Experimental Research on Mechanical Performance of Rebar Sleeve Grouting Connector

Xudong Chen\textsuperscript{1,2}, Lu Shen\textsuperscript{3}, Guodong Shi\textsuperscript{1,2}, Yuhu Wei\textsuperscript{1,2}, Yiwen Wang\textsuperscript{1,2}

\textsuperscript{1}. School of Civil Engineering, Anhui Jianzhu University, Hefei, Anhui 230601, China;
\textsuperscript{2}. National and Local Joint Engineering Laboratory of Building Health Monitoring and Disaster Prevention Technology, Anhui Jianzhu University, Hefei 230601, Anhui, China;
\textsuperscript{3}. Anhui Zhutong Prefabricated Building Research Institute Co.Ltd, Hefei, Anhui 230601, China

chenxd@ahjzu.edu.cn

\textbf{Abstract.} The rebar sleeve grouting connector is an important vertical connection component in the fabricated structure. This paper focuses on the study of the mechanical performance of the reinforcement sleeve grouting connector under unidirectional loading and high-stress cyclic loading. Through experimental analysis, the researcher studied the mechanical properties and anchoring mechanism of a total of 54 rebar sleeve grouting connectors with 2 test methods, 9 sizes, and 3 defect types under unidirectional loading and high-stress cyclic loading. The test results show that there occurred two types of failure, namely, rebar fracture and bond-slip. To be more specific, the specimens with anchorage lengths of 8.0 d and 7.0 d both encountered the result of rebar fracture, which meets the relevant regulations on the strength and deformation of the joints of the level-I connection in Technical Specification for Mechanical Connection of Steel Bars (JGJ 107-2010); and the test pieces with the anchorage length of the steel bar of 6.0 d all had the steel bond-slip failure, which does not meet the requirements of the specification.

\section{1. Introduction}
The prefabricated building refers to a building assembled on the site with prefabricated parts and components [1]. The improvement and development of the fabricated building structure system constitutes a key technical problem that urgently needs solving in China's industrialization of construction industry. The rebar sleeve grouting connector is the main vertical connector component in the fabricated structure. The strength of its mechanical performance is directly related to the safety of the vertical connector components, and then affects the sound development of the entire assembly structure.

At the end of the 1960s, Yee AA invented the grouting connection method for rebar sleeves [2]. This method is mainly to insert ribbed steel bars into the metal sleeve to realize the force transmission connection by pouring the mixture. It is widely used in engineering practice in developed countries such as in Europe and America [3-5]. At present, the domestic research on the sleeve grouting connector is based on the difference of the inner cavity of the sleeve [6-9]. The rebar sleeve grouting connector is shown in Figure 1. The experimental studied the mechanical performance of 54 rebar sleeve grouting connectors with 2 test methods, 9 sizes, and 3 types of defects under unidirectional loading and high-stress cyclic loading.
2. Test overview

2.1. Specimen design
The mechanical properties of the steel bars in the specimens are obtained by drawing tests using a universal testing machine, as shown in Table 1. The test block (40mm*40mm*160mm) of the grouting material and the rebar sleeve grouting connector was poured and cured for 7 days at the same time, and the grunting material’s property parameters were measured, as shown in Table 2.

Table 1. Rebar material properties (take the average value of 3 test pieces)

| Nominal diameter (mm) | Nominal yield strength (MPa) | Measured yield strength (MPa) | Nominal tensile strength (MPa) | Measured tensile strength (MPa) | Elastic modulus (MPa) |
|----------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------------|
| 12                   | 400                           | 461                           | 540                           | 561                           | 2.0*10^5             |
| 14                   | 400                           | 450                           | 540                           | 572                           | 2.0*10^5             |
| 16                   | 400                           | 458                           | 540                           | 585                           | 2.0*10^5             |

Table 2. Grouting material properties (take the average of 6 test blocks)

| Water-cement ratio (w/c) | Elastic modulus (MPa) | Compressive strength (MPa) | Flexural strength (MPa) |
|--------------------------|-----------------------|---------------------------|------------------------|
| 0.12                     | 3.8*10^5              | 77.3                      | 13.6                   |

In the test, the diameters of the rebar sleeve grouting connection specimens are 12mm, 14mm and 16mm, the steel bar grade is HRB400, the grouting strength grade is M80, and the sleeve’s specifications are corresponding to the size of the steel bars. The design of the specimen’s size, quantity and anchoring length is shown in Table 3.

