A Preliminary Study on Testing the Compressive Strength of Sleeve Grouting Material Based on the Leeb Hardness Method

Chenchen Ding1,*, Sheng Gu2, Yiwei Yuan1 and Yulong Wu2
1 Jiangsu University of Science and Technology, Jiangsu, China
2 Kunshan Construct Engineering Quality Testing Center, Kunshan, Suzhou, China

*Corresponding author e-mail: 13285136815@163.com

Abstract: In order to explore the feasibility of testing the compressive strength of sleeve grouting material in practical engineering by the Leeb hardness method, we made 12 groups of standard specimens out of grouting material, analyze the correlation between surface hardness and compressive strength of grouting material by experiments. Experimental results show that, The surface hardness test results of the sleeve grouting material are in accordance with the normal distribution. With the guarantee rate of 95%, eliminating the extreme value in the hardness test data can significantly reduce the discreteness of the data and improve the accuracy of the calculation results. There is a significant correlation between surface hardness and compressive strength of grouting material, the best fitting effect is by using exponential function, the average relative error is 7.45%, the relative standard deviation is 8.61% and the correlation coefficient is 0.864. The experimental results provide a reference for testing the compressive strength of sleeve grouting material by the Leeb hardness method.

1. Introduction
In recent years, as China's economic development has entered a new normal, the traditional construction industry has been unable to meet the needs of sustainable economic development. Under this background, the Ministry of Housing and Rural-Urban Development actively promotes the transformation of the development mode of the construction industry, that is, from the past "extensive scale development" to "quality intensive development". The construction industry no longer pursues high economic growth, but high quality development with green and environmental protection. Prefabricated building has become an important means for structural adjustment and transformation of the construction industry due to its advantages of fast construction speed and high quality of prefabricated components, has been our government's policy support and vigorously promoted[1].

Precast concrete structure is one of the most widely used prefabricated building forms, compared with the traditional cast-in-place structure, it has the advantages of less environmental pollution, short construction period, low construction cost and high industrialization level. Precast concrete structure guarantees the overall stress of the structure through the reliable connection between prefabricated components and between prefabricated components and post-cast concrete. Therefore, the connection technology is the key link of the precast concrete structure and an important guarantee for the building to meet the design requirements of equivalent to a cast-in-place structure. At present, the vertical
reinforcement connection of precast concrete structure mainly adopts the grout sleeve splicing of rebars\textsuperscript{[2]}. Grout sleeve splicing of rebars is to insert the ribbed bar that needs to be connected into the metal sleeve to achieve "opposite joint". High-strength and early-strength grouting material with micro-expansion characteristics was injected into the sleeve, the grouting material forms a large positive stress between the inner wall of the sleeve and the steel bar, it produces greater friction on the rough surface of ribbed bar. Thus the axial force of the reinforcement can be transmitted. According to the above principle, grouting material is the main medium for load transfer of different components\textsuperscript{[3]}. Therefore, the compressive strength of grouting materials needs to meet the design requirements to ensure the bearing capacity and seismic performance of the structure.

In China, "Cementitious grout for coupler of rebar splicing" JG/T408-2013 has clearly stipulated the compressive strength of sleeve grouting material: Under standard curing conditions, 1d compressive strength should not be less than 35MPa, 3d compressive strength should not be less than 60MPa and 28d compressive strength should not be less than 85MPa\textsuperscript{[4]}. However, due to the short development time of prefabricated building in China, the construction personnel lack of training and low efficiency of construction quality management. In practice, the phenomenon of increasing water-cement ratio or misuse of bed mortar material often appears. This will lead to low compressive strength of grouting material and seriously affect the safety of the structure. Therefore, it is of great significance to research and develop a method for testing the compressive strength of sleeve grouting material.

2. Select the Test Method

After completion of grouting, the grouting material is wrapped in metal sleeve and concrete layer by layer. The testing instrument can only contact with the grouting material in the sleeve from the grouting port and outlet port on the surface of the components. Considering that the grouting material in grouting channel, sleeve and outlet channel has set and hardened into a whole. It is feasible to characterize the grouting material in the sleeve by the grouting material in the channel\textsuperscript{[5]}

At present, there are surface hardness method, pull-out method and core drilling method to test the entity compressive strength of materials in the construction site. Pull-out and core drilling are destructive methods, they will cause some damage to the structure, generally not preferential use. Surface hardness method as a non-destructive testing method, it uses the correlation between the surface hardness and the strength of materials to realize the purpose of strength testing, such as concrete rebound method, mortar penetration resistance method and metal Leeb hardness method,etc\textsuperscript{[6-8]}. Sleeve grouting material is a cement-based cementitious material, its aggregate size is less than 2mm, and it has good uniformity. There may be some correlation between its surface hardness and compressive strength\textsuperscript{[9-11]}. The compressive strength of sleeve grouting material can be tested by surface hardness method, and the compressive strength of the grouting material in the sleeve is inferred by using the surface hardness of the grouting material at the grouting port and the outlet port.

