for the coefficient of determination. The coefficient of determination, R^2, is an indicator of how well the data fits the curve. This means that the higher the coefficient of determination, the more accurate the predicted strength.

Among the 3-calibration curve equations, M30 achieved an R^2 value of 93.95% which is nearest to 1. This indicates that M30 has the most accurate predicted strength compared to M20 and M25.

From Table 2.0, it can be observed that M20 cured for 7 days has a lower average compressive strength of 19.19 MPa among other specimens and obtained an average strength of 31.08 MPa after 28 days of curing. According to Standard Specification for Building Work (JKR Standard 2005), the strength of concrete grade M20 obtained is 14 MPa in the first 7 days and 20 MPa in 28 days. An approximate difference of 11.0 MPa was found compared to the standard mentioned after 28 days of curing. For grade M25 specimens, the average compressive strength obtained after 7 days of curing was 24.62 MPa which approached the average compressive strength of M30 in the same curing period. The difference in average compressive strength between M25 and M30 specimens for the same curing period was only 0.3 MPa.

According to Standard Specification for Building Work (JKR Standard 2005), the strength of grade M25 concrete obtained in the first 7 days is 17 MPa and 25 MPa in 28 days. An approximate difference of 8.25 MPa was found compared to the standard mentioned on 28 days of curing which has the least difference compared to M20 and M30 specimens. The M30 concrete test specimens at 28 days obtained the highest average compressive strength among all, which is 41.97 MPa. However, an obvious difference in compressive strength of 11.97 MPa was observed between the experimental results and standard stated.

Table 2 - Average compressive strength obtained by test specimens of different grades within 4 different curing periods

Concrete grade of test specimens	Average compressive strength (MPa)			
	7 days	14 days	21 days	28 days
M20	19.19	22.69	24.24	31.08
M25	24.62	27.60	30.87	33.25
M30	25.91	32.58	37.34	41.97

Table 3 - Variation and average between experimental strength and predicted strength of concrete (28 days)

Grade of test specimens	Experimental Strength (MPa)	Predicted Strength (MPa)	Overall variation between experimental strength and predicted strength by rebound hammer test (%)
M20	31.08	29.52	1.56
M25	33.25	33.52	-0.27
M30	41.97	43.08	-1.11
Average			**0.18**

From Table 3, the overall variation between experimental strength and predicted strength via rebound hammer test at 28 days ranges between -0.27 % to 1.56 %, with an average value of 0.18 %. The relationship between non-destructive and non-destructive concrete tests can be developed through correlation between the actual compressive strength of concrete test specimens with different concrete mix designs in different curing periods. The actual compressive strength can be obtained from the compression test whereas the predicted strength can be obtained from the rebound hammer test. From the results, the non-destructive test shows a margin of less than 1 % error compared to the destructive test. Thus, non-destructive tests are recommended to predict the strength of concrete as it does not affect the arrangement of inner particles and the life span of concrete.

4. Conclusion

From the results, it is evident that the higher the rebound number, the higher the predicted strength. It was found that the rebound hammer test has a higher coefficient of determination, which indicates a greater accuracy of predicted strength. Moreover, the rebound hammer test requires no electrical current and can easily be conducted at any location. Thus, the rebound hammer test is recommended as a non-destructive test for concrete specimens. The difference between predicted strength for non-destructive tests and experimental strength was found to be less than 1 %. This proves that the rebound hammer test is reliable for the prediction of strength due to its good correlation with actual strength. It is also a faster, cheaper and more convenient alternative to destructive tests.

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