Table 3. Parameter setting of the test piece

| Rebar diameter (mm) | Anchorage length setting | Anchorage length (mm) | Quantity (pieces) | No.         | Density or defect state |
|---------------------|--------------------------|-----------------------|-------------------|-------------|------------------------|
| 12                  | 7.0d                     | 84                    | 6                 | 12-B-1 ~ 12-B-6 | defect                |
|                     | 6.0d                     | 72                    | 6                 | 12-C-1 ~ 12-C-6 | defect                |
| 14                  | 8.0d                     | 112                   | 6                 | 14-A-1 ~ 14-A-6 | dense                 |
7.0d 98 6 14-B-1~14-B-6 defect
6.0d 84 6 14-C-1~14-C-6 defect
8.0d 128 6 16-A-1~16-A-6 dense
16 7.0d 112 6 16-B-1~16-B-6 defect
6.0d 96 6 16-C-1~16-C-6 defect

* Among the 6 specimens of number 12-A-1~12-A-6 in the above table, specimens number 1, 2, and 3 bearing the same working conditions are engaged in the uniaxial tensile test; specimen number 4, 5, 6 bearing the same working conditions are engaged in the high-stress repeated tensile test.

2.2. Test plan
The trail on the rebar sleeve grouting connector adopts both the loading of unidirectional tension and of high-stress repeated tension and compression. The loading adopts the electro-hydraulic servo universal testing machine with a full load of 1000KN, equipped with electronic extensometer and strain collector, to perform the uniaxial tension loading until the specimen is broken. The high-stress repeated tension and compression test adopts repeated and continuous loading until the specimen is broken. The yield load, ultimate load and force change process of the specimen are read through the universal testing machine of electro-hydraulic servo. The electronic extensometer measures the deformation of the specimen, and the strain collector collects the strain value of the specimen. The test device is shown in Figure 3.

![Figure 2. Diagram of test device](image)

3. Test results

3.1. Destruction mode and main mechanical performance indicators

3.1.1. Destruction mode.
Under uniaxial tension and repeated tension and compression of high stress, the specimens showed two destruction modes, namely, rebar fracture and bond-slip failure, as shown in Figure 3.
3.1.2. Mechanical performance indexes of typical specimens.

Typical specimen data such as residual deformation, yield loading, ultimate bearing capacity and destruction mode of the specimen under uniaxial tensile load are shown in Table 4.

| Specimen No. | Residue Deformation (mm) | Residual deformation standard value (mm) | Yield load (KN) | Ultimate bearing capacity (KN) | \( f_u / f_{byk} \) | \( f_u / f_{buk} \) | Destruction mode |
|--------------|--------------------------|----------------------------------------|----------------|-----------------------------|----------------|----------------|-----------------|
| 12-A-2       | 0.04                     | 0.10                                   | 52.6           | 72.5                        | 1.60           | 1.19           | Rebar fracture  |
| 12-B-2       | 0.04                     | 0.10                                   | 52.4           | 72.1                        | 1.59           | 1.18           | Rebar fracture  |
| 12-C-2       | 0.05                     | 0.10                                   | 52.0           | 63.2                        | 1.40           | 1.04           | Bond-slip       |
| 14-A-3       | 0.05                     | 0.10                                   | 76.1           | 93.4                        | 1.53           | 1.13           | Rebar fracture  |
| 14-B-3       | 0.05                     | 0.10                                   | 75.1           | 93.1                        | 1.51           | 1.12           | Rebar fracture  |
| 14-C-3       | 0.05                     | 0.10                                   | 75.2           | 83.8                        | 1.36           | 1.01           | Bond-slip       |
| 16-A-1       | 0.06                     | 0.10                                   | 89.1           | 120.2                       | 1.50           | 1.11           | Rebar fracture  |
| 16-B-1       | 0.06                     | 0.10                                   | 88.5           | 119.5                       | 1.48           | 1.10           | Rebar fracture  |

From the main test data in Table 4, it can be seen that the destruction state of the two series of specimens A and B is rebar fracture; the destruction state of the C series specimens is bond-slip; the tensile strength of the specimens is \( f_u \geq 1.25f_{byk} \); The tensile strengths of the two series of specimens A and B are both \( f_u \geq 1.10f_{buk} \); the tensile strength of the C series specimens is \( f_u \leq 1.10f_{buk} \), where \( f_u \) represents the tensile strength, \( f_{byk} \) represents the standard value of tensile strength, \( f_{buk} \) represents the standard value of yield strength; the corresponding residual deformation is all less than 0.10mm. This further shows that the force performance of the rebar sleeve grouting connector of the A and B series test pieces meets the specification requirements of the level-1 joint, while the force of the rebar sleeve grouting connector of the test pieces of C series does not meet the specification requirements.