The diameter of grouting port and outlet port is only about 20mm, the concrete rebound method is not suitable for testing the compressive strength of sleeve grouting material due to the large size and too strong impact force of the impact bar. The strength testing range of mortar penetration method is 5MPa–30MPa, which cannot meet the high strength test requirements of grouting materials and is not applicable either. The impact device of the Leeb hardness method is small in size and can adapt to the narrow testing environment of the grouting port and outlet port, impact energy moderate, will not damage the grouting material in the sleeve, the testing range is wide, which can meet the high strength testing requirements of sleeve grouting material. Therefore, this paper considers testing the compressive strength of sleeve grouting material by the Leeb hardness method. A batch of test pieces were designed and made to study the correlation between the surface hardness and compressive strength of the sleeve grouting material.
3. Experimental Research

3.1. Test instrument and material

3.1.1. Introduction to test instrument

Leeb hardness tester is an instrument used to test the surface hardness of steel. It is based on the elastic impact principle. The impact body with certain mass (tungsten carbide or diamond ball head) is used to impact the sample surface under the action of fixed impact force. The impact velocity and rebound velocity at 1mm from the impact body to the sample surface were measured. The ratio of the rebound velocity and rebound velocity of the impact body represented the Leeb hardness value. The formula is as follows:

\[ HL = 1000 \times \left( \frac{v_b}{v_A} \right) \]  

In the formula, \( HL \) is the hardness value on the Richter scale, \( v_A \) is the impact velocity of the impator, \( v_b \) is the rebounding velocity of the impator.

This paper adopts Beijing Time Chuanghe Leeb hardness tester, and the model is TIME5350. As shown in Fig. 1. The technical parameters of the Leeb hardness tester are shown in Table 1.

![Figure 1. Leeb hardness tester.](image)

Table 1. Technical parameters of Leeb hardness tester.

| Range of values/HL | Testing angle/Degree | Working voltage/V | Indication error/HL | Boundary dimension/mm |
|-------------------|----------------------|-------------------|---------------------|-----------------------|
| 170~960           | 0~360                | 3.7               | ±12                 | 148.6×81.8×22.5       |

3.1.2. The experimental materials

Grouting material used in this experiment is Beijing SIDA JIANMAO CGMJM-VI. The material performance parameters are shown in Table 2.

Table 2. Performance parameters of grouting material

| Initial mobility/mm | Liquidity at 60 minutes/mm | Vertical expansion rate difference between 24h and 3h/% | Water permeability/% | Chlorine ion content/% | Compressive strength/MPa |
|---------------------|----------------------------|-----------------------------------------------------|---------------------|-----------------------|-------------------------|
| ≥300                | ≥260                       | 0.02~0.5                                            | 0                   | ≤0.03                 | ≥35                     |
|                     |                            |                                                     |                     |                       | ≥60                     |
|                     |                            |                                                     |                     |                       | ≥85                     |
3.2. The experimental scheme

3.2.1. The experimental design
A batch of standard specimens (40mm×40mm×160mm) out of grouting material were made in this experiment. The surface hardness of the standard specimens was tested by the Leeb hardness tester at 3, 7 and 28 days. The compressive strength was tested at the same age and the correlation between the surface hardness and compressive strength of standard specimens was analyzed.

3.2.2. Specimen making
Take a certain amount of grouting material and water according to the design mix ratio (12%). Planetary stirrer is used for stirring according to standard procedures. After stirring, let stand for 2 minutes, then pour the paste into the steel mold to form. Remove the adhesive sand bonded around the mold and put it into the fog chamber for curing. The temperature of the fog chamber is controlled at 20°C ± 1°C and the relative humidity is not lower than 90%. After curing for 20h~24h in the fog chamber, the specimens were taken out of the mold, marked and placed vertically in the water for curing, and the temperature of the curing water was controlled at 20°C ± 1°C. After the standard specimens reach the corresponding age, they are taken out of the curing pool, the sediments on the surface of the specimens are wiped off, and the specimens are left in a natural state for 6 hours to dry the moisture on the surface of the specimens. The steel mold is shown in Fig.2. The standard specimens is shown in Fig. 3. The number of specimens is shown in Table 3.

![Fig.2. Steel mold. Fig. 3. Standard specimens.](image)

| Test age | Group number | Total |
|----------|--------------|-------|
| 3d       | 4 groups     |       |
| 7d       | 4 groups     | 12 groups |
| 28d      | 4 groups     |       |

Table 3. Number of specimens.

Note: "1 group" in the table represents 3 standard specimens.

3.2.3. Surface hardness test
The specimen whose surface water has been completely dried was placed vertically on the pressure test machine, and then fixed by slowly applying pressure. The pressure was maintained at 2kN~3kN. D type impact device of TIME5350 was used to test the surface hardness of specimens. 8 Leeb hardness values were collected from the left and right sides of each standard specimen, and a total of 16 Richter hardness values were collected. When testing, pay attention to avoid pores on the surface of the specimen, and the distance between any two points should not be less than 3mm, and the distance between any point and the edge of the specimen should not be less than 5mm. The surface hardness test is shown in Fig. 4.

3.2.4. Compressive strength test
The specimen which has been tested for surface hardness has been subjected to bending and compression tests successively. After each piece of standard specimen is broken, two sections A and B are formed. The compressive strength of two sections A and B is obtained by compressive test of two sections A and B respectively. The compressive strength test is shown in Fig. 5.
3.3. Test results and analysis

3.3.1. Analysis of surface hardness test results

1) Normality test

Before analyzing the correlation between surface hardness and compressive strength of grouting material standard specimens, the results of surface hardness test of grouting material standard specimens were analyzed statistically. The mean value, standard deviation and coefficient of variation of each group of data are shown in Table 4.

Mathematical statistics and probability distribution fitting were performed on the Leeb hardness values of the 12 groups of grouting material standard specimens. The fitting results of some specimens are shown in Fig. 6. In order to verify whether the hardness values of the standard samples conform to the normal distribution, Chi-square test was carried out for each group of test results. Take the significance level \( \alpha = 0.05 \), the null hypothesis \( H_0 \), "The probability distribution of each group of Leeb hardness values follows a normal distribution." Test statistics for each group of data are calculated according to formula 2.

\[
\chi^2 = \sum_{i=1}^{k} \frac{(f_i - np_i)^2}{np_i}
\]

In the formula, \( f_i \) is the number of samples falling within each range of hardness, \( p_i \) is the estimated value of probability calculated according to the assumed normal distribution, \( n \) is the total number of samples of each group of data, taking 48, \( k \) is the number of ranges, DOF \( d_f = k - 3 \).

The rejection region of the hypothesis test is \( \chi^2 \geq \chi^2_{\alpha}(d_f) \). The test statistics calculated according to formula 2 are shown in Table 5. As can be seen from Table 5, the Chi-square test results of each group of specimens are outside the rejection region. Therefore, the null hypothesis was accepted at the significance level of 0.05, that is, the surface hardness test results of grouting material standard specimens were normally distributed. It is feasible to test the surface hardness of grouting material with Leeb hardness tester.
Table 5. The calculation results of test statistics

| Specimen number | $\chi^2$ | $d_f$ | $\chi^2_{a}(d_f)$ | Specimen number | $\chi^2$ | $d_f$ | $\chi^2_{a}(d_f)$ |
|-----------------|----------|-------|---------------------|-----------------|----------|-------|---------------------|
| SDJM-3d-1       | 1.61     | 3     | 7.81               | SDJM-7d-3       | 3.93     | 3     | 7.81               |
| SDJM-3d-2       | 8.39     | 4     | 9.49               | SDJM-7d-4       | 3.55     | 3     | 7.81               |
| SDJM-3d-3       | 4.59     | 3     | 7.81               | SDJM-28d-1      | 7.39     | 3     | 7.81               |
| SDJM-3d-4       | 6.89     | 3     | 7.81               | SDJM-28d-2      | 4.42     | 4     | 9.49               |
| SDJM-7d-1       | 3.72     | 3     | 7.81               | SDJM-28d-3      | 2.45     | 3     | 7.81               |
| SDJM-7d-2       | 3.22     | 4     | 9.49               |                  |          |       |                    |

Fig. 6. Histogram of surface hardness test results.