Typical specimen data such as residual deformation, ultimate bearing capacity and destruction mode of specimens under repeated tension and compression with high stress are shown in Table 5.
### Table 5. Mechanical properties of typical specimens under high stress repeated tension and compression

| Specimen No. | Residue deformation (mm) | Residual deformation Standard value (mm) | Ultimate bearing capacity (KN) | $f_u/f_{bak}$ | Destruction mode   |
|--------------|--------------------------|------------------------------------------|-------------------------------|----------------|-------------------|
| 12-A-4       | 0.23                     | 0.30                                     | 73.5                          | 1.21           | Rebar fracture    |
| 12-B-5       | 0.23                     | 0.30                                     | 72.6                          | 1.19           | Rebar fracture    |
| 12-C-6       | 0.23                     | 0.30                                     | 62.7                          | 1.02           | Bond-slip         |
| 14-A-4       | 0.23                     | 0.30                                     | 93.1                          | 1.12           | Rebar fracture    |
| 14-B-4       | 0.21                     | 0.30                                     | 92.7                          | 1.12           | Rebar fracture    |
| 14-C-4       | 0.23                     | 0.30                                     | 82.9                          | 1.00           | Bond-slip         |
| 16-A-5       | 0.24                     | 0.30                                     | 119.5                         | 1.10           | Rebar fracture    |
| 16-B-4       | 0.21                     | 0.30                                     | 118.9                         | 0.93           | Rebar fracture    |
| 16-C-4       | 0.22                     | 0.30                                     | 100.9                         | 0.93           | Bond-slip         |

From the main test data in Table 5, it can be seen that the destruction state of the specimens of series A and B is rebar fracture; the destruction state of the C series specimens is bond-slip. The residual deformation of the test piece is less than the standard requirement of 0.30mm for the value of 20 cycles of the connection joint of the Level-1 steel bar. The tensile strength of the A and B series specimens meets the requirement of $f_u \geq 1.10f_{bak}$, while the tensile strength of the C series specimens all correspond to $f_u < 1.10f_{bak}$, which does not meet the requirements of the specification, whereof $f_u$ means the tensile strength and $f_{bak}$ means the standard value of tensile strength.

### 3.2. Uniaxial tensile load-displacement relationship after repeated loading

In order to obtain the ultimate load value of the specimen after high-stress repeated loading, 27 specimens were subjected to 20 cycles of high-stress repeated tension and compression, and then the three series of specimens A, B, and C were unidirectionally stretched for test until they were failed. Specimens 16-A-5, 16-B-4 and 16-C-4 under typical working conditions were selected to study the changes in the load-displacement curve, as shown in Figure 4.

![Load-displacement curve](image)

Figure 4. Load-displacement curve of uniaxial tensile test after repeated loading

After analysing the typical working conditions of tests 16-A-5, 16-B-4 and 16-C-4, it can be seen that the test results of the test pieces 16-A-5 and 16-B-4 show that the connecting steel bars are broken and the load-displacement curve tends to be consistent. And the test results of specimen 16-C-4 show...
that the anchoring section of the anchoring steel bar is pulled out by the bond-slip destruction. After repeated tension and compression under high stress, there is no yield stage in the load-displacement curve of these two destruction modes in the uniaxial tensile test. Instead, the elastic stage enters the strengthening stage directly, and after reaching the ultimate bearing capacity, it then reaches the necking. In the stage, the specimens with bond-slip destruction still show strong ductility when they fail.

4. Summary
In the uniaxial tensile test and the high-stress repeated tension and compression test, the mechanical properties of the specimens of A and B series all meet the relevant requirements of the Lever-I joint specification, while the C-series specimens have all encountered bond-slip failure of anchored steel bars in the test, which does not meet the relevant regulations of Level-I joint specifications.

The load-displacement curves of the A and B series specimens in the test show linear correlation and peak values. The stiffness of the specimens is almost not degraded, and the bond-slip damage is small.

The specimens subjected to high stress and repeated tension and compression showed two destruction modes in the uniaxial tensile test, namely Rebar fracture and bond-slip. The load-displacement curves of the two failure modes showed no yield. At this stage, the specimens damaged by bond-slip still showed strong ductility when they failed.

In this paper, only three types of rebar sleeve grouting connectors with diameters d of 12, 14, and 16 have been subjected to high-stress repeated tensile tests. For larger diameter specimens and specimens under repeated loads of large deformation, their performance needs further study.

Acknowledgments
This research was funded by General Program of Nature Science Foundation of Anhui Province of China (1908085ME144), and AHJZU-Anhui Huali Construction Co. Ltd. Joint Research Project (HYB20190152).

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