2) Data processing method

Above, it has been verified that the Leeb hardness values of the grouting material standard specimens follow a normal distribution. According to rule $2\sigma$

$$p(-2\sigma \leq x - \mu \leq 2\sigma) > 0.95$$  \(3\)

In the formula, $p$, $\mu$, and $\sigma$ represent probability, mathematical expectation and standard deviation respectively. From formula 3, it can be seen that the hardness value greater than $\mu + 2\sigma$ or less than $\mu - 2\sigma$ is a small probability event. Therefore, in order to determine the true hardness value of standard specimens accurately, the values of such anomalies can be eliminated. After calculation and analysis, a data processing method was developed to eliminate 3 maximum and 3 minimum values of 16 Leeb hardness values of a single standard specimen and take the arithmetic mean value of the remaining 10 values as the representative value of Leeb hardness. Take the Leeb hardness value of 12 standard specimen at 3 days as an example. The comparison results before and after data processing are shown in Table 6.

Table 6. Before and after data processing

| Specimen number | Mean      | Absolute deviation | Standard deviation | CV   | Mean      | Absolute deviation | Standard deviation | CV   |
|-----------------|-----------|--------------------|--------------------|------|-----------|--------------------|--------------------|------|
| SDJM-3d-11      | 340.3     | -65.3–39.7         | 29.47              | 0.09 | 344.9     | -7.9–13.1          | 8.44               | 0.02 |
| SDJM-3d-12      | 319.8     | -37.8–28.2         | 18.18              | 0.06 | 321.3     | -9.3–7.7           | 5.77               | 0.02 |
| SDJM-3d-13      | 339.8     | -51.8–14.2         | 17.6               | 0.05 | 344       | -13–9             | 8.89               | 0.03 |
| SDJM-3d-21      | 332.7     | -145.7–37.3        | 40.53              | 0.12 | 340.9     | -8.9–9.1          | 6.69               | 0.02 |
| SDJM-3d-22      | 351.9     | -23.9–38.1         | 19.71              | 0.06 | 349.3     | -12.3–27.7        | 11.49              | 0.03 |
| SDJM-3d-23      | 351.9     | -66.1–34.9         | 24.16              | 0.07 | 346.9     | -13.9–15.1        | 10.32              | 0.03 |
| SDJM-3d-31      | 352.6     | -91.6–54.4         | 34.29              | 0.1  | 354.1     | -20.1–19.9        | 13.14              | 0.04 |
| SDJM-3d-32      | 362.4     | -33.4–30.6         | 17.15              | 0.05 | 362.1     | -15.1–14.9        | 9.95               | 0.03 |
| SDJM-3d-33      | 352.8     | -36.8–43.2         | 18.98              | 0.05 | 350.7     | -9.7–9.3          | 7.15               | 0.02 |
| SDJM-3d-41      | 377       | -29–37             | 21.48              | 0.06 | 374.8     | -14.8–27.2        | 12.78              | 0.03 |
| SDJM-3d-42      | 376.1     | -29.1–31.9         | 21.09              | 0.06 | 376       | -18–16           | 15.06              | 0.04 |
| SDJM-3d-43      | 374.3     | -33.3–28.7         | 24.96              | 0.07 | 376       | -32–21           | 21.13              | 0.06 |
From Table 6, it can be seen that the Leeb hardness values of 12 groups of standard specimens are significantly different before and after processing. Before processing, the maximum deviation between the extreme value of hardness and the mean value in a group of data is up to -145.7HL. After processing, the deviation range was controlled within ±25HL, and the standard deviation and coefficient of variation also decreased significantly. It shows that the value of the Leeb hardness obtained by this method can reflect the true value of the standard specimen.

3.3.2. Analysis of compressive strength test results

Statistical results of compressive strength of grouting material standard specimens are shown in Table 7. It can be seen from Table 7 that the minimum value of variation coefficient of compressive strength of standard specimens is 0.03, the maximum value is 0.11, and the average value is 0.07. The variation coefficient of compressive strength of standard specimens was statistically analyzed, as shown in Fig. 7. It can be seen from the interval distribution that the variation coefficient is mainly distributed in 0.04–0.06, accounting for 41.67% of the total.

| Specimen number | Maximum /MPa | Minimum /MPa | Mean /MPa | Standard deviation | CV   |
|-----------------|--------------|--------------|-----------|--------------------|------|
| SDJM-3d-1       | 65.2         | 57.5         | 62.0      | 3.29               | 0.05 |
| SDJM-3d-2       | 80.3         | 72.9         | 75.3      | 2.60               | 0.03 |
| SDJM-3d-3       | 86.3         | 73.8         | 78.1      | 4.49               | 0.06 |
| SDJM-3d-4       | 79.0         | 69.3         | 74.3      | 4.23               | 0.06 |
| SDJM-7d-1       | 91.6         | 67.8         | 81.0      | 8.08               | 0.10 |
| SDJM-7d-2       | 91.4         | 69.2         | 80.0      | 8.96               | 0.11 |
| SDJM-7d-3       | 76.4         | 58.9         | 69.5      | 6.77               | 0.10 |
| SDJM-7d-4       | 87.8         | 67.3         | 79.6      | 7.95               | 0.10 |
| SDJM-28d-1      | 110.1        | 99.7         | 105.1     | 4.63               | 0.04 |
| SDJM-28d-2      | 106.2        | 88.6         | 97.7      | 6.51               | 0.07 |
| SDJM-28d-3      | 98.1         | 83.3         | 91.3      | 5.43               | 0.06 |
| SDJM-28d-4      | 113.1        | 99.5         | 107.4     | 5.93               | 0.06 |

Fig.7. Variation coefficient histogram.

3.4. Correlation analysis of surface hardness and compressive strength

In order to study the correlation between surface hardness and compressive strength of grouting material standard specimen. The representative value of Leeb hardness of a single standard specimen
corresponds to the mean value of compressive strength of the two sections A and B. One standard specimen identifies one coordinate point, the abscissa is the Leeb hardness value and the ordinate is the compressive strength value. The scatterplot is drawn and the regression fitting is carried out by linear, binomial, exponential and power functions respectively. The fitting results are shown in Table 8, and the scatter diagram and the fitting curve are shown in Fig.8. The mean relative error of the four equations is less than 8% and the relative standard deviation is less than 10%. It shows that the surface hardness of grouting material has a strong correlation with the compressive strength. The mean relative error and relative standard deviation fitted by exponential function are the smallest.

**Table 8. Fitting results**

| Equation          | From                | Fitting results                | Mean relative error $\delta$ | Relative standard deviation $e_r$ | correlation coefficient $r$ |
|-------------------|---------------------|--------------------------------|------------------------------|----------------------------------|-----------------------------|
| Linear            | $y = ax$            | $y = 0.209x$                   | 7.71%                        | 9.27%                            | 0.862                       |
| Binomial          | $y = ax^2 + bx$     | $y = 0.0001x^2 - 0.1675x$       | 7.48%                        | 8.73%                            | 0.875                       |
| Exponential       | $y = a e^{bx}$      | $y = 25.589 e^{0.0029x}$        | 7.45%                        | 8.61%                            | 0.864                       |
| Power functions   | $y = ax^b$          | $y = 0.069 x^{1.184}$           | 7.49%                        | 8.73%                            | 0.862                       |

![Fig.8. Surface hardness-Compressive strength relationship curve.](image)

**4. Conclusions**

In this paper, through experimental research, the feasibility of testing the entity compressive strength of sleeve grouting material by the Leeb hardness method is preliminarily explored, and the following conclusions are obtained.

1) The surface hardness test results of standard specimens of sleeve grouting material were analyzed by chi-square test, the results show that the surface hardness of the grouting material is normally distributed. It is feasible to test the surface hardness of grouting materials with the Leeb hardness tester.
2) In order to accurately estimate the true hardness value of the grouting material standard specimens, three maximum and three minimum values of the 16 Leeb hardness values were eliminated, and the arithmetic mean of the remaining 10 values was taken as the Leeb hardness representative value of the specimen. Through calculation and analysis, this data processing method can effectively improve the accuracy of the calculation results.

3) Under the standard curing condition, the compressive strength value of the grouting material standard specimens at 3 days is not less than 60MPa, and the compressive strength value at 28 days is not less than 85MPa, which can all meet the design requirements. The variation coefficient of compressive strength of 12 groups of standard specimens was concentrated in 0.04–0.06.

4) Linear, binomial, exponential and power functions were used to fit the Leeb hardness value and compressive strength value of 12 groups of grouting material standard specimens. Among them, the fitting effect of exponential function is the best. the average relative error is 7.45%, the relative standard deviation is 8.61% and the correlation coefficient is 0.864. The fitting results show that there is a strong correlation between surface hardness and compressive strength of grouting material.